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Ministry of Industry and Trade (MOIT)

Guideline for Technical Regulation Volume 2

Design of Thermal Power Facilities

Book 3/12

« Gas Turbine »

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List of Acronyms/Abbreviations

ACC	Advanced Combined Cycle
ACFTD	Air Cleaner Test Dust
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
APC	Automatic Particle Counter
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
BTU	British Thermal Unit
CC	Conventional Cast
CDA	Controlled Diffusion Airfoil
DS	Directionally Solidified
DS	Directionally Solidification
HBR	Hybrid Burner Ring
IGCC	Integrated Coal Gasification Combined Cycle
ISO	International Organization of Standardization
IEC	International Electrotechnical Commission
JEAC	Japan Electric Association Code
JESC	Japan Electric Association Guide
JIS	Japanese Industrial Standard
LHV	Low Heating Value
MACC	More Advanced Combined Cycle
MCA	Multiple Circular Arc
MIL	Military Standard
NAS	National Aerospace Standard
NEGA	Nippon Engine Generator Association
NFPA	National Fire Protection Association
NOx	Nitrogen Oxide
RAMS	Reliability Availability Maintainability and Safety
SAE	Society of Automotive Engineers
SC	Single Crystal
TBC	Thermal Barrier Coating
TIT	Turbine Inlet Temperature

Chapter-1. Comparison between Technical Regulation and Technical Guideline of gas turbine

The article number of this guideline is shown in the Table-1 contrasted technical regulation with technical guideline for easy understanding.

Table- 1: Comparison between technical regulation and technical guideline of gas turbine

Technical Regulation		Technical Guideline	
Article 36.	General provision	Article 36.	General provision
-1.	—	—	—
-2.	—	—	—
—	—	-1.	Classification of gas turbine
		-2.	Typical latest major gas turbine
		-3.	Materials for main part of gas turbine
		-4.	Materials application for blade and vane
		-5.	Composition of Ni-base Super-alloy of single crystal type gas turbine blade
		-6.	Application materials for blades and vanes of representative models
		-7.	Materials for gas turbine and jet engine
		-8.	Gas turbine performance characteristics
Article 37.	Material for auxiliary facilities of gas turbine	Article 37.	Material for auxiliary facilities of gas turbine
-1.	Pressure part	-1.	Pressure part
-2.	Stable chemical composition and mechanical strength	-2.	Stable chemical composition and mechanical strength
—	—	-3.	Required calculation thickness of pipe and tube
Article 38.	Structure of gas turbine, etc.	Article 38.	Structure of gas turbine, etc.
-1.	Rotation speed when emergency governor operates	-1.	Rotation speed when emergency governor operates
-2.	Abnormal wear, transformation and over-heat	-2-1.	Abnormal wear, transformation and over-heat
—	—	-2-2.	Air bearing
		-2-3.	Bearing
		-2-4.	Clearance of bearing
		-2-5.	Alignment
		-2-6.	Lubricant
		-2-7.	Lubrication oil purifier
		-2-8.	Fire-fighting system
-3-1.	Minimum rotation speed which can be adjusted by governor	-3-1.	Minimum rotation speed which can be adjusted by governor
-3-2.	The case being taken sufficient measure	-3-2.	The case being taken sufficient measure
—	—	-3-3.	Harmful vibration during operation
		-3-4.	Natural frequency
		-3-5.	Rotor coupling

Technical Regulation		Technical Guideline	
		-3-6.	Field balancing
-4.	Safety structure	-4-1.	Safety Structure
—	—	-4-2.	Casing
		-4-3.	Combustor
		-4-4.	Rotor
		-4-5.	Disc
		-4-6.	Turbine blade
		-4-7.	Turbine nozzle and vane
		-4-8.	Coating
		-4-9.	Compressor blade
		-4-10.	Compressor vane
Article 39.	Speed governing device for gas turbine, etc.	Article 39.	Speed governing device for gas turbine, etc.
-1.	—	—	—
—	—	-1.	Speed governing device
		-2.	Terms related with rotation speed
		-3.	Instantaneous maximum 2peed
		-4.	Maximum speed rise
		-5.	Steady state speed regulation
		-6.	Incremental speed variation
		-7.	Governor test
		-8.	Over-speed trip setting of emergency governor
		-9.	Over-speed test
Article 40.	Emergency stop device for gas turbine, etc.	Article 40.	Emergency stop device for gas turbine, etc.
-1.	Immediately	-1.	Immediately
-2.	Over-speed and other abnormal situation	-2-1.	Over-speed and other abnormal situation
—	—	-2-2.	Safety equipment
		-2-3.	Control unit
		-2-4.	Main valve
Article 41.	Pressure relief device for gas turbine, etc.	Article 41.	Pressure relief device for gas turbine, etc.
-1.	Over-pressure	-1.	Over-pressure
-2.	Appropriate pressure relief device	-2.	Appropriate pressure relief device
Article 42.	Instrument equipment for gas turbine, etc.	Article 42.	Instrument equipment for gas turbine, etc.
-1.	Instrument device to monitor the operation status	-1-1.	Instrument device to monitor the operation status
—	—	-1-2.	Other instrument devices

Chapter-2. Each Items of Guideline

Article 36. General provision

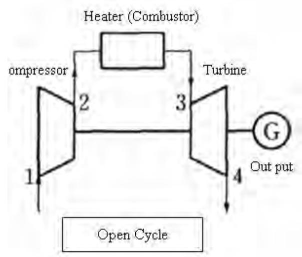
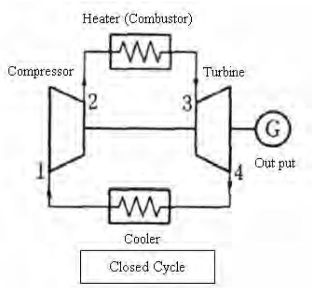
1. Classification of Gas Turbine

The general characteristic of the gas turbines which are classified by the element of gas turbine is summarized as shown in following tables. The appropriate type of gas turbine shall be selected depending on the purpose, required output and circumstances.

(2) Classification of Types by System

The gas turbine is roughly classified in basic “Open Cycle” and “Closed Cycle” as shown in Table-2.

Table- 2: Classification of types by system

Open Cycle	➢ The energy of flue gas generated in the combustor work gas turbine, remaining energy is recovered by heat exchanger, if necessary, and is emitted to the atmosphere from chimney. The most cycle which is currently utilized is the “Open Cycle”. 
Closed Cycle	➢ The low boiling fluid such as nitrogen, helium, and carbon dioxide is applied to circulation medium for “Closed Cycle”. 

(3) Classification of Type by use

The open cycle type gas turbine is roughly classified in “Aircraft Gas Turbine” which is used for jet air plane, “Land-use Gas Turbine” which is used for power generation or prime mover and “Aero-diverted Gas Turbine” which is used for power generation or prime mover as shown in Fable-3.

Table- 3: Classification of types by use

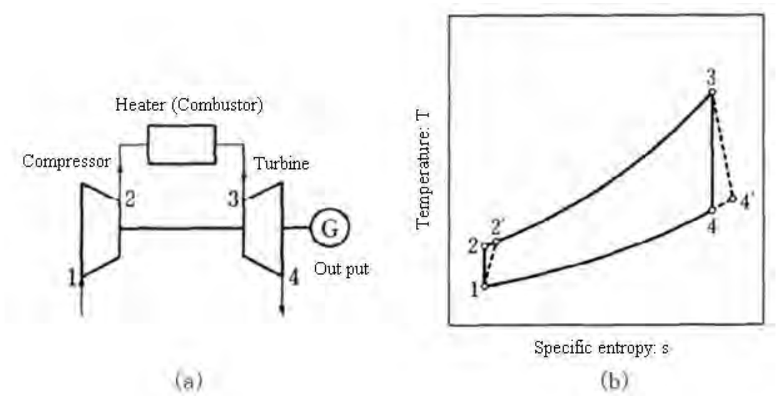
Aircraft Gas Turbine	➢ The aim of application for aircraft was because that it has been noted characteristics that compact, high output (greater output power per body weight of the machine is available than other heat engine). The turbojet engine which utilizes exhaust gas as promotion energy has been developed; moreover, the high efficiency turbofan engine which drives fan has been developed. In any event, the aircraft gas turbine gets reaction promotion force by ejecting

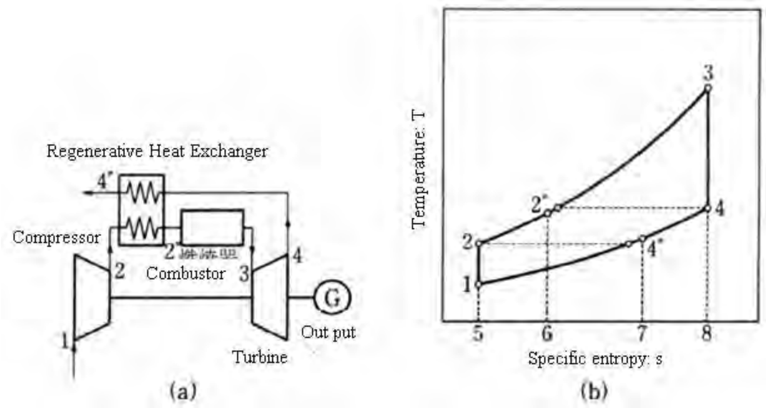
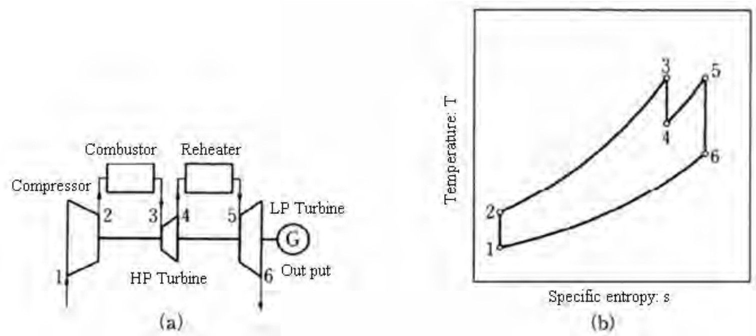
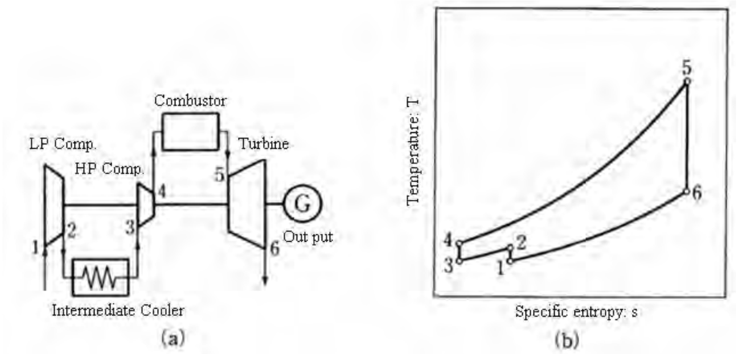
	combustion gases.
Land use Gas Turbine	➢ "Land use gas turbine", particularly for power generation is used to be called "Heavy Duty Gas Turbine", because the operation time in the year is more than aircraft gas turbine remarkably. It is varied the different indicators such as efficiency and durability characteristics, etc. different with aircraft gas turbine. The gas turbine which is developed specially for power generation is endeavoring to improve the reliability of long-term operation and have simple structure and long-term reliability. Generally, the one axis type which conducts compression and power generation by a gas turbine is the mainstream method.
Aero-derivative Type Gas Turbine	➢ The aircraft-derivative gas turbine is one which is utilized the aircraft jet engine, in general, power recovery turbine for compression and power turbine for generation are separated.

(4) Classification of Type by Heat Cycle

The gas turbine is based on the Brayton heat cycle and other options to perform higher performance as shown in Table-4.

Table- 4: Classification of types by heat cycle

Simple Cycle	➢ The solid line in the T-S figure shows the ideal cycle without any losses (reversible adiabatic expansion). The actual gas turbines shows the dotting line cycle which is under influence of compressor internal loss, turbine internal loss, pressure drop, heat loss and mechanical loss (irreversible process). This is the real baseline of gas turbine. 
Regenerative Cycle	➢ This system provides heat exchanger in the turbine outlet which exchange heat from flue gas to combustion air.

	
Reheat Cycle	➢ Generally, this system provides the HP combustor and re-heater to heat up HP flue gas temperature. 
Intermediate Cooling Cycle	➢ This system provides the intermediate cooler between air compressor 

(5) Classification of Types by Compressor

There are two types for the compressor which is used with turbine as shown in Table-5.

Table- 5: Classification of types by Compressor

Axial Type	➢ Generally, the multistage axial flow compressor is applied to large and high pressure gas turbine. The pair of blades and vanes is arranged alternately as the constitution of the compressor. The blades itself rotate with rotor and energize the fluid, the vanes forming static pressure rise with a role in slowing down the velocity of fluid.

Centrifugal Type	➢ Generally, the centrifugal compressor is employed for small scale compressor. The main reason is to avoid the complexity of the system seen in axial compressor in order to be more compact device

(6) Classification of Types by Turbine

There are two types for the turbine which is used with compressor as shown in Table-6.

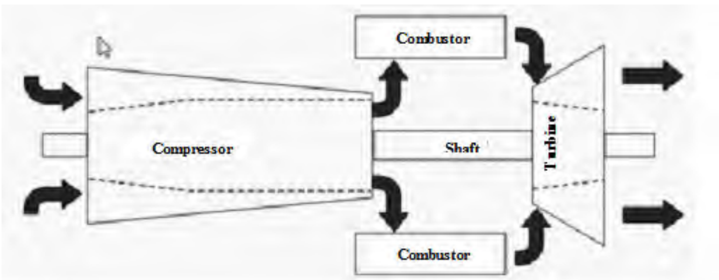
Table- 6: Classification of types by turbine

Axial Type	➢ Generally, the multistage axial flow turbine is applied to large gas turbine. The basic structure of the multi-stage axial-flow type is consist of blades and vanes, the former have the role to convert the direction of gas flow and produce high gas flow, and the latter have the role to convert kinetic energy into rotational energy.
Centrifugal Type	➢ The centrifugal type is adopted for small scale gas turbine.

(7) Classification of Types by Numbers of Shaft

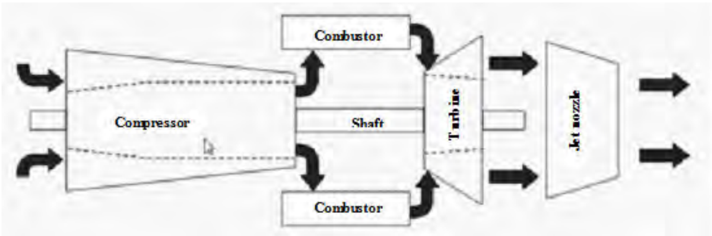
The numbers of shaft is classified in single and two depending on the use and its nature as shown in Table-7.

Table- 7: Classification of types by numbers of shaft

Simple-cycle, Single-shaft Type	➢ If the rotation speed fell down from 100% at all, it finds that the torque has fallen sharply. The output is still more rapid decline, because the torque is the product of both. It is necessary to maintain 60~70% of rated speed for idling, and the gas turbine will stall if it has further down. In this, it is not capable to drive a wide range of speed range. The power band is said to be narrow, because the gas turbine has only narrow range. However, the single-shaft gas turbine looking like recalcitrant has advantages. When rotating in high speed, gas generator shaft has a large moment of inertia, because the compressor has many stages significantly than turbine and heavy. Therefore, even if the load is momentarily changes, the change of shaft rotation speed is less under the flywheel effect. Typically, in case of the alternator power generation by commercial frequency, the changes of rotation speed should be avoided because it affects the device frequency by its change. Thus, the single-shaft gas turbine is useful depending on the difficulty of changing the rotation speed.  http://1.bp.blogspot.com/-5PKiPO-f3m0/TWVJGrp00OI/AAAAAAAAAw0/_muicVufcnY/s1600/Image+013.png

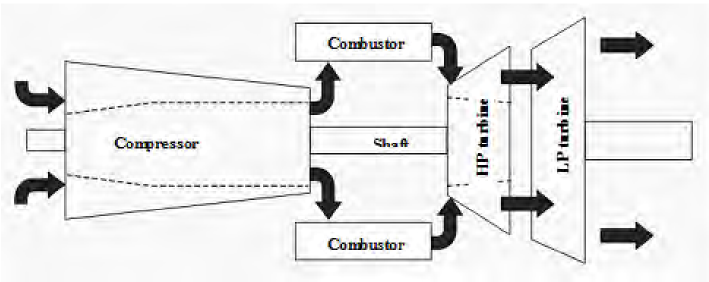
<table>
<tr><td></td><td></td></tr>
<tr><td>Single-shaft, Simple-cycle Gas Turbine with Jet Nozzle Type</td><td>

➢ This is the system which the single- shaft gas turbine is used as the gas generator and the thrust force is obtained from high-speed flow of exhaust gases.



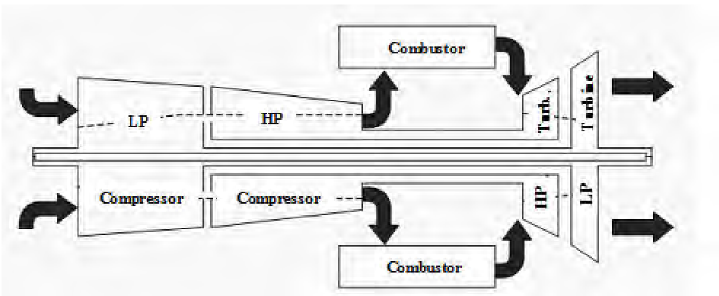
http://3.bp.blogspot.com/-lAtL0qDqkss/TWVJFTMnWwI/AAAAAAAAAww/nyzriRvXq6c/s1600/Image+012.png
</td></tr>
<tr><td>Industrial Two-shaft Gas Turbine with LP Free-turbine Type</td><td>

➢ This is the system which the single- shaft gas turbine is used as the gas generator. This is called the two-axis turbine. The downstream turbine is called free turbine which is capable to turn freely changed from stop to maximum speed. Even if the fee-turbine stopped, gas generator speed does not fall down and is capable continue to supply a large amount of combustion gas, hit the gas combustion gas onto gas turbine and create a strong rotational force. This gas turbine system can generate a large torque at low speed, less efficiency drop due to the change of speed than single-shaft type. As shown below, the torque tends to keep not much influence by the speed and has the property that output falls down with rotation speed.



http://1.bp.blogspot.com/-XM0zfhhbPck/TWVJHm42YsI/AAAAAAAAAw4/zt9e9VPPQwE/s1600/Image+014.png
</td></tr>
<tr><td>Multi-shaft Jet Engine Type</td><td>

➢ This is the system which two of HP and LP rotate in the jet engine. Basically, the thrust force is obtained from high-speed flow of exhaust gases.



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</td></tr>
</table>

(8) Classification of Types by Combustion Method

There are many combustion types to keep good combustion and perform good environmental performance as shown in Table-8.

Table- 8: Classification of types by combustion method

Premixed Combustion	➢ It is better to keep low Nox, because it is possible to burn at lower flame temperature. However, there is problem that it has instability because of the narrow range of combustion.
Diffusion Combustion Type	➢ This has wide combustion range and stable flame. However, there is a problem caused by high levels of NOx.
Hybrid Type	➢ It has become more common to adopt a hybrid type as low Nox combustion method which combined both characteristics. In an event, while it is required to resolve to minimize the peak flame temperature in the high temperature combustor and equalize the outlet temperature of combustor, there are likely to fall into the combustion instability problems such as limited for specific air-fuel mixture ratio of high temperature combustion. There are major issues on how to resolve.

(9) Classification of Types by Gas Temperature

The gas turbine is progressing to get higher performance by performing higher turbine inlet gas temperature. It depends on the development of new heat resistant materials.

The history of progress of TIT (Turbine Inlet Temperature) class the related technology is summarized as shown in Table-9. The 1700^{o}C Class is still under development.

Table- 9: Characteristic of gas turbine class

Class	1,100^{o}C	1,300^{o}C	1,500^{o}C	1,600^{o}C	1,700^{o}C
Combined Plant Efficiency (LHV)	48%	55%	59%	61%	62%
Material for 1st stage blade	* Polycrystal * Oxidation resistant coating	* Directional solidification * Thermal barrier coating	* Polycrystal or Unidirectional solidification * Constant thermal conductivity thermal barrier ceramic coating	* Single crystal solidification * Thermal barrier coating	* Single crystal * Thermal barrier coating which have metal crystal binder to combined ceramic coating and heat resistant metal
Cooling Method of blade	Air cooling	Advanced air cooling	Steam cooling	Steam cooling	Steam cooling
De-Nox Combustion	Air/fuel pre -mix	Air/fuel pre -mix	Air/fuel pre -mix	Air/fuel pre -mix	* Air/fuel pre -mix * Low oxygen combustion by recirculation of flue gas
Compressor	* Compression ratio: less than 30 * Variable vane	* Compression ratio: less than 30 * Variable vane	* Compression ratio: less than 30 * Variable vane	* Compression ratio: less than 30	* Compression ratio: more than 30 * Shock controlled transonic airfoil forward vane

(10) Classification of Types by Blade Production Method

The production method has been progressed to get homogeneous and defect-free metal structure with high temperature creep resistance as shown in Fig-1, Fig-2and Table-9. It depends much on advanced new and precision casting and forging. The appropriate material and production method shall be selected to suit selected class.

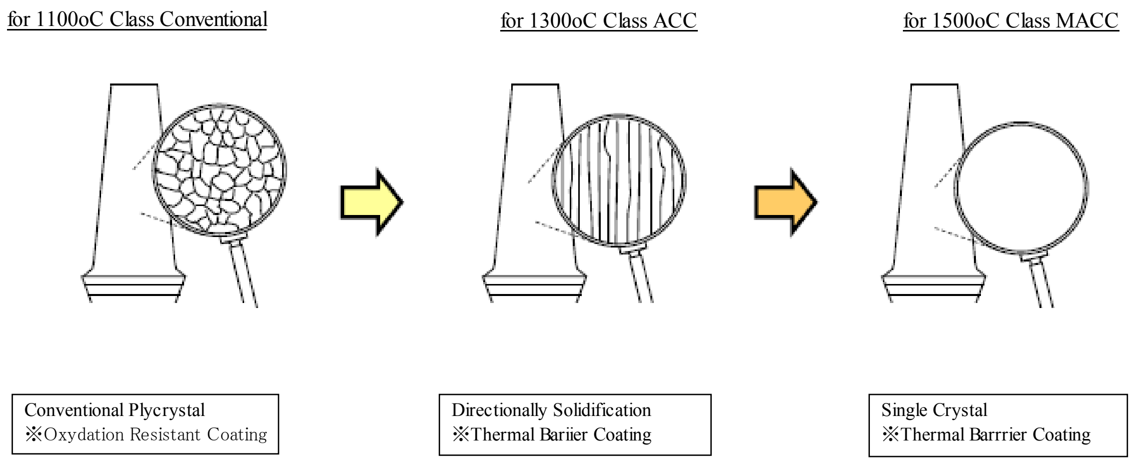


Fig- 1: Production method of gas turbine blade

Reference: P-11 of Journal (No. 655: Dec. /2011): TENPES

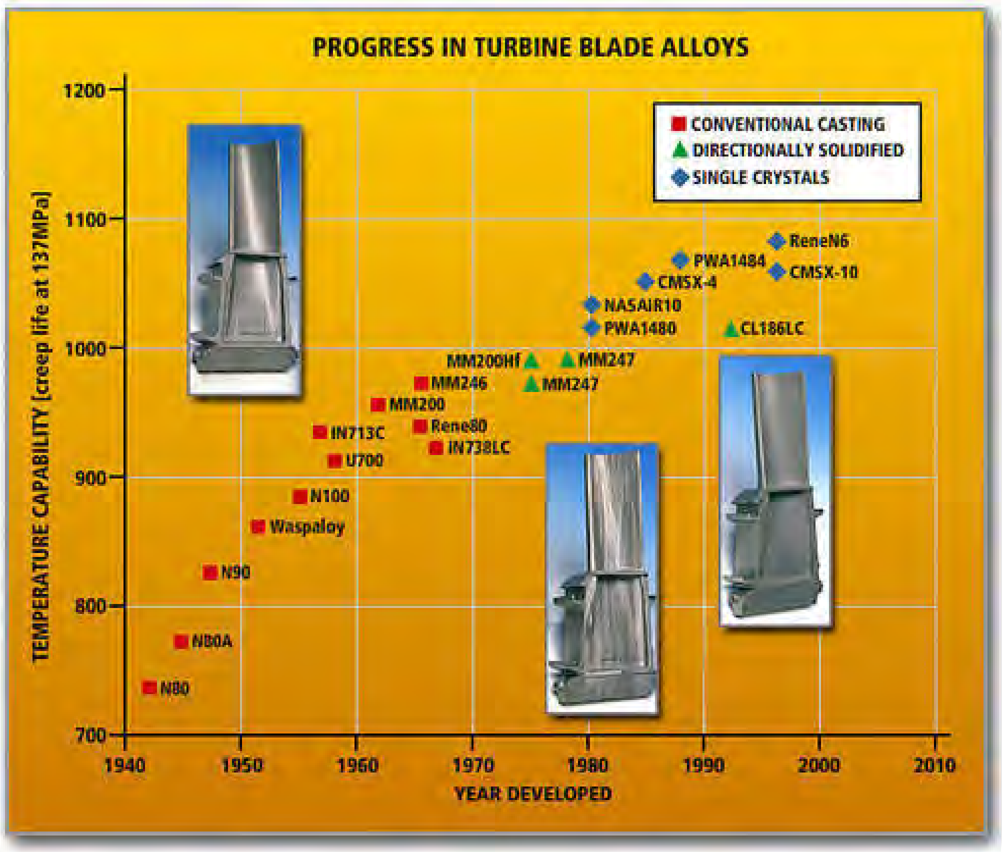


Fig- 2: Progress in blade alloys and production method of gas turbine

http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/turbine_blades.html

(11) Classification of Types by Blade Cooling Method

The cooling method of blade has been progressed from non-cooling to air-cooling and steam-cooling to reduce metal temperature low and to reduce heat losses as shown in Fig-3. This has become possible due to the progress of precision casting or production method, for instance, laser processing. The appropriate cooling method shall be selected to suit selected class.

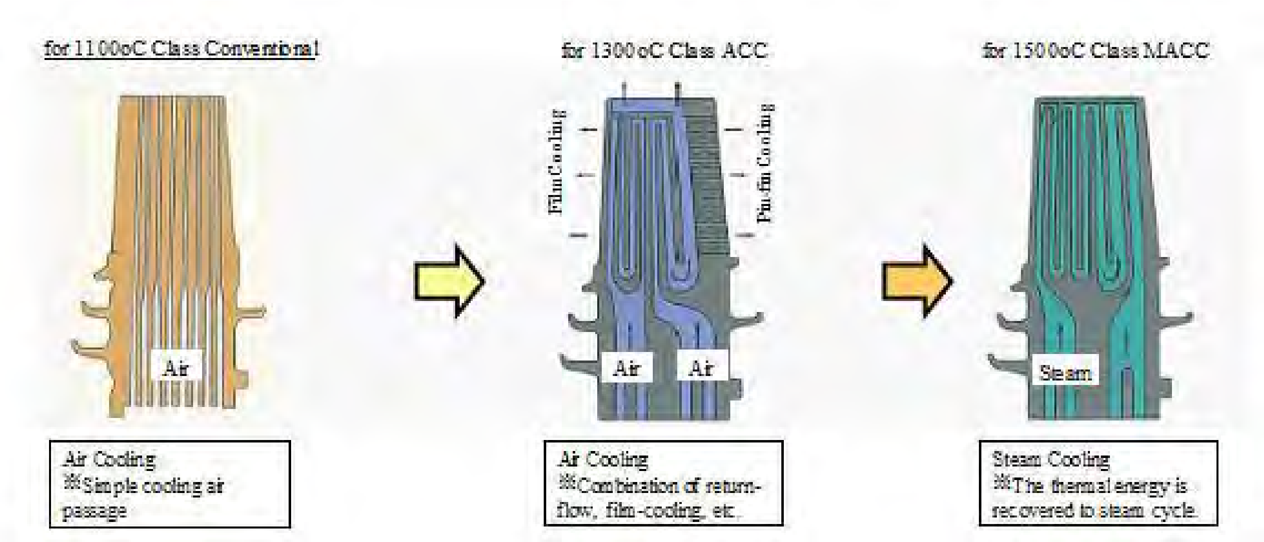


Fig- 3: Gas Turbine cooling method

Reference: P-11 of Journal (No. 655: Dec. /2011): TENPES

(12) Typical Construction of Gas Turbine

The typical construction of gas turbine is illustrated as shown in Photo-1~Photo-6. The appropriate type shall be selected to suit location, arrangement, purpose for use or installed capacity.

Photo- 1: 30~200kW class GT (Capstone)

http://jcwinnie.biz/wordpress/?p=1073

Photo- 2: 200~6000kW class GT (Kawasaki)

http://www.khi.co.jp/gasturbine/product/industry/emergency.html

Photo- 3: 20MW class GT (Solar-TITAN250)

http://mysolar.cat.com/cda/components/fullArticle?m=301895&x=7&id=1219482

Photo- 4: 28MW class GT (GE-LM2500)

http://www.ihi.co.jp/powersystems/motor/pdf/lm6000.pdf

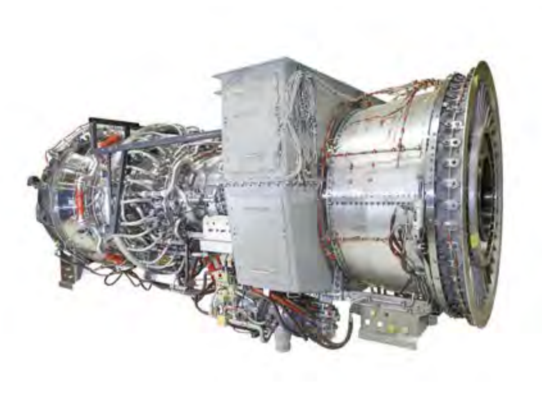


Photo- 5: 40MW class GT (GE-LM6000)

http://www.ihi.co.jp/powersystems/motor/pdf/lm6000.pdf

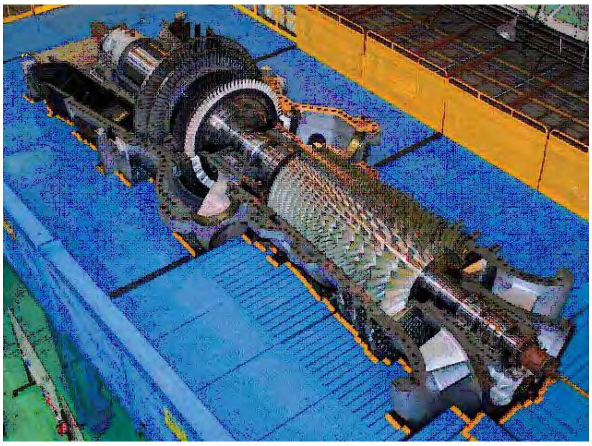


Photo- 6: 90MW class GT (Hitachi-H80)

http://www.hitachihyoron.com/2010/04/pdf/04a07.pdf

2. Typical Latest Major Gas Turbine

2-1. Siemens Gas Turbine

The VX4.3A (3A) type is the 1400°C class and it is improved based on the third generation VX4.3 machine which is 1300°C class, the first unit which commenced commercial operation in 1990. The new technical features introduced in 3A type are the following improvement compatible to the high temperature.

1) Hybrid Burner Ring (HBR) which the large 24 annular type combustors are placed on the circumference
2) The compressor and gas turbine which is introduced aircraft technology of Pratt & Whitney, and is re-designed. The blade row of V84.3A／V94.3A is shown in the cross section in Fig-4~Fig-5 and

Photo- 7: 340MW class GT (Siemens-SGT5-8000H)

http://www.dlr.de/blogs/en/desktopdefault.aspx/tabid-6192/10184_read-255/

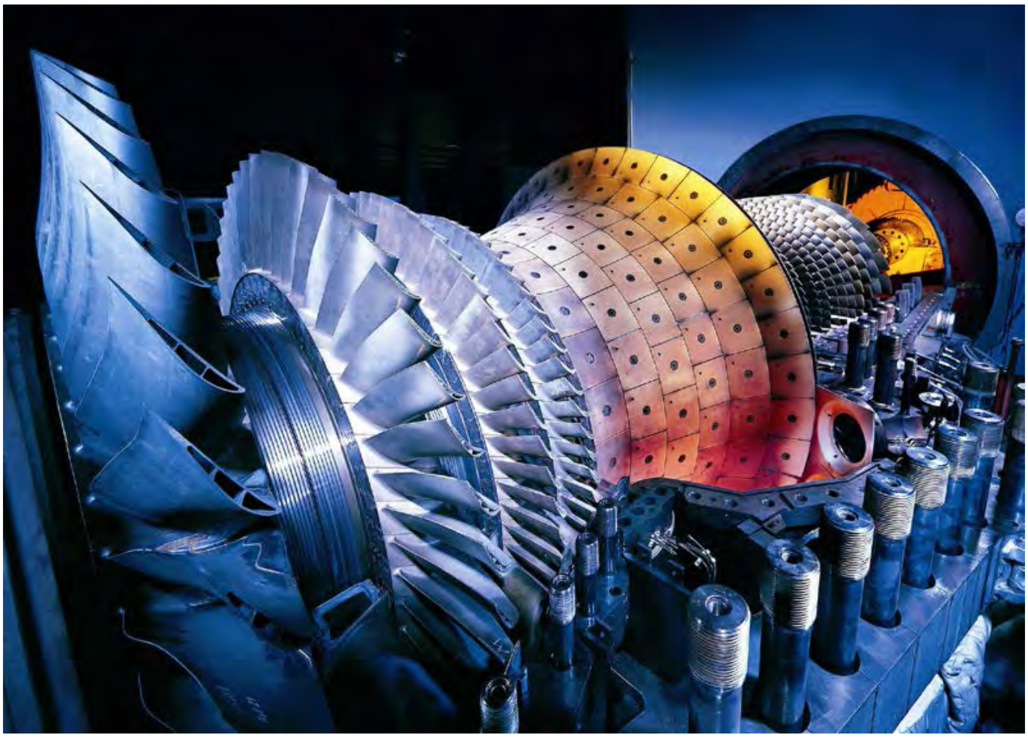


Photo- 8: 185MW class GT (Siemens-SGT5-4000F)

http://www.power-technology.com/contractors/condition/holland-controls/holland-controls1.html

(1) Gas Turbine Body

The outer casing supports combustor, compressor and turbine vane holder inside, and the compressor inlet casing and turbine exhaust casing are connected in back and forth of it. The bearing pedestals of compressor and turbine are supported by radial struts in a compressor inlet casing and exhaust casing of turbine respectively. The rotor has the construction which is assembled each disc with three hollow shafts by a center tai-bolt. Each disc and hollow shaft is engaged by a Hearse Serration joint processed radically on the contacting end surface shown as Fig-6. This serration has a self-aligning feature that holds the thermal expansion of each individual when each disk with a high torque transmission functions. The construction of latest gas turbine of Siemens is shown in Photo-7 and Photo-8.

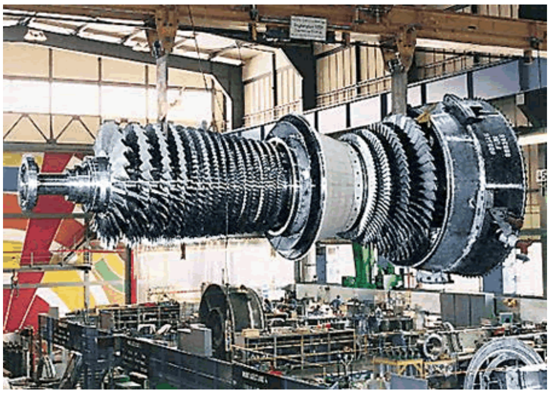


Photo- 9: Rotor assembly of V94.3A

http://www.gasnet.com.br/imagens/487.gif

Fig- 4: Assembly of V94.3A

http://upload.wikimedia.org/wikipedia/fa/5/5b/RudeshurTurbine.jpg

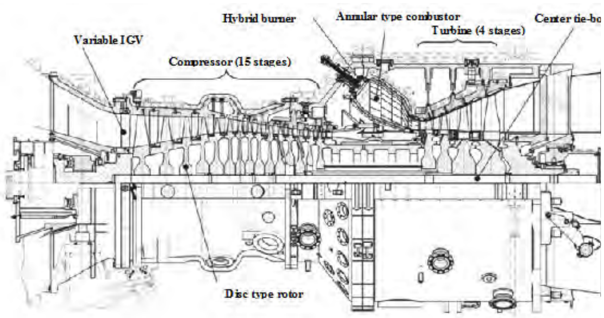


Fig- 5: V84.3A/V94.3A (SGTx-4000F)

Reference: P-41 of Journal (No.645: Jun. /2010): TENPES

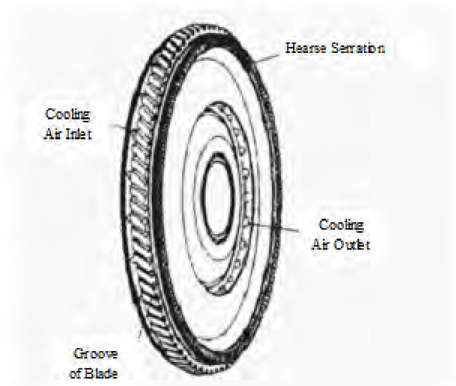


Fig- 6: Hearse serration disc

Reference: P-80 of Journal (No.578: Nov. /2004):

(2) Gas Turbine Blade and Vane

The number of turbine is the traditional four stages. The blade is cooling type except the fourth stage. The cooling air for the 2^{nd} ~4^{th} stage vane is supplied from the extraction of each intermediate stage of the compressor; some air passing through the seal-ring protects the disc surface from high temperature gas.

The 1st stage vane is cooled more effectively than conventional model by convection cooling, combination cooling of impingement and film shown in Fig-7, and the 1st stage blade by combination of return-flow and film shown in Fig-8. The material is selected Ni-based alloy and the single crystal (SC blade) is adopted for 1st stage blade. The thermal barrier coating (TBC) is adopted for the 1st ~3rd stage vanes.

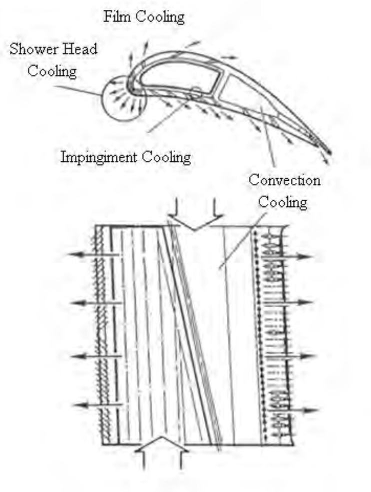


Fig- 7: Turbine 1st-stage vane

Reference: P-44 of Journal (No.645: Jun. /2010): TENPES

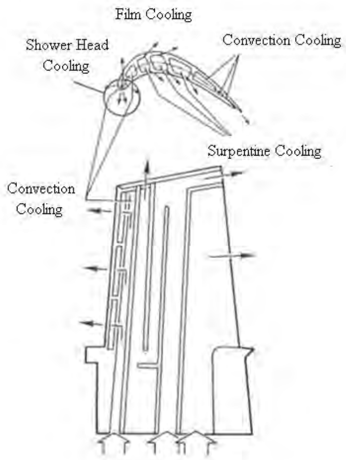


Fig- 8: Turbine 1st-stage blade

Reference: P-44 of Journal (No.645: Jun. /2010): TENPES

(3) Compressor

The cascade of compressor blades has been designed by 3 Dimensional Flow Design. The pressure ratio is about 17 which are suitable for combined-cycle. The number of compressor blades is 15 stages which are 2 stages less than 17 stages of conventional model by increasing in diameter of front 5 stages and increasing the peripheral speed. The controlled diffusion aerofoil blade (CDA) which is adopted for all stages form control the development of the boundary layer and separation by keeping the slow-down uniform on the blade surface. Moreover, the low energy flow at the border region is taken advantage by adopting airfoil wall modifications at the inside and outside diameter.

(4) Hybrid Burner Ring Combustor

The HBR combustor which is developed from traditional silo type combustor of Siemens is the annular type combustor which has the construction placing 24 burners and combustion area on the circumference of 1st stage inlet shown in Fig-9. As usual, the cascade of compressor blades in the large combustor room is designed by 3 Dimensional Flow Design. The high pressure ratio compressor cascade has been designated by 3 Dimensional Flow Design. The high pressure ratio combustion is advantageous for low NOx and high combustion efficiency because of the even combustion temperature. The dry low NOx burner type hybrid-burner as shown in Photo-11, 12 is switched from the diffusion combustion at low-load to pre-mix combustion at high-load. The main flame for pre-mix combustion is stabilized by burning pilot flame in diffusion partly. The combustion chamber is a double wall structure which is affixed a large number of heat shields inside of cast steel combustion chamber shown in Photo-10, 11, 12. The heat shield is Ni-based alloy and the outer surface exposed by hot combustion gases is coated by thermal barrier coating (TBC), the back surface is cooled by impingement cooling method applied discharge air from compressor.

Photo- 10: HBR combustion chamber

http://idw-online.de/pages/de/newsimage23962.jpg

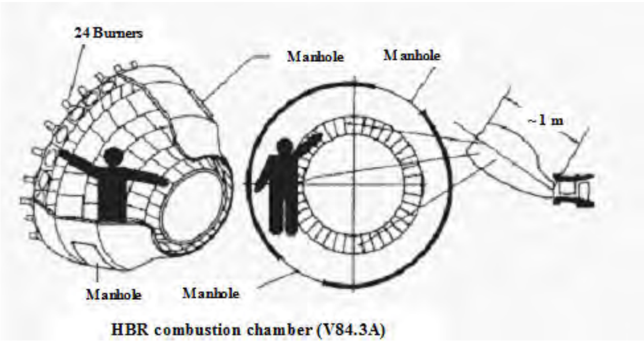


Fig- 9: HBR (Hybrid Burner Ring)

Reference: P-81 of Journal (No.578: Nov. /2004): TENPES

Photo- 11: HBR combustion chamber for V94.3A

http://4energetic.ru/images/L14_18.jpg

Photo- 12: HBR combustion chamber for V94.2

http://images-en.busytrade.com/186041800/Inner-Casing-Parts.jpg

2-2. ALSTOM Gas Turbine

(1) Maintenance-free Welded Rotor

ALSTOM's welded rotor was first introduced in 1929 for steam turbines and has been operating successfully in both ALSTOM gas and steam turbines. The rotor is welded from forged discs that ensure high rotor stiffness with two-bearing support. The welded rotor design eliminates maintenance work such as restacking and disk replacement during the service life of the rotor. Thus there is no need for the so called "Major Overhaul" of the gas turbine where this type of work is necessary. The construction of the welded rotor is shown in Photo-13, 14.

(2) Highly-efficient Compressor

The development of the GT24/GT26 compressor is the result of an evolutionary process with a gradual increase in the pressure ratio to over 30 bar. The GT24/GT26 employs controlled diffusion airfoil (CDA) blading, where each compressor stage is individually optimized according to specific requirements and boundary layer conditions. This leads to higher overall compressor efficiency while retaining a high surge margin. In addition, three rows of variable guide vanes are used to optimize the operation concept at every load. The construction of the compressor is shown in Fig-10.

(3) Dry low NOx EV Burner

EV (Environmental) burner technology, operating successfully for millions of hours throughout the ALSTOM gas turbine fleet, gives long burner life, no maintenance between hot gas path inspections and low emissions. The EV burner gives the benefit of dry low NOx combustion for operation with different natural gases, with the option to run with liquid fuel as an alternative. The burner is shaped like two half-cones slightly offset laterally to form two inlet slots of constant width running the component's full length. Combustion air enters the cone through these slots and fuel is injected through a series of fine holes in their edges. With this arrangement, fuel and air spiral into a vortex form and are intensively mixed. The construction of EV Burner is shown in Fig-13.

(4) Annular Combustion

The fully annular combustion chambers distribute the circumferential temperature evenly while avoiding problem zones such as cross-firing tubes or transition pieces. In addition the annular combustion systems of Alstom do not need a so called "Combustor Inspection" as for can-annular systems which reduce the amount of maintenance leading to higher availability. The construction of SEV Burner and EV Burner is shown in Fig-13.

(5) Turbine

The sequential combustion concept results in a gas turbine exhibiting extremely high power density resulting in the smaller blade dimensions of the GT24/GT26 machines. The five rows of turbine blades are anchored in fir tree slots. Air from the compressor cools the high-pressure turbine stage and the first three low-pressure turbine stages utilizing a combination of film and convection cooling techniques. The overall construction of GT26 is shown in Fig-10.

(6) Secondary Air System

The cooling air for the hot gas path components is taken from four extraction points along the compressor. Air from two of these secondary airflows is used directly, while the two other streams are cooled by heat exchangers (Once-through Coolers) before entering the hot gas path components. The heat rejected is recovered in the water-steam cycle, which maximizes the performance of the GT24/GT26 in combined cycle applications. In simple cycle applications, the cooling is achieved by quenching water, which is introduced directly into the secondary air stream. The secondary air system is shown in Fig-12.

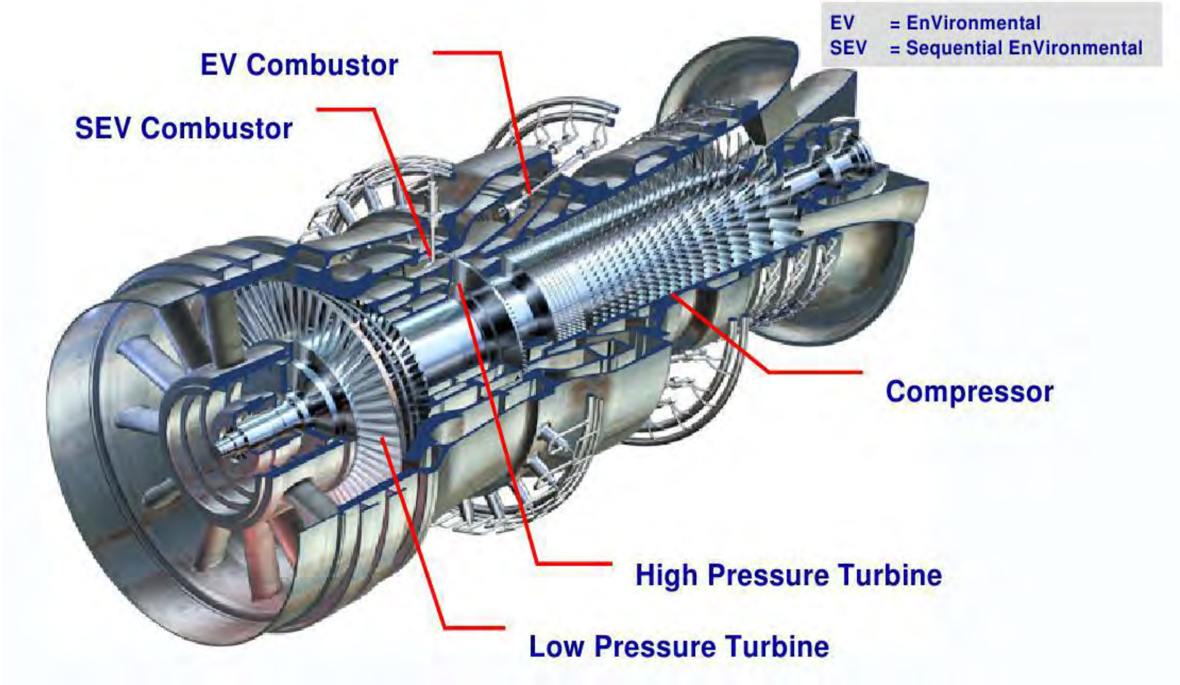
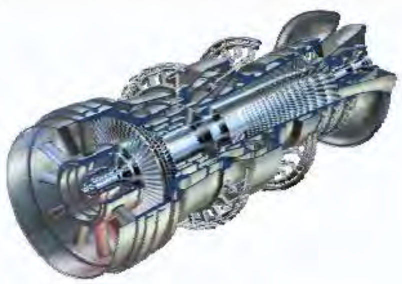


Fig- 10: 288MW class ALSTOM GT (GT26)

http://www.td.mw.tum.de/tum-td/de/forschung/themen/autoignition/TestBild.gif



Gross Gas Turbine ISO Rating

GT26	288.3 MW	38.3 %

Net Combined Cycle Plant Output		KA26-1 Single Shaft 1 on 1	KA26-2 Multi Shaft 2 on 1	KA26-2 ICS™ Multi Shaft 2 on 1
Plant Net Output	MW	424.0	850.3	857.7
Plant Net Efficiency	%	58.3	58.5	59.0
Plant Net Heat Rate	kJ/kWh	6'172	6'156	6'103

Fig- 11: 288MW class ALSTOM GT (GT26)

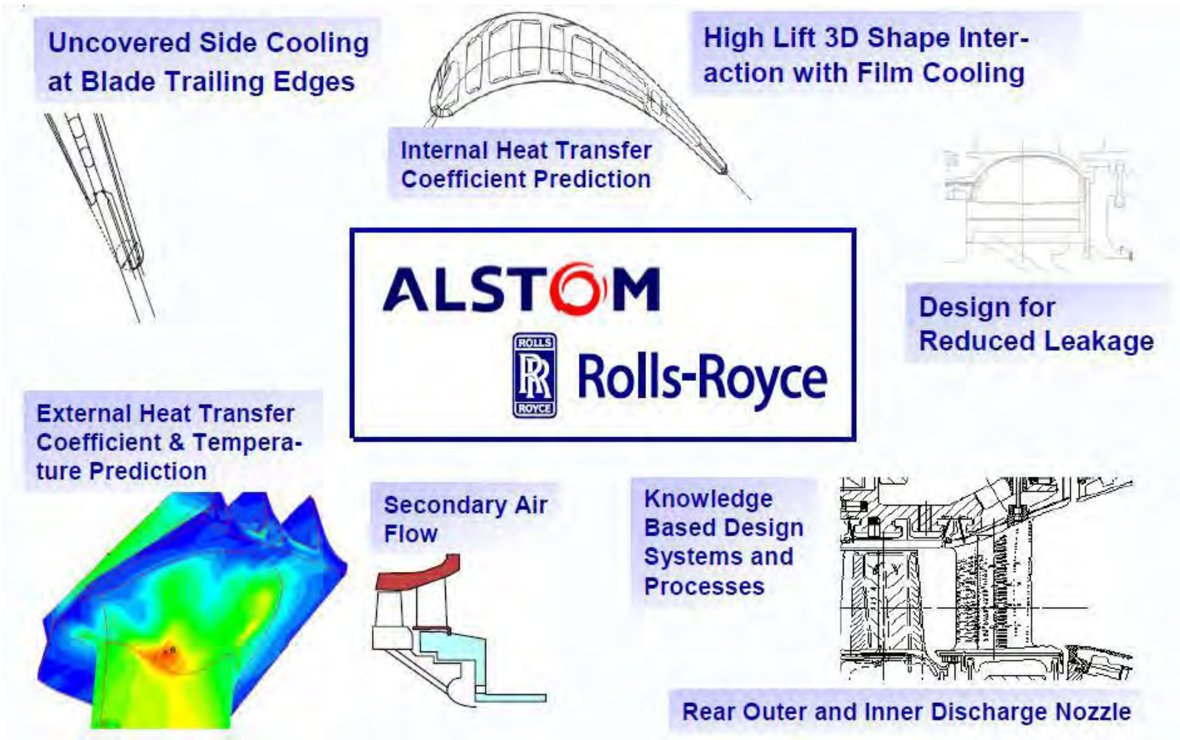


Fig- 12: 288MW class ALSTOM GT (GT26)

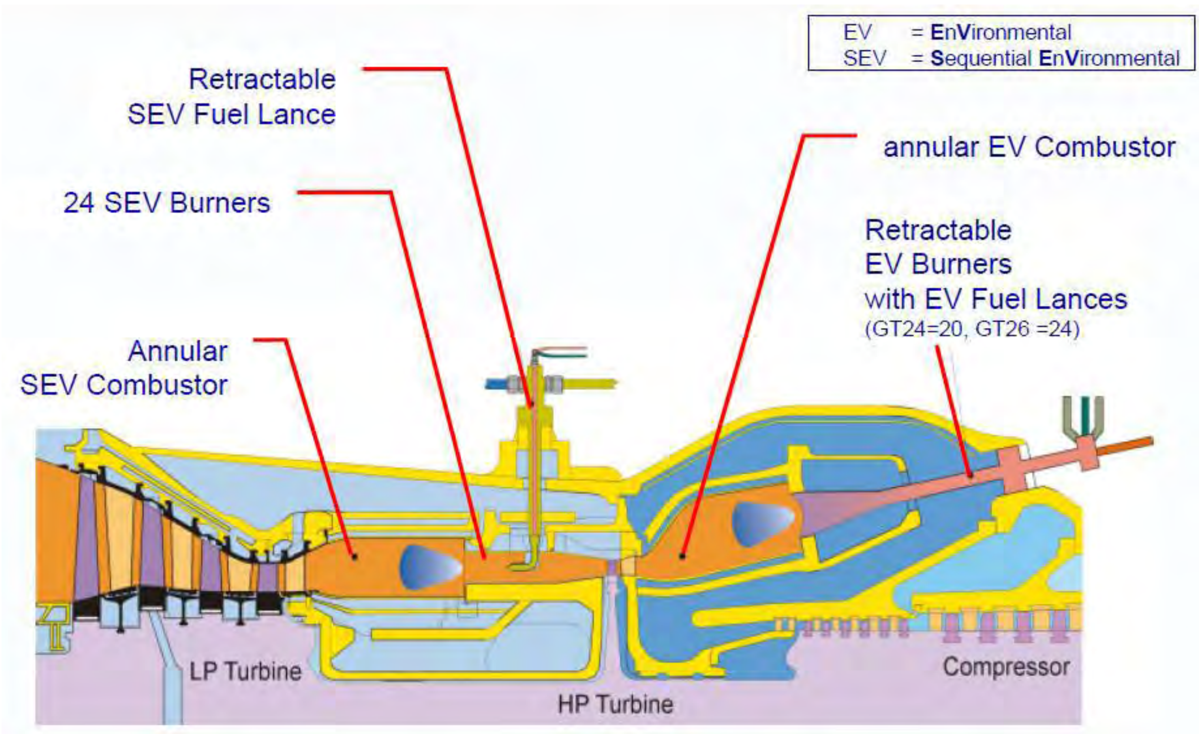


Fig- 13: 288MW class ALSTOM GT (GT26)

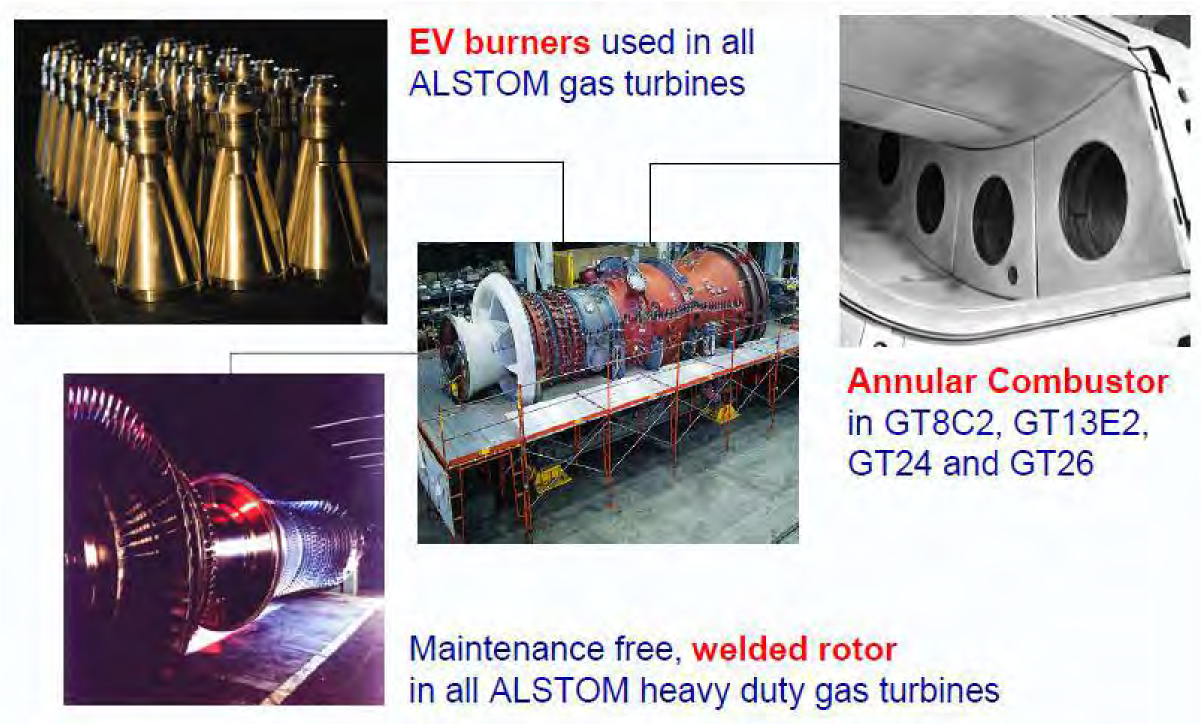


Photo- 13: 288MW class ALSTOM GT (GT26)

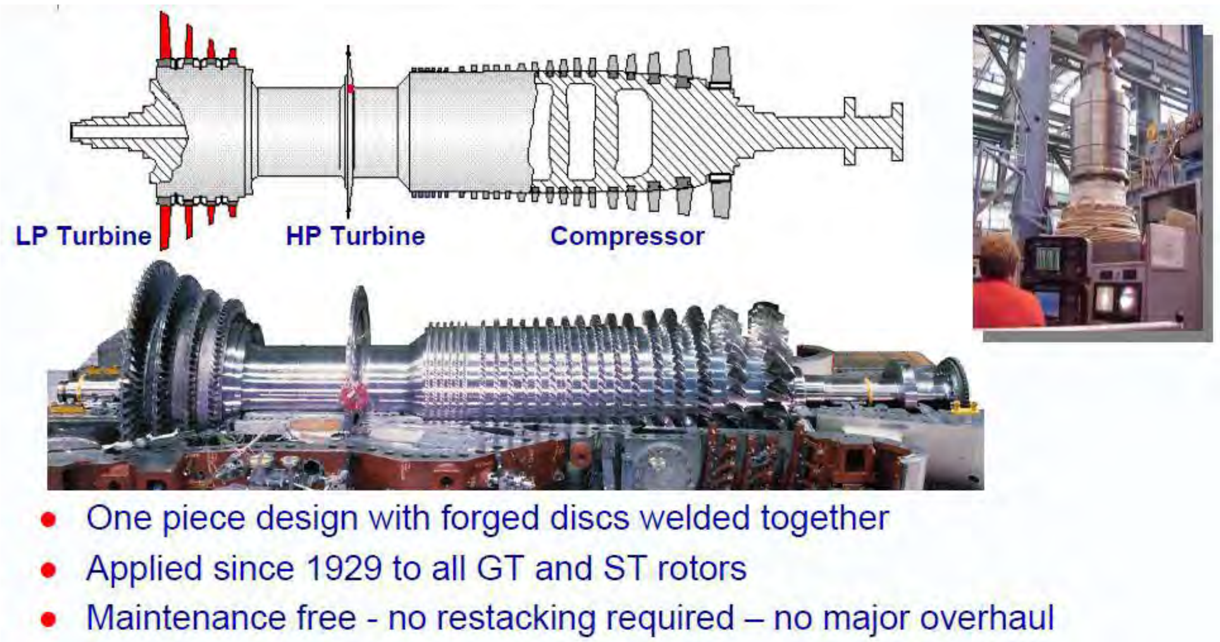


Photo- 14: 288MW class ALSTOM GT (GT26)

2-3. MHI Gas Turbine

Mitsubishi Heavy Industry has developed 1,500C class G-type gas turbine (M501G/ M701G) as shown in Fig-14, 15 which applied the recovery stem cooling combustor continued with the development of 1,150C class D-type and 1,350C class F-type. The basic construction of G-type gas turbine has following features followed the design concept of the gas turbine began with turbine inlet temperature (TIT) 1,150C class D-type.

1) Two bearing supports structure
2) Tangential strut supports
3) Horizontal split casing
4) Cannular type combustor
5) Cold-end drive axial exhaust
6) Transmission of turbine torque by curvic coupling

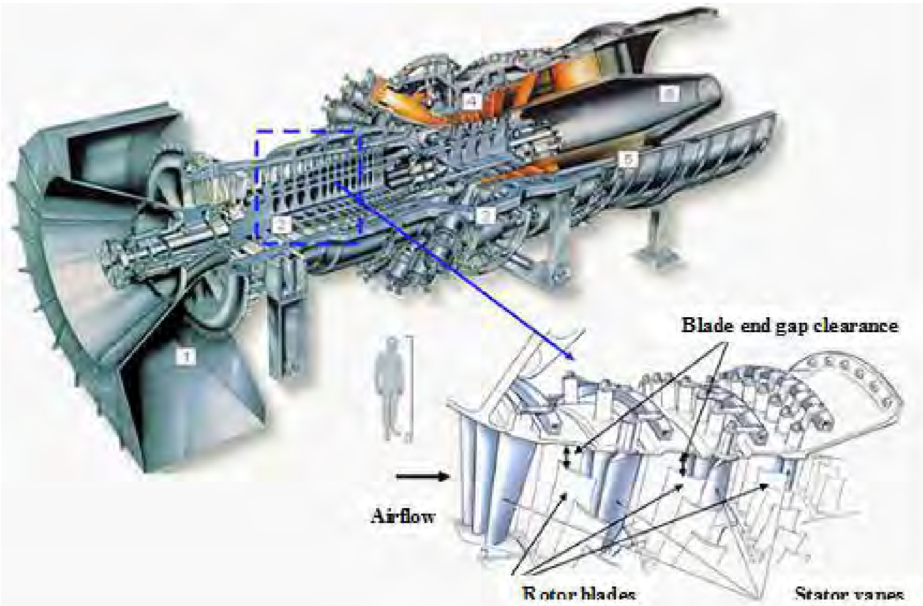


Fig- 14: 334MW class MHI GT (M701G)

http://web.mit.edu/aeroastro/labs/gtl/images/choon-1small.png

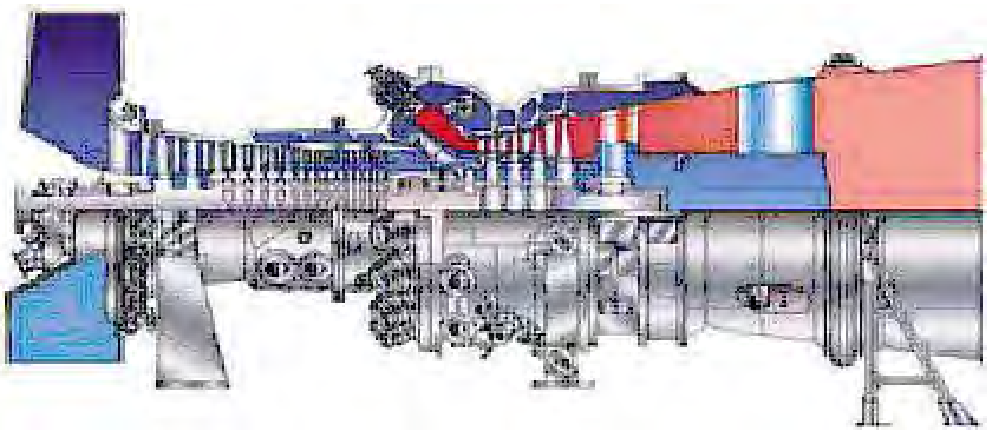


Fig- 15: MHI GT M501G

Reference: P-47 of Journal (No.645: Jun. /2010): TENPES

(1) Gas Turbine Body

The rotor bearing is supported by the radial strut at compressor side and by the tangential strut at turbine side, especially the thermal expansion which cause shaft misalignment on the exhaust side is absorbed shown in Fig-16. The rotor is the disc assembly type which the disc with spigot is bind by bolt in compressor part and which the disc with curvic joint on contact surface is bind by bolt in turbine part. The shape of the tooth for curvic coupling is the shape of an hourglass which one side is center is small and the other is barrel like shape is well shown in Fig-17. It is possible to transmit large torque and to couple shafts without misalignment by meshing of the teeth.

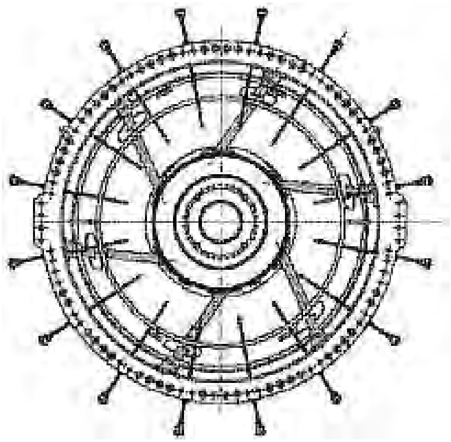


Fig- 16: Tangential strut

Reference: P-82 of Journal (No.578: Nov. /2004): TENPES

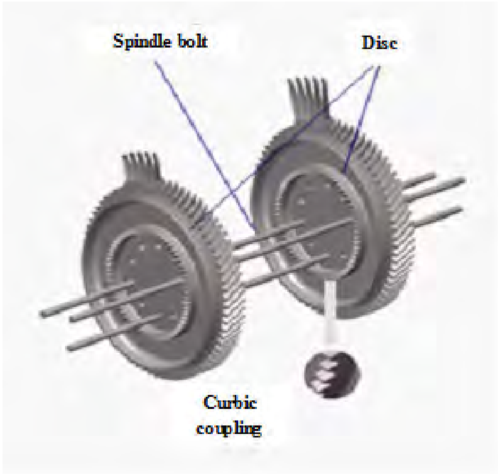


Fig- 17: Curvic coupling

Reference: P-75 of Journal (No.578: Nov. /2004): TENPES

The turbine is 4 stage axial flow type. The same 1st and 2nd stage blade and vane are used for 50Hz and 60Hz machine from the design concept of hot parts haring. In other words, the blade and vane for 1st stage of M501G and M701G turbine are same structure and size.

(2) Combustor

It is important to reduce Nox for large gas turbine and the countermeasure to prevent the formation of high temperature region is effective. However, the combustion temperature is raised up for the output and efficiency improvement from F-type to G-type. Fig-18 and Fig-19 are the comparison of the combustor of F-type and G-type. The recovery steam cooling (to cool down combustor by extracted steam from boiler and recover it to boiler after cooling) is adopted for the first time in the world for 1,500°C class G-type, and it performs high efficiency applying higher temperature gas to gas turbine while maintaining almost same flame temperature as F-class by preventing contamination of the cooling air at downstream of combustor.

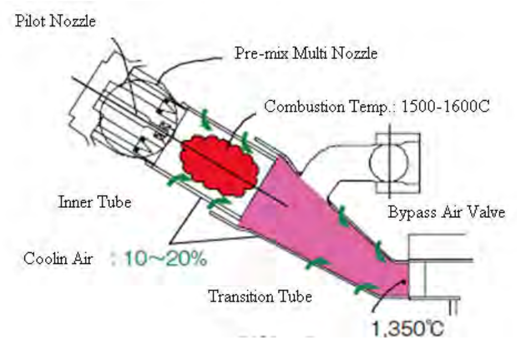


Fig- 18: 1,350°C class pre-mix combustor

Reference: P-49 of Journal (No.645: Jun. /2010): TENPES

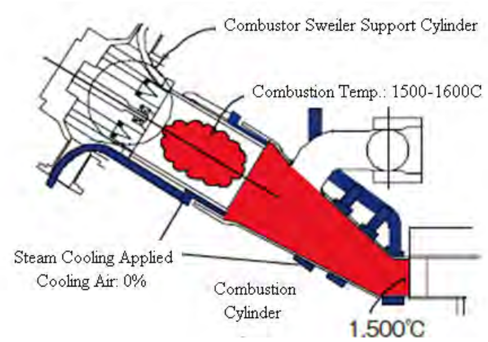


Fig- 19: 1,500 °C class pre-mix combustor

Reference: P-49 of Journal (No.645: Jun. /2010): TENPES

The combustor is the multi-can dry low NOx type. The combustor for G-type followed the technology of D-type, F-type, and the eight main nozzles are arranged around the periphery of pilot nozzle and the pre-mixed combustion flame of main nozzle keep stable by the periphery flame of pilot nozzle. It is necessary to increase combustion air for the pre-mix combustion of G-type to perform same NOx level as 1,500°C class F-type gas turbine. However, it is not capable to obtain required amount of cooling air for combustor by conventional cooling system as shown in Fig-20. Thus, the recovery steam cooling method which is not necessary cooling air for combustor wall is adopted as shown in Fig-21. It performs high efficiency applying higher temperature gas to gas turbine while maintaining almost same flame temperature as F-class by preventing contamination of the cooling air at downstream of combustor. The heat gained to steam during cooling is recovered in the steam cycle and contribute to overall plant thermal efficiency.

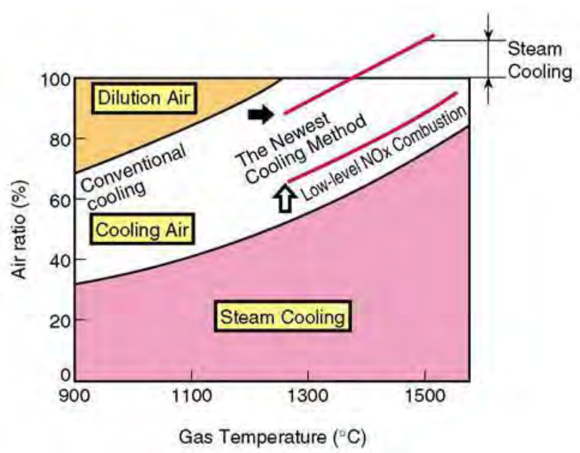


Fig- 20: Turbine inlet temp. vs. air ratio

Reference: P-50 of Journal (No.645: Jun. /2010): TENPES

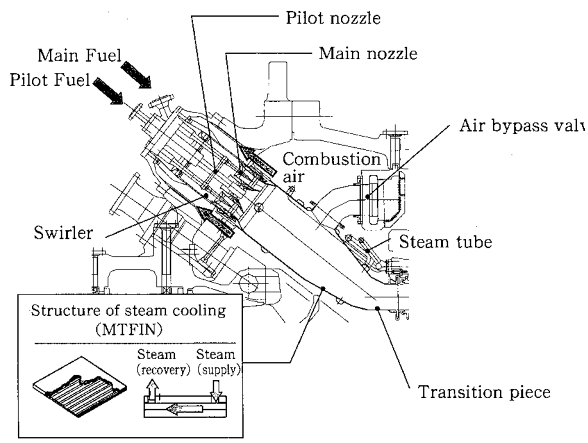


Fig- 21: Steam cooling combustor

Reference: P-399 Handbook Ver. 7 2008 TENPES

(3) Turbine Blade and Vane

The gas turbine inlet temperature (TIT) has been rising from D, F to G-type as shown Fig-22 because of the technical advantages in cooling technology; however the metal temperature is maintained on a par with conventional models.

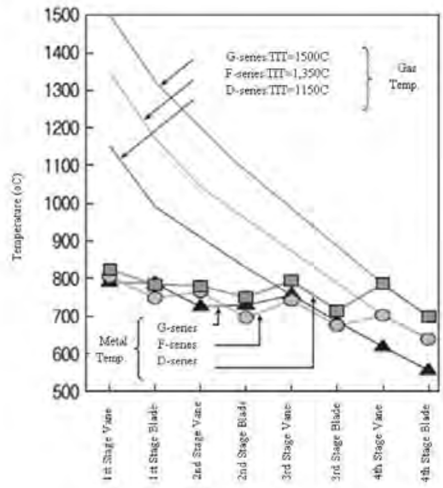


Fig- 22: Metal temperature of each class

Reference: P-62 of Journal (No.625:Oct. /2008):

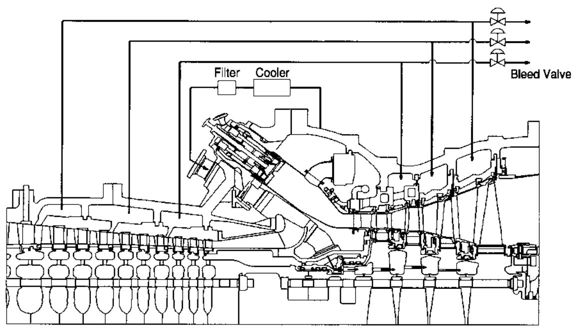


Fig- 23: Cooling air system

Reference: P-84 of Journal (No.578: Nov. /2004): TENPES

In particular, the 1st stage vane for G-type is the construction of 3 insert type, the internal cooling by impingement or the full coverage film cooling through shaped film cooling was developed and commercialized. The serpentine cooling pass and angled turbulence promoters are adopted for the 1st stage blade and is increased the performance by full coverage film cooling with shaped film cooling same as the 1st stage vane as shown in Fig-26.

The cooling air system for turbine blade is followed the conventional gas turbine cooling system, and is cooled by air bled from the compressor intermediate stage and discharge as shown in Fig-23. The number of extraction stage is determined by considering the pressure balance which minimizes the loss of gas turbine performance as much as possible.

The full coverage of ceramic thermal barrier coating (TBC) has been applied to both profile and shroud. The cooling construction of 1st stage vane is shown in Fig-24. The shower head cooling and film cooling is applied to trailing edge, the pin fin cooling, 3 cavities, impingement cooling by insert are combined for the trailing edge. The cooling of the inner and outer shroud has been done by the convective cooling, impingement cooling and film cooling. The return flow cooling with turbulence in the pass is adopted as usual to the 1st blade as shown in Fig-25. The shaped-film cooling hole has been adopted to blowing hole as well as vane in order to increase efficiency of film cooling. The film cooling has been adopted to ensure the cooling of rotor blade and tip of the platform. The full coverage of thermal barrier coating (TBC) has been applied to both profile and shroud as well as vane.

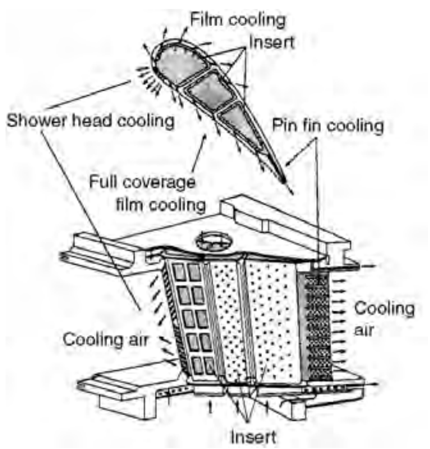


Fig- 24: 1st stage vane cooling system

Reference: P-84 of Journal (No.578: Nov. /2004): TENPES

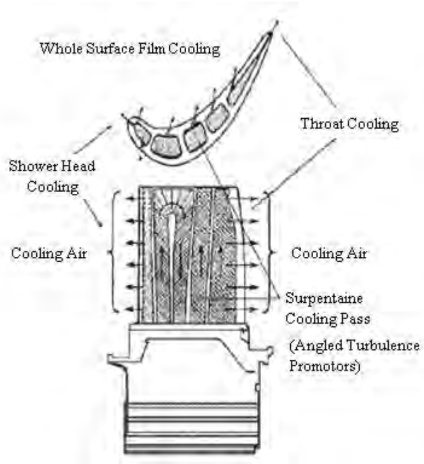


Fig- 25: 1st stage blade cooling system

Reference: P-84 of Journal (No.578: Nov. /2004): TENPES

Moreover, the cooling of the blades and rotor is done by cooled compressor discharge air cooled down through outside cooler. The material of 1st stage vane is Ni-based super alloy MGA2400 and produced by precision casting (single blade). The 1st stage vane is capable to remove by removing the combustor without overhauling the turbine casing as usual design. The 2nd stage vane is composed by 2 segment MGA2400 precision casting vane. The 3rd and 4th stage vane is composed by 3 segment and 4 segment precision casting vane. The MGA2400 precision casting blades are used to whole stages. The 1st and 2nd blade is directionally solidified (DS) blade.

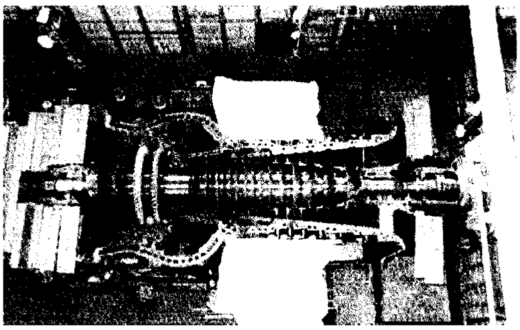


Photo- 15: MHI M501H GT

Reference: P-85 of Journal (No.578: Nov. /2004): TENPES

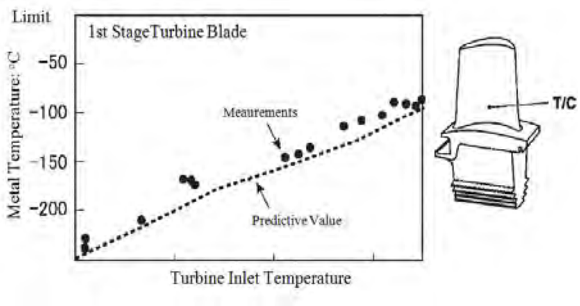


Fig- 26: Metal temperature of 1st stage blade (MHI)

Reference: P-85 of Journal (No.578: Nov. /2004): TENPES

(4) Heat Resistant Material

The progress of heat-resistant material is important same as the cooling technology. The heat-resistant alloys are classified by groups such as Fe, Co and Ni, and there difference by manufacturing method such as casting and forging. Currently, the precision casting to form complex cooling passes has become mainstream of production for blade and vane, and the control of crystal (directionally solidification, single crystal) increase the strength in the casting process. Especially, MGA2400 which the weldability is improved is adopted to the vane material. The directionally solidified MGA1400 is adopted to 1st and 2nd stage blade in order to secure high creep strength and thermal fatigue strength, as the result of that the creep rupture strength has been improved in terms of metal temperature about 50°C compared with conventional IN718LC usual casting blade as shown in Fig-27.

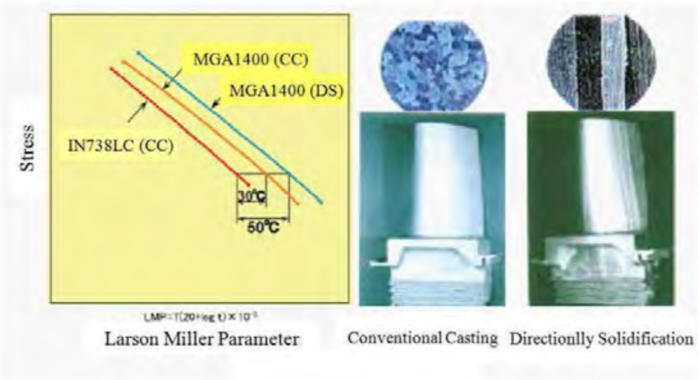


Fig- 27: Comparison of material for blade

Reference: P-51 of Journal (No.645: Jun. /2010): TENPES

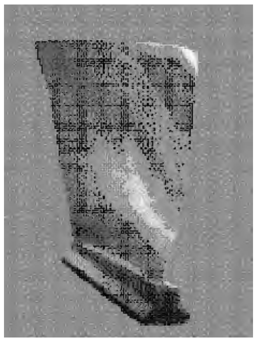


Photo- 16: 1st stage compressor blade (MHI)

Reference: P-83 of Journal (No.578: Nov. /2004): TENPES

(5) Aerodynamic Design Technology

In order to achieve large capacity, high pressure ratio and high efficiency, the multiple circular arc (MCA) airfoil for front stage and the controlled diffusion airfoil (CDA) for rear stage is adopted to the compressor. The 1st stage compressor blade is shown in Photo-16. The air volume has been adjusted by the intermediate extraction and inlet valuable guide vane to avoid surging. Meanwhile, 4 stages axial turbine is applied to turbine blade which corresponding heavy load and high performance due to the rise of TIT. The turbine is adopted the 3-dimentional design of F-type which is evolved from 2-dimentional design of D-type gas turbine, moreover, the perfect 3-dimentional design blade which curved radially superimposed on the airfoil is adopted for G-type to reduce secondary flow loss occur near the blade wall. Also, the overall performance has improved by analyzing multistage viscous flow at the steady and unsteady considering the leakage of cooling air through a multi-stage model stack blades and vanes. The multi circular arc (MCA) blade is adopted for front blade of G-type gas turbine, and the controlled diffusion airfoil blade is adopted for other cascade of blades as shown in Fig-28.

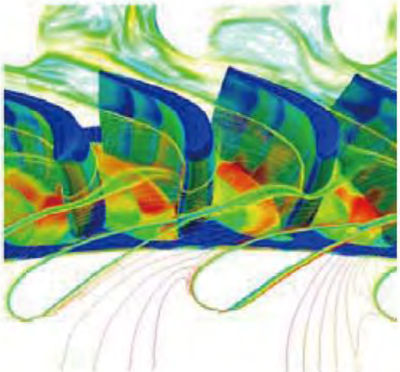


Fig- 28: Optimizing multi-channel flow analysis

(Gas temperature distribution)

Reference: P-51 of Journal (No.645: Jun. /2010): TENPES

2-4. General Electric Gas Turbine

Fig- 29: 340MW class GT (GE-9FB)

http://www.ge-energy.com/products_and_services/products/gas_turbines_heavy_duty/

(1) Steam Cooling Gas Turbine

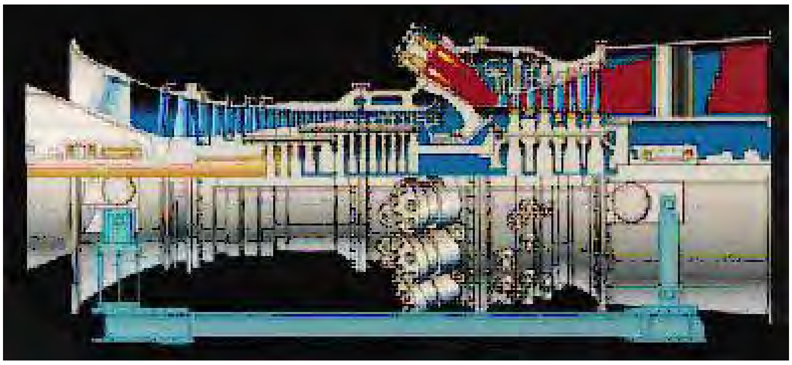


Fig- 30: 1500°C class GT (GE-9FB)

Reference: P-36 of Journal (No.645: Jun. /2010): TENPES

The heat recovery system cooling system has been applied to the 1st or 2nd stage in order to achieve the high temperature of first characteristic of the H-system of gas turbine as shown in Fig-29. By this way, the inlet temperature of 1st blade of turbine is achieved over 1,430°C which have been measured more than 110°C higher compared to 1,300°C class. In addition, cooling steam is returned to steam turbine and the heat is recovered because of the heat recovery system structure, and the temperature drop of main exhaust gas due to the cooling medium flowing into the gas path is avoided and a lower combustion temperature is achieved for the same inlet temperature of turbine. Therefore, the reduction of generation of NOx is measured in the combustor; it is possible to satisfy demands for environmental protection. Also, the single crystal material with excellent high temperature strength is applied to the 1st stage vane which bears most severe conditions as, and the equivalent life as conventional air-cooled blade has been achieved. Moreover, a thermal barrier coating (TBC) has been applied to 1st and 2nd stage blade in order to protect the base metal from high temperature gas.

The frame-9H as shown in Photo-17 is the most advanced gas turbine of GE, is designed with steam cooling technology, the first combined cycle system which achieved the high thermal efficiency and the core of the H-system.

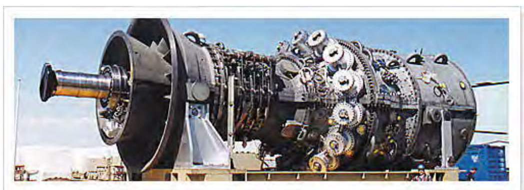


Photo- 17: GE GT-9H

http://www.emprise-usa.com/images/industrial.jpg

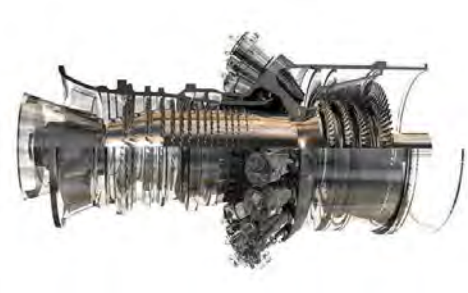


Fig- 31: GE GT-9FB

http://www.ge-energy.com/content/multimedia/_files/photos/9FBGT-lg.jpg

H-system reduces fuel use by high thermal efficiency and the exhaust gas from power generation per MW. The single combined cycle by frame-9H has superior performance that reducing 87,000m-t of greenhouse gas emissions per year compared to the conventional combined cycle gas turbine to generate equivalent amount of power. The F-type gas turbine of GE is the most reliable one in the F-class gas turbine and the newest frame-9FB as shown if Fig-30, 31 in F-fleet has achieved the combined cycle efficiency of more than 58%.

The F-type gas turbine of GE has features an excellent operational flexibility and the 40% of turndown while maintaining single digit of NOx and CO emission level can be achieved as the first in its class. The example of applying the latest technology in the product line F-class gas turbine is the 10 minute start-up performance of GT-7FA as shown in Fig-32 and Photo-18. This machine begins to generate electricity in 10 minutes after originating the startup signal and NOx and CO emission have been achieved even during this below 9ppm. Also, GE supplies other gas turbines including the E-class mid-range service units in addition to a large model.

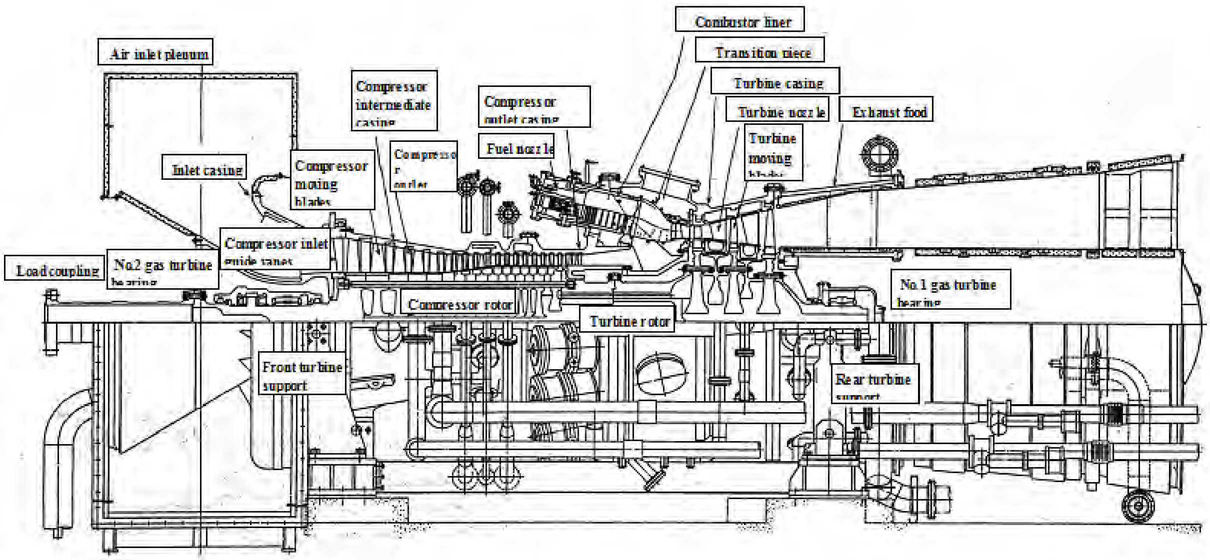


Fig- 32: GE-F7FA

Reference: P-397 Handbook for Thermal and Nuclear Power Engineers English Ver. 7 2008 TENPES

(2) Aero-diverted Type Gas Turbine

The GE LM-series of aero-diverted gas turbine has maintained its position as industrial leader in the flexibility of the technology, performance, flexibility of operation. The aero-diverted gas turbine has gained broad support from industry and has the overall running time more than 92 million hours because it has been designed with exhaust control technology and is capable to operate with multiple fuel and in the range 18~100MW. These gas turbine equipments have been used in various applications such as the power generation, the exploration, production and distribution of oil or gas, the marine propulsion system for the cruise ship, ferry boat, cargo ship.

One of the latest products of GE-energy in the areas of the aero-diverted gas turbine is LMS100 which has most efficient in the world as shown in Photo-19. This technology is an example of a first substantially improved the efficiency of gas turbine components by means of integrating large gas turbine and aero-diverted gas turbine. LMS100 supplies power of 100MW with 44% thermal efficiency and provides the flexibility to accommodate a wide range of operating conditions such as peak, mid-range or base load.

Photo- 18: Heavy duty GT GE-7FA

http://www.geenergyfinancialservices.com/images/GETurbine1.JPG

Photo- 19: Aero-diverted GT GE-LMS100

http://www.ge-energy.com/content/multimedia/_files/photos/LMS100%20PSP30649-01.jpg

Also, GE has set out the development of 4th generation machine LM2500+G4 in order to greatly increase the output of the aero-diverted gas turbine LM2500 as shown in Fig-33. This is a variant of the LM2500+advanced gas turbine which is designed for higher output capacity. LM2500G4 which supplies 46,000 shaft hose power or 34.3MW has improved its power supply capacity more than 12% under a wider range operation conditions than the conventional models.

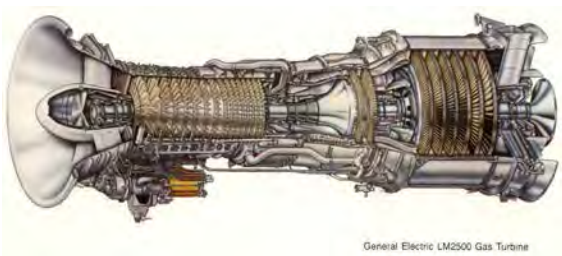


Fig- 33: Aero-diverted GT GE-LM2500

http://emcon-systems.com/images/GE.LM2500.Gas.Turbine.jpg

Photo- 20: Aero-diverted GT GE-LM6000

http://files.ecomagination.com/wp-content/uploads/2010/07/LM6000_PF_upangle.jpg

LM6000 as shown in Photo-20 is the characterized product in the line of GE aero-diverted gas turbine.

LM6000 has got a favorable reception from the wide range of users in the power generation industry because it provides the advanced exhaust technology, flexibility of package and ability to support multiple fuel compared with other product of same class. LM6000 which is designed as package to meet customer needs is applied to the utility, the industry and an application for oil and gas industry and offers a reliable 45% efficiency and 99% of fleet. The design of LM6000 and its package have been improved to correspond to wide variety of the needs of users through technological development such as 15ppm dry low NOx combustion, inter-cooling by spray to enhance power output, control equipment applied fiber optic wiring and flexibility of off-gas or liquid fuel.

In addition, recently GE-energy announced latest LM6000PG (single annular combustor type) and LM6000PH (dry low NOx combustor type) which are improved from the proven LM6000. These latest types have made possible to increase 25% of simple cycle output and to improve 18% of improvement of exhaust energy. LM6000PH and LM6000PG has about 65MW output and can be achieved 52~55% thermal efficiency in combined operation. This power increase is possible in the same footprint and package of 4.5m x 21.5m as existing LM6000 for 50Hz and the output per footprint has increased in about 20%.

3. Materials for Main Part of Gas Turbine

The general application of materials for gas turbine is listed as shown Table-10, Fig-34 and Table-18 for reference. The exact materials to be applied for each gas turbine shall be determined depending on the operation condition required by purchaser under the responsibility of manufacturer.

Table- 10: Materials for main part of gas turbine

Part	Representative Material
Turbine Vane	AISI304, AISI310, CMSX-4(SC) 5), ECY768, FSX-414, GTD111, GTD222, INCO700 1), INCO713C1), INCO9391), LCN155, MarM2472), MarM4212), MarM4322), MarM5092), MGA2400, N-155, RENE1083), RENE413), RENE-N5(SC) 3), U500, X-40, X-45,
Turbine Blade	Alloy738, CMSX-4(SC) 5), GTD111, GTD444, IN738, INCO700 1), INCO738LC 1), MarM2472), NCF80A, NCF750, M252, MGA1400, PWA1483(SC) 6), PWA1484, RENE-N5(SC) 3), RENE77 3), RENE80 3), S816, S590, U500, U520, U700, U710, U720,
Rotor	CR422, Cr-Mo-V steel, DISCALOY, H53V, IN7061), NCF718, Ni-Cr-Mo steel, Ni-Cr-Mo-V steel, SUH660,
Turbine Wheels	Alloy718, Alloy706, A286,Cr-Mo-V steel, M152
Compressor Blade & Vane	AISI403, ANSI403+Cb, Cr steel, Cr-Mo steel, GTD450, Ni-Cr steel, Ni-Cr-Mo-Mn steel, Ni-Cr-Mo steel
Combustor Inner Tube, Tail Covert	AISI310, H-1884), HA-188, INCO6171), NCF800, N253, N-263,NW6002, HAST-X, RA333, SS309, TOMILLOY,

Note: 1) INC family of companies 2) Martin Marietta Corporation 3) General Electric Company 4) Haynes International Inc.

5) Cannon Muskegon *6) Pratt & Whitney*

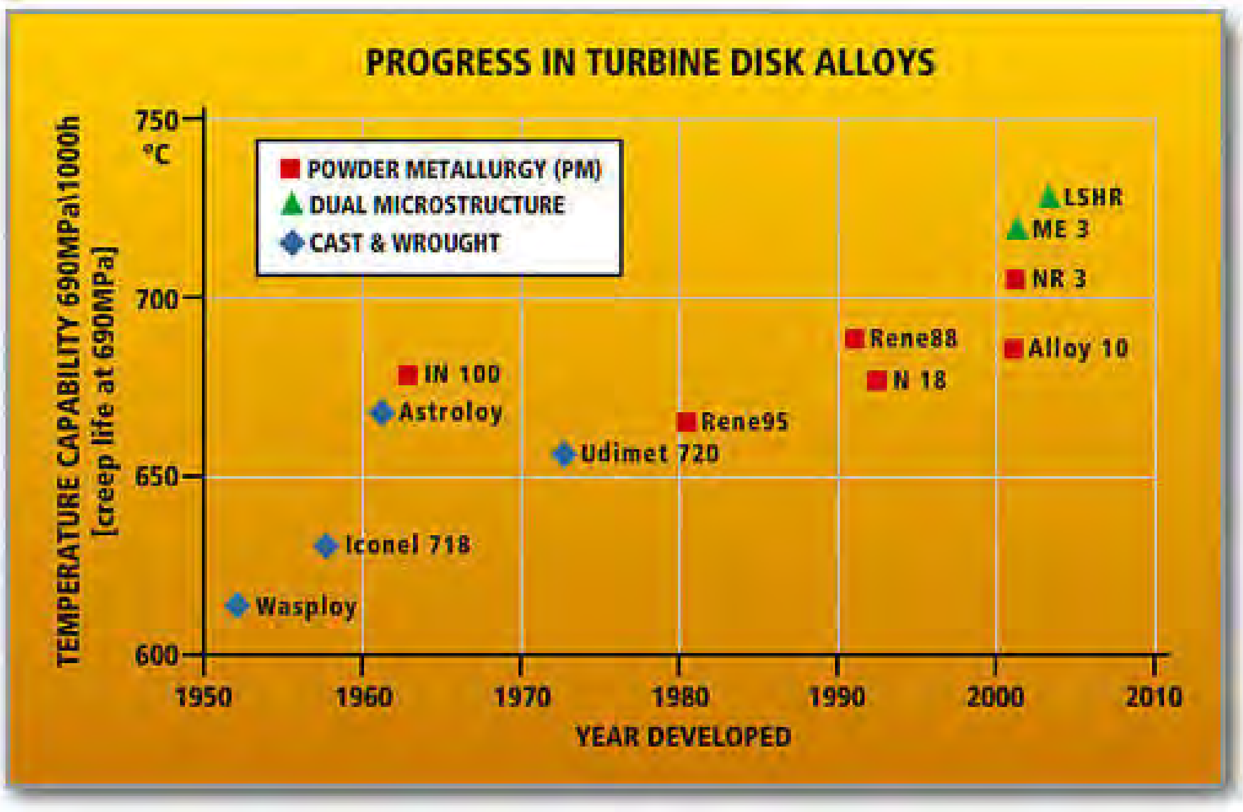


Fig- 34: Progress in gas turbine disk alloys

http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/turbine_disks.html

3.1 Reference Web site of super alloy for gas turbine

(1) http://www.rolexalloys.com/sdp/312241/4/pd-1225130/5445152.html

(2) http://www.dsml.co.jp/pages/products_heat.htm

(3) http://www.sulzerts.com/portaldata/5/Resources//resourcecenter/toolsforyou/Super_Alloy_Compositions_.pdf

(4) http://www.haynesintl.com/htalloys.htm

4. Material Application for Blade and Vane

The general application of materials for gas turbine hot part is listed as below for reference. The exact materials to be applied for each gas turbine shall be determined depending on the operation condition required by purchaser under the responsibility of manufacturer.

The super alloys which are high temperature resistant have been developed continuously in the last 60 years for the high temperature structural material for jet engine, such as Ni-base and Co-base as shown in Fig-34.

Particularly, the Ni-base alloys have progressed spectacularly. The progress of process technology is remarkable, for example, the use of reinforcement by precipitation and distribution of inter-metallic compound〔$Ni_3(Al,Ti)$〕which is called plenty γ' phase, strengthening of solid solution between both phases, the progress of design method of alloy with consideration of the misfit control for atomic arrangement due to the delicate balance of the composition of two phases in the boundary of crystals, adoption of vacuum melting, changing a manufacturing method from forging to precision casting and crystal control from isometric crystal which applied unidirectional solidification method to prismatic crystal and single crystal.

The Table-11 shows the chemical composition of major single crystal super-alloy. They are developed from earlier 1st generation to 4th generation, and 5th generation is intended to explore. On the other hand, it has become to apply forced cooling of blade and bane with hollow structure by the progress of precision casting; moreover the operation temperature of get-engine has reached above 1500°C at maximum power take-off in commercial aircraft and still arising. However, Ni-base super-alloy significantly reduces its strength above 1000°C with advantage clearly greater than Fe-base or Co-base super-alloy.

The temperature of heavy duty gas-turbine for generation is going to be higher further from 1500°C. It is possible to raise operation temperature further 100 to 150°C by the innovation of cooling system and the advance of thermal barrier coating by ceramic spraying. However, it is necessary to strengthen more cooling to correspondent to the further high temperature and it is inevitable the heat efficiency soon reach a sealing. Thus, it has to say that the development of super-alloys is close to the limit.

5. Composition of Ni-base Super-alloy of Single Crystal Type Gas Turbine Blade

The composition of typical Ni-base super-alloy is shown in Table-11 as below. These super-alloys have been developed by composition and production method in order to get high creep resistance in every generation.

Table- 11: Comparison of Ni-base super-alloy of single crystal type gas turbine blade

Process	Name of alloy	Composition (wt%: Ni balance)														Generation
		Co	Cr	Mo	W	Al	Ti	Nb	Ta	Hf	Re	C	B	Zr	Others	
CC	IN738	8.5	16	1.7	2.6	3.4	3.4	—	1.7	—	—	0.17	0.01	0.1	—	—
CC	IN792	9	12.4	1.9	3.8	3.1	4.5	—	3.9	—	—	0.12	0.02	0.2	—	—
CC	Rene'80	9.5	14	4	4	3	5	—	—	—	—	0.17	0.015	0.03	—	—
CC	MarM247	10	8.5	0.7	10	5.6	1	—	3	—	—	0.16	0.015	0.04	—	—
CC	TM-321	8.2	8.1	—	12.6	5	0.8	—	4.7	—	—	0.11	0.01	0.05	—	—
DS	GTD111	9.5	14	1.5	3.8	3	4.9	—	2.8	—	—	0.1	0.1	—	—	1st
DS	MGA1400	10	14	1.5	4	4	3	—	5	—	—	0.08	?	0.03	—	1st
DS	CM247LC	9	8	0.5	10	5.6	0.7	—	3.2	1.4	—	0.07	0.015	0.01	—	1st
DS	TMD05	9.5	5.8	1.9	13.7	4.6	0.9	—	3.3	1.4	—	0.07	0.015	0.015	—	1st
SC	PWA1480	5	10	—	4	5	1.5	—	12	—	—	—	—	—	—	1st
SC	CMSX-2	8.2	5.6	1.9	10.9	5.1	—	—	7.7	—	—	—	—	—	—	1st
DS	PWA1426	12	6.5	1.7	6.5	6	—	—	4	1.5	3	0.1	0.015	0.03	—	2nd
DS	CM186LC	9	6	0.5	8.4	5.7	0.7	—	3.4	—	3	0.07	0.015	0.005	—	2nd
SC	PWA1484	10	5	2	6	5.6	—	—	9	—	3	—	—	—	—	2nd
SC	Rene'N5	8	7	2	5	6.2	—	—	7	0.2	3	—	—	—	—	2nd
SC	CMSX-4	9	6.5	0.6	6	5.6	1	—	6.5	0.1	3	—	—	—	—	2nd
SC	TMS-82+	7.8	4.9	1.9	8.7	5.3	0.5	—	6	0.1	2.4	—	—	—	—	2nd
SC	YH 61	1	7.1	0.8	8.8	5.1	—	0.8	8.9	0.25	1.4	0.07	0.02	—	—	2nd
SC	Rene'N6	12.5	4.2	1.4	6	5.75	—	—	7.2	0.15	5.4	0.05	0.004	—	0.01Y	3rd
SC	CMSX-10	3	2	0.4	5	5.7	0.2	0.1	8	0.03	6	—	—	—	—	3rd
SC	TMS-75	12	3	2	6	6	—	—	6	0.1	5	—	—	—	—	3rd
DS	TMD-103	12	3	2	6	6	—	—	6	0.1	5	0.07	0.015	—	—	3rd
DS	TMD-107	6	3	3	6	6	—	—	6	0.1	5	0.07	0.015	—	2 Ru	4th
	MX-4/PWA1497	16.5	2	2	6	5.55	—	—	8.25	0.15	5.95	0.03	0.004	—	3 Ru	4th
SC	TMS-138	5.8	3.2	2.8	5.9	5.9	—	—	5.6	0.1	5	—	—	—	2 Ru	4th
SC	TMS-162	5.8	2.9	3.9	5.8	5.8	—	—	5.6	0.1	4.9	—	—	—	6 Ru	5th

※The 4th and 5th generation single crystal super-alloy contains the platinum group Ru.

※ CC: Conventional Cast, DS: Directionally Solidified, SC: Single-crystal

Reference: Proceedings of the International Gas turbine Congress 2003 “High Temperature Materials for Gas Turbines

http://www.matweb.com/search/SearchUNS.aspx

6. Application Materials for Blades and Vanes of Representative Models

The actual case of application of gas turbine blades and vanes materials for representative heavy duty gas turbines are shown in Table-12~ Table-17 as below.

Table- 12: Materials for blade and vanes (1)

Stage	Material	1,100°C		1,100°C	
		MS7001E (GE)			
		Blade	Vane	Blade	Vane
1st	Substrate	GTD111(DS)			
	Coating	Co-Ni-Cr-Ai-Y			
2nd	Substrate	IN738LC	GTD222		
	Coating	—			
3rd	Substrate	U500	GTD222		
	Coating	—			
4th	Substrate				
	Coating				

Table- 13: Materials for blade and vanes (2)

Stage	Material	1,100°C		1,500 °C	
		501D/701D original (MHI)		501G/701G (MHI)	
		Blade	Vane	Blade	Vane
1st	Substrate	U520	ECY768	MM002 (DS) or CM247 (DS)	IN939
	Coating	TBC(N)/M-Cr-Al-Y	—	TBC(EB-PVD)(N+B)	—
2nd	Substrate				
	Coating				
3rd	Substrate				
	Coating				
4th	Substrate				
	Coating				

Table- 14: Materials for blade and vanes (3)

Stage	Material	1,300°C		1,500 °C	
		501F/701F original (MHI)		501F/701F improved (MHI)	
		Blade	Vane	Blade	Vane
1st	Substrate	IN738LC	ECY768	MGA1400(DS)	MGA2400
	Coating	Co-Ni-Cr-Al-Y/TBC		TBC	TBC
2nd	Substrate	IN738LC	ECY768	MGA1400	MGA2400
	Coating	Co-Ni-Cr-Al-Y		TBC	TBC
3rd	Substrate	IN738LC	X45	MGA1400	MGA2400
	Coating	Co-Ni-Cr-Al-Y		—	—
4th	Substrate	U520	X45	MGA1400	X45
	Coating	Co-Ni-Cr-Al-Y	—	—	—

※Reference: MHI “M501F/M701F Gas Turbine Uprating”

http://www.mhi.co.jp/en/products/detail/new_material_development.html

Table- 15: Materials for blade and vanes (4)

Stage	Material	1,300°C		1,100°C	
		MS7001/9001FA (GE)		MS7001/9001EA(GE)	
		Blade	Vane	Blade	Vane
1st	Substrate	GTD111(DS)	FSX-414	GTD111(EA)	FSX-414
	Coating	Co-Ni-Cr-Al-Y + Aluminizing/TBC	—	RT22dGT29In+(B)	—
2nd	Substrate	GTD111			
	Coating	Co-Ni-Cr-Al-Y + Aluminizing/Co-Ni-Cr-Al-Y			
3rd	Substrate	GTD111			
	Coating	Chromizing			
4th	Substrate				
	Coating				

Table- 16: Materials for blade and vanes (5)

Stage	Material	1,300°C			
		11N2 (ABB→Alstom)		GT24/GT26 (ABB→Alstom)	
		Blade	Vane	Blade	Vane
1st	Substrate	IN738LC	IN939	CM247lLC(DS)	CM247lLC(DS)
	Coating	Ni-Cr-Al-Y+Si	—	TBC(N)/Ni-Cr-Al-Y +Si (B)	—
2nd	Substrate				
	Coating				
3rd	Substrate				
	Coating				
4th	Substrate				
	Coating				

Table- 17: Materials for blade and vanes (6)

Stage	Material	1,100 °C			
		V84/94.2 (Siemens)		V84/94.3A (Siemens)	
		Blade	Vane	Blade	Vane
1st	Substrate	IN738LC	IN939	PWA1483 (SC)	PWA1483 (SC)
	Coating	Co-Ni-Cr-Al-Y+Si	—	TBC (EB-PVD)(B)	—
2nd	Substrate				
	Coating				
3rd	Substrate				
	Coating				
4th	Substrate				
	Coating				

※Reference: OMMI Vol1 Aug/2002 CT Hot Section Life Management

7. Materials for gas turbine & jet engine

Table- 18: Materials for gas turbine & jet engine

No.	Alloy Name	Use & Remarks	Standard					Mitsubishi Material	Pratt & Whitney	General Electric Company	Nippon Yakin Kogyo	Daidou Special Metal	NIMS	MHI	Nippon Koshuha Steel	INC Family of Companies	Deloro Stellite	Martine Marietta Corporation	Haynes International Inc.	Cannon Muskegon	Avesta Sheffield	Rolled Alloy
			UNS No.	ASME, ASTM	AISI	AMS	JIS															
1	15-5 PH		S15500			5659																
2	17-4 PH		S17400																			
3	17-7 PH	SUS631	S17700			5528, 5644, 5676, 5824																
4	A286	Disc, Casing	S66286			5737	G4312	MA286			NAS660				KTA286							
5	AISI 304L	Vane	S30403		AISI 304L																	
6	AISI 308		S30800		AISI 308																	
7	AISI 309		S30900		AISI 309																	
8	AISI 310	Vane, Combuster	S31008 S31000		AISI 310																	
9	AISI 312		S31200		AISI 312																	
10	AISI 314		S31400		AISI 314																	
11	AISI 316L		S31600		AISI 316L																	
12	AISI 317L		S31700 S31703		AISI 317L																	
13	AISI 321		S32100		AISI 321																	
14	AISI 347		S34700		AISI 347																	
15	AISI 403	Comp.-Blade	S40300		AISI 403																	
16	AISI 403 Cb	Comp.-Blade			AISI 403 Cb																	
17	AISI 405		S40500		AISI 405																	
18	AISI 409		S40900		AISI 409																	
19	AISI 410		S41000		AISI 410																	
20	AISI 414		S41400		AISI 414																	
21	AISI 416		S41600		AISI 416																	
22	AISI 420		S42000		AISI 420																	
23	AISI 422		S42200		AISI 422	5655																
24	AISI 430		S43000		AISI 430																	
25	AISI 431		S43100		AISI 431																	
26	AISI 439		S43035		AISI 439																	
27	AISI 440A		S44002		AISI 440A	5631																
28	AISI 440B		S44003		AISI 440B																	
29	AISI 440C		S44004		AISI 440C	5618																
30	AISI 446		S44600		AISI 446																	
31	Alloy 706	Disc,(Pyromet)	N09706																			
32	Alloy 713C																					
33	Alloy 713LC		N07713			5377, 5391																
34	Alloy 718	Disc,(Pyromet)	N07718																			
35	AM1																					
36	AM2																					
37	Avesta 253MA																				Avesta 253MA	
38	Avesta 353MA																				Avesta 353MA	
39	B-1900					5405			PWA663													
40	C-1023																					

No.	Alloy Name	Use & Remarks	Standard					Mitsubishi Material	Pratt & Whitney	General Electric Company	Nippon Yakin Kogyo	Daidou Special Metal	NIMS	MHI	Nippon Koshuha Steel	INC Family of Companies	Deloro Stellite	Martine Marietta Corporation	Haynes International Inc.	Cannon Muskegon	Avesta Sheffield	Rolled Alloy
			UNS No	ASME, ASTM	AISI	AMS	JIS															
41	CM 186LC																			CM 186LC		
42	CM247	Blade-(DS):1500℃Class																CM247				
43	CM247LC	Blade-(DS):1500℃Class																		CM247LC		
44	CMSX-10	Vane, Blade(SC)																		CMSX-10		
45	CMSX-11B	Vane, Blade(SC)																		CMSX-11B		
46	CMSX-11C	Vane, Blade(SC)																		CMSX-11C		
47	CMSX-2	Vane, Blade(SC)																		CMSX-2		
48	CMSX-3																			CMSX-3		
49	CMSX-4	Vane, Blade(SC):1990 era							CPW 637											CMSX-4		
50	CMSX-6	Vane, Blade(SC)																		CMSX-6		
51	CMSX-486																			CMSX-486		
52	CUSTOM 450	Carpenter Tech.	S45000			5773, 5763																
53	CUSTOM 455	Carpenter Tech.	S45500																			
54	DD 3																					
55	DD 6																					
56	DISCALOY	Rotor, Disc																				
57	DR422	Rotor																				
58	ECY768	Vane:1100 & 1300℃Class																				
59	FSX 414	Vane								B50A489												
60	Greek Ascoloy																					
61	GTD 111	Blade-1100℃Class , (DS)-1300℃Class	–							B50A719												
62	GTD 222	Vane								C50TF101 B50A850												
63	GTD 241																					
64	GTD 444	Blade-1500℃Class																				
65	GTD 450	Comp.-Blade																				
66	H53V	Rotor																				
67	Hast X																		Hast X			
68	Hastelloy C					5388C									KTA-HC				Hastelloy C			
69	Hastelloy S																		Hastelloy S			
70	Hastelloy X		N06002	ASME B435		5536		MA-X			NAS HX				KTA-HX				Hastelloy X			
71	Haynes 120																		Haynes 120			
72	Haynes 150																		Haynes 150			
73	Haynes 160																		Haynes 160			
74	Haynes 188	Combuster	R30188					MA188											Haynes 188			
75	Haynes 214							MA24											Haynes 214			
76	Haynes 230							MA23											Haynes 230			
77	Haynes 242																		Haynes 242			
78	Haynes 25-L-605							MA25											Haynes 25-L-605			
79	Haynes 282																		Haynes 282			
80	Haynes 556		R30556			5768		MA5560											Haynes 556			

No.	Alloy Name	Use & Remarks	Standard					Mitsubishi Material	Pratt & Whitney	General Electric Company	Nippon Yakin Kogyo	Daidou Special Metal	NIMS	MHI	Nippon Koshuha Steel	INC Family of Companies	Deloro Stellite	Martine Marietta Corporation	Haynes International Inc.	Cannon Muskegon	Avesta Sheffield	Rolled Alloy
			UNS No	ASME, ASTM	AISI	AMS	JIS															
81	HK 40																					
82	In 100		N13100			5397			PWA658 PWA1494							In 100						
83	In 600															In 600						
84	In 601															In 601						
85	In 617	Combuster														In 617						
86	In 6201															In 6201						
87	In 6203															In 6203						
88	In 625															In 625						
89	In 738	Blade:1970 era							PWA1451	B50A563						In 738						
90	In 738LC	Blade: 1300℃Class																				
91	In 792															In 792						
92	In 939	Vane:1500℃Class							PWA1495							In 939						
93	INCOLOY alloy 020		N08020													INCOLOY alloy 020						
94	INCOLOY alloy 028		N08028													INCOLOY alloy 028						
95	INCOLOY alloy 25-6MO		N08926													INCOLOY alloy 25-6MO						
96	INCOLOY alloy 25-7MO		S31277													INCOLOY alloy 25-7MO						
97	INCOLOY alloy 330		N08330	ASME B511-2, B535-6, 710, 739		5592, 5716						DS-330				INCOLOY alloy 330						
98	INCOLOY alloy 330HC															INCOLOY alloy 330HC						
99	INCOLOY alloy 800		N08800	ASME B407-9, 514-5, 163, 564, 751		5766, 5871	G4901-4	MA800			NAS800	DS-800			KTA800	INCOLOY alloy 800						
100	INCOLOY alloy 800H		N08810	ASME B409				MA800H			NAS800H					INCOLOY alloy 800H						
101	INCOLOY alloy 800HT		N08811	ASME B435, 572, 619, 622, 626, 751		5390, 5536, 5587-8, 5754, 5798, 7237	H4551-3	MA800HT				DS-800HT				INCOLOY alloy 800HT						
102	INCOLOY alloy 801					5552									KTA801	INCOLOY alloy 801						
103	INCOLOY alloy 802					–									KTA802	INCOLOY alloy 802						
104	INCOLOY alloy 803		S35045			–						DS-803				INCOLOY alloy 803						
105	INCOLOY alloy 805															INCOLOY alloy 805						
106	INCOLOY alloy 825		N08825												KTA825	INCOLOY alloy 825						
107	INCOLOY alloy 832		–													INCOLOY alloy 832						
108	INCOLOY alloy 840											DS-840				INCOLOY alloy 840						
109	INCOLOY alloy 864		S35135	ASTM A420								DS-864				INCOLOY alloy 864						
110	INCOLOY alloy 890		N08890													INCOLOY alloy 890						
111	INCOLOY alloy 901					5660		MA901							KTA901	INCOLOY alloy 901						
112	INCOLOY alloy 903		N19903					MA903								INCOLOY alloy 903						
113	INCOLOY alloy 904															INCOLOY alloy 904						
114	INCOLOY alloy 907		N19907													INCOLOY alloy 907						
115	INCOLOY alloy 908		N19908													INCOLOY alloy 908						
116	INCOLOY alloy 909		N19909													INCOLOY alloy 909						
117	INCOLOY alloy 925		N09925													INCOLOY alloy 925						
118	INCOLOY alloy A-286		S66286	ASTM A456, 638		5525-6, 5731	G4311					DS-A286				INCOLOY alloy A-286						
119	INCOLOY alloy DS		–			–						DS-DS				INCOLOY alloy DS						
120	INCOLOY alloy MA956		S67956													INCOLOY alloy MA956						

No.	Alloy Name	Use & Remarks	Standard					Mitsubishi Material	Pratt & Whitney	General Electric Company	Nippon Yakin Kogyo	Daidou Special Metal	NIMS	MHI	Nippon Koshuha Steel	INC Family of Companies	Deloro Stellite	Martine Marietta Corporation	Haynes International Inc.	Cannon Muskegon	Avesta Sheffield	Rolled Alloy
			UNS No	ASME, ASTM	AISI	AMS	JIS															
121	INCOLOY alloy MA957															INCOLOY alloy MA957						
122	Inconel 182															Inconel 182						
123	Inconel 62															Inconel 62						
124	Inconel 657															Inconel 657						
125	Inconel 718					5596				B5T0TF14						Inconel 718						
126	Inconel 800H															Inconel 800H						
127	Inconel 800HT			ASME B409												Inconel 800HT						
128	Inconel 82															Inconel 82						
129	Inconel alloy 050															Inconel alloy 050						
130	Inconel alloy 22		N06622													Inconel alloy 22						
131	Inconel alloy 230															Inconel alloy 230						
132	Inconel alloy 600 & 600T		N06600	ASME B167, 168, 564, 163		5540, 5580, 5588-7 7232		MA600 & 600T			NAS600	DS-600			KTA600	Inconel alloy 600 & 600T						
133	Inconel alloy 600SP															Inconel alloy 600SP						
134	Inconel alloy 601		N06601	ASME B166-8		5870, 5715	G4901-2	MA601			NAS601	DS-601			KTA601	Inconel alloy 601						
135	Inconel alloy 601GC		–													Inconel alloy 601GC						
136	Inconel alloy 603XL															Inconel alloy 603XL						
137	Inconel alloy 604															Inconel alloy 604						
138	Inconel alloy 606														KTA606	Inconel alloy 606						
139	Inconel alloy 613															Inconel alloy 613						
140	Inconel alloy 617		N06617	ASME B166-8		5587-9						DS-617				Inconel alloy 617						
141	Inconel alloy 622					–										Inconel alloy 622						
142	Inconel alloy 625		N06625	ASME B160, 161, 162, 163		5553	H4551, 4552, 4553	MA625			NAS625	DS-625			KTA625	Inconel alloy 625						
143	Inconel alloy 625LCF		N06625	ASME B443		5599, 5879	G4902					DS-625LCF				Inconel alloy 625LCF						
144	Inconel alloy 671															Inconel alloy 671						
145	Inconel alloy 672															Inconel alloy 672						
146	Inconel alloy 686		N06686													Inconel alloy 686						
147	Inconel alloy 690 & 690HT		N06690					MA690								Inconel alloy 690 & 690HT						
148	Inconel alloy 691															Inconel alloy 691						
149	Inconel alloy 693		N06693													Inconel alloy 693						
150	Inconel alloy 702					5550										Inconel alloy 702						
151	Inconel alloy 706		N09706			Feb-57		MA706								Inconel alloy 706						
152	Inconel alloy 718		N07718	ASME B637, 670		5589, 5590, 5596, 5597, 5832, 5562, 5563, 5564	G4901, G4902	MA718				DS-718			KTA718	Inconel alloy 718						
153	Inconel alloy 718SPF		N07719													Inconel alloy 718SPF						
154	Inconel alloy 721															Inconel alloy 721						
155	Inconel alloy 722					5541										Inconel alloy 722						
156	Inconel alloy 725		N07725													Inconel alloy 725						
157	Inconel alloy 725HS															Inconel alloy 725HS						
158	Inconel alloy 740		–													Inconel alloy 740						
159	Inconel alloy 751		N07751			–										Inconel alloy 751						
160	Inconel alloy 783		R30783													Inconel alloy 783						

No.	Alloy Name	Use & Remarks	Standard					Mitsubishi Material	Pratt & Whitney	General Electric Company	Nippon Yakin Kogyo	Daidou Special Metal	NIMS	MHI	Nippon Koshuha Steel	INC Family of Companies	Deloro Stellite	Martine Marietta Corporation	Haynes International Inc.	Cannon Muskegon	Avesta Sheffield	Rolled Alloy
			UNS No	ASME, ASTM	AISI	AMS	JIS															
161	Inconel alloy C-276		N10276													Inconel alloy C-276						
162	Inconel alloy G															Inconel alloy G						
163	Inconel alloy G-3		N06985													Inconel alloy G-3						
164	Inconel alloy HX		N06002	ASME B435, 572 619, 622, 626, 751		5390, 5587-8, 5798, 7237	H4551-3					DS-HX				Inconel alloy HX						
165	Inconel alloy MA6000															Inconel alloy MA6000						
166	Inconel alloy MA754		N07754													Inconel alloy MA754						
167	Inconel alloy MA758		–													Inconel alloy MA758						
168	Inconel alloy X-750		N07750	ASME B637		5542, 5582, 5583, 5598, 5667, 5668, 5669, 5670, 5671	G4901, G4902	MA750			NAS750	DS-X750			KTAX-750	Inconel alloy X-750						
169	Inconel alloy X-751							MA751				DS-X751				Inconel alloy X-751						
170	Inconel MA6000															Inconel MA6000						
171	LCN 155	Vane													KTA155							
172	M152	Disc																				
173	M252	Blade																				
174	MC-NG																					
175	Mar-M-200+Hf	Vane, Blade							PWA 1422									Mar-M-200+Hf				
176	Mar-M-247	Vane, Blade:1980 era																Mar-M-247				
177	Mar-M-247 DS	Vane, Blade																Mar-M-247 DS				
178	Mar-M-421	Vane, Blade:1970 era				–												Mar-M-421				
179	Mar-M-432	Vane, Blade																Mar-M-432				
180	Mar-M-509/ECY 768	Vane, Blade							PWA 647	B50TF89								Mar-M-509/ECY 768				
181	Mar-M-918	Vane, Blade				–												Mar-M-918				
182	MERL76																					
183	MGA1400	Blade-(DS)1500℃Class												MGA1400								
184	MGA2400	Vane												MGA2400								
185	MM002	Blade-(DS): 1500℃Class																				
186	N 155	Vane						MA155N														
187	N253	Combuster																				
188	NCF718	Rotor																				
189	NCF750	Blade																				
190	NCF800	Combuster																				
191	NCF80A	Blade																				
192	Nimonic 101															Nimonic 101						
193	Nimonic 105		–			–										Nimonic 105						
194	Nimonic 108															Nimonic 108						
195	Nimonic 115		–			–										Nimonic 115						
196	Nimonic 263		N07263					MA263								Nimonic 263						
197	Nimonic 70															Nimonic 70						
198	Nimonic 75		N06075					MA75N				DSN-75			KTAN-75	Nimonic 75						
199	Nimonic 80A		N07080	ASME B637		–	G4901-2	MA80A				DSN-80A			KTAN-80A	Nimonic 80A						
200	Nimonic 81		–													Nimonic 81						

No.	Alloy Name	Use & Remarks	Standard					Mitsubishi Material	Pratt & Whitney	General Electric Company	Nippon Yakin Kogyo	Daidou Special Metal	NIMS	MHI	Nippon Koshuha Steel	INC Family of Companies	Deloro Stellite	Martine Marietta Corporation	Haynes International Inc.	Cannon Muskegon	Avesta Sheffield	Rolled Alloy
			UNS No	ASME, ASTM	AISI	AMS	JIS															
201	Nimonic 90		N07090	ASME B5829		–		MA90N				DSN-90			KTAN-90	Nimonic 90						
202	Nimonic 91		–													Nimonic 91						
203	Nimonic alloy PE11		N09901													Nimonic alloy PE11						
204	Nimonic alloy PE16		–			–										Nimonic alloy PE16						
205	Nimonic alloy PK31					–										Nimonic alloy PK31						
206	Nimonic alloy PK33		–			–										Nimonic alloy PK33						
207	Nimonic alloy PK37															Nimonic alloy PK37						
208	NW6002	Combuster																				
209	PH13-8Mo					5629																
210	PH15-7Mo																					
211	Preci222																					
212	PWA 1480	Blade							PWA 1480													
213	PWA 1482								PWA 1482													
214	PWA 1483	Blade							PWA 1483													
215	PWA 1484	Blade							PWA 1484													
216	PWA 1947	Blade							PWA 1947													
217	RA 330		N08330	ASME B536, B511		5592, 5716																RA 330
218	RA 333	Combuster	N06333	ASTM B718		5593																RA 333
219	Rene 41	Vane, Casing	N07041		683	5545, 5712, 5713, 5800		MA41R		Rene 41												
220	Rene 77	Blade-1100℃Class、(DS)-1300℃Class	N07500			–				Rene 77												
221	Rene 80	Blade				–				Rene 80												
222	Rene 80H									Rene 80H												
223	Rene 95					–				Rene 95												
224	Rene N4	Vane, Blade								Rene N4												
225	Rene N5	Vane, Blade-(SX)1500℃Class								Rene N5												
226	Rene N6	Vane, Blade								Rene N6												
227	Rene108	Vane								Rene108												
228	RR 2000	Rolles-Royce																				
229	RR 3000	Rolles-Royce																				
230	S 816														KTA816							
231	S590	Blade																				
232	S816	Blade																				
233	SC 180																					
234	SRR 99																					
235	Stellite 1																Stellite 1					
236	Stellite 100																Stellite 100					
237	Stellite 107																Stellite 107					
238	Stellite 12																Stellite 12					
239	Stellite 190																Stellite 190					
240	Stellite 20																Stellite 20					

No.	Alloy Name	Use & Remarks	Standard					Mitsubishi Material	Pratt & Whitney	General Electric Company	Nippon Yakin Kogyo	Daidou Special Metal	NIMS	MHI	Nippon Koshuha Steel	INC Family of Companies	Deloro Stellite	Martine Marietta Corporation	Haynes International Inc.	Cannon Muskegon	Avesta Sheffield	Rolled Alloy
			UNS No	ASME, ASTM	AISI	AMS	JIS															
241	Stellite 21																Stellite 21					
242	Stellite 238																Stellite 238					
243	Stellite 3																Stellite 3					
244	Stellite 306																Stellite 306					
245	Stellite 31																Stellite 31					
246	Stellite 4																Stellite 4					
247	Stellite 6																Stellite 6					
248	Stellite 694																Stellite 694					
249	Stellite F																Stellite F					
250	Stellite SF1																Stellite SF1					
251	Stellite SF12																Stellite SF12					
252	Stellite SF2																Stellite SF2					
253	Stellite SF20																Stellite SF20					
254	SUH660	Rotor																				
255	TMS-26												TMS-26									
256	TMS-138	Blade											TMS-138									
257	TMS-162	Blade, World's highest Temp.1100℃											TMS-162									
258	TMS-196												TMS-196									
259	TMS-75	Blade											TMS-75									
260	TMS-82+	Blade											TMS-82+									
261	TOMILLOY	Combuster																				
262	Tribaloy T400																Tribaloy T400					
263	Tribaloy T700																Tribaloy T700					
264	Tribaloy T800																Tribaloy T800					
265	U 500	Vane, Blade-1100℃Class	N07500			5384			C50T39													
266	U 500 bar																					
267	U 520	Blade:1100℃Class																				
268	U 700								C50TF15													
269	U 710	Blade	N07500																			
270	U 720	Blade																				
271	W-545							MA545														
272	Waspaloy		N07001	ASTM A567		5544		MA-WASP	Waspaloy													
273	X 750	(PyromevAlloy X-750)	N07750	–		–																
274	X40	Vane																				
275	X45	Vane																				
276	YH61	Blade-Hitachi																				
277																						

http://www.c-mgroup.com/vacuum_melt_index/nickel_base_equiax.htm

http://www.townmining.co.jp/products/co_alloy.html

http://www.cmkmetal.com/main/?skin=prod_06.htm

(CC) : Conventional Casting

(DS) : Directionl Solidification

(SC) : Single Crystal

8. Gas Turbine Performance Characteristics

(1) Air Temperature and Site Elevation

Since the gas turbine is an air-breathing engine, its performance is changed by anything that affects the density and/or mass flow of the air intake to the compressor. Ambient weather conditions are the most obvious changes from the reference conditions of 59 F/15 C and 14.7 psia/1.013 bar. Fig-35 shows how ambient temperature affects the output, heat rate, heat consumption, and exhaust flow of a single-shaft MS7001. Each turbine model has its own temperature- effect curve, as it depends on the cycle parameters and component efficiencies as well as air mass flow. Correction for altitude or barometric pressure is more straightforward. The air density reduces as the site elevation increases. While the resulting airflow and output decrease proportionately, the heat rate and other cycle parameters are not affected. A standard altitude correction curve is presented in Fig-36.

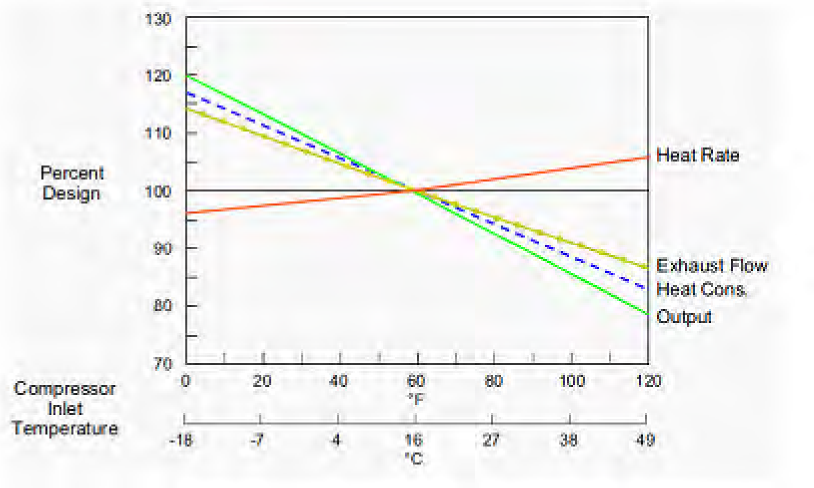


Fig- 35: Effect of ambient temperature

Reference: P-8 of "GE gas turbine performance characteristics" (GER－3567H) : GE Power Systems

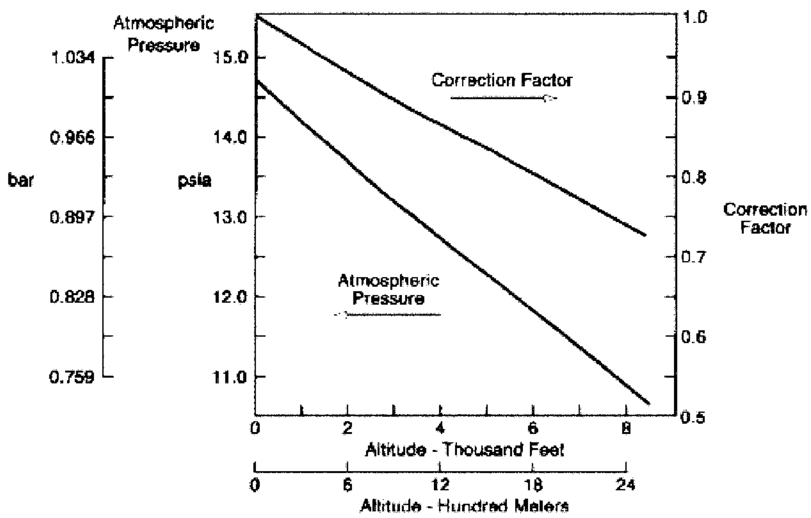


Fig- 36: Altitude correction curve

Reference: P-9 of "GE gas turbine performance characteristics" (GER－3567H) : GE Power Systems

(2) Humidity

Similarly, humid air, which is less dense than dry air, also affects output and heat rate, as shown in Fig-37. In the past, this effect was thought to be too small to be considered. However, with the increasing size of gas turbines and the utilization of humidity to bias water and steam injection for NOx control, this effect has greater significance. It should be noted that this humidity effect is a result of the control system approximation of firing temperature used on GE heavy-duty gas turbines. Single-shaft exhaust temperature biased by the compressor pressure ratio to the approximate firing temperature will reduce power as a result of turbines that use turbine increased ambient humidity. This occurs because the density loss to the air from humidity is less than the density loss due to temperature. The control system is set to follow the inlet air temperature function. By contrast, the control system on aero-derivatives uses unbiased gas generator discharge temperature to approximate firing temperature. The gas generator can operate at different speeds from the power turbine, and the power will actually increase as fuel is added to raise the moist air (due to humidity) to the allowable temperature. This fuel increase will increase the gas generator speed and compensate for the loss in air density.

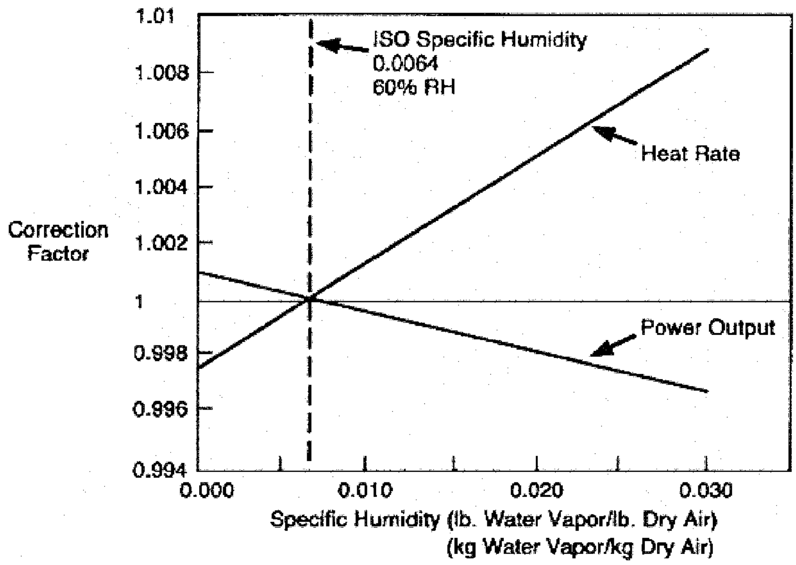


Fig- 37: Effect of ambient temperature

Reference: P-9 of "GE gas turbine performance characteristics" （GER－3567H）: GE Power Systems

(3) Inlet and Exhaust Losses

Inserting air filtration, silencing, evaporative coolers or chillers into the inlet or heat recovery devices in the exhaust causes pressure losses in the system. The effects of these pressure losses are unique to each design. The Table-19 shows the effects on the MS7001EA, which are typical for the E technology family of scaled machines (MS6001B, 7001EA, 9001E).

Table- 19: Pressure drop effects (GE-MS7001EA)

4 inches (10mbar)H^2O Inlet Drop Procedures:	1.42% Power Output Loss
	0.45% Heat Rate Increase
	1.9F(1.1C) Exhaust Temperature Increase
4 inches (10mbar)H^2O Exhaust Drop Procedures:	0.42% Power Output Loss
	0.42% Heat Rate Increase
	1.9F(1.1C) Exhaust Temperature Increase

Reference: P-10 of "GE gas turbine performance characteristics" （GER－3567H）: GE Power Systems

(4) Fuels

Work from a gas turbine can be defined as the product of mass flow, heat energy in the combusted gas (Cp), and temperature differential across the turbine. The mass flow in this equation is the sum of compressor airflow and fuel flow. The heat energy is a function of the elements in the fuel and the products of combustion. Table-20 show that natural gas (methane) produces nearly 2% more output than does distillate oil. This is due to the higher specific heat in the combustion products of natural gas, resulting from the higher water vapor content produced by the higher hydrogen/carbon ratio of methane. This effect is noted even though the mass flow (lb/h) of methane is lower than the mass flow of distillate fuel. Here the effects of specific heat were greater than and in opposition to the effects of mass flow. Fig-38 shows the total effect of various fuels on turbine output. This curve uses methane as the base fuel. Although there is no clear relationship between fuel lower heating value (LHV) and output, it is possible to make some general assumptions. If the fuel consists only of hydrocarbons with no inert gases and no oxygen atoms, output increases as LHV increases. Here the effects of Cp are greater than the effects of mass flow. Also, as the amount of inert gases is increased, the decrease in LHV will provide an increase in output. This is the major impact of IGCC type fuels that have large amounts of inert gas in the fuel. This mass flow addition, which is not compressed by the gas turbine's compressor, increases the turbine output. Compressor power is essentially unchanged. Several side effects must be considered when burning this kind of lower heating value fuels:

Table- 20: GE gas turbine performance characteristics (Generator drive gas turbine ratings)

GE generator drive product line									
Model	Fuel	ISO Base Rating (kW)	Heat rate (Btu/kWh)	Heat rate (kJ/kWh)	Exhaust Flow (lb/hr)×10-3	Exhaust Flow (kg/hr)×10-3	Exhaust Temp. (oF)	Exhaust Temp. (oC)	Pressure Ratio
PG5371 (PA)	Gas	26,070	12,060	12,721	985	446	905	485	10.6
	Dist.	25,570	12,180	12,847	998	448	906	486	10.6
PG6581 (B)	Gas	42,100	10,640	11,223	1158	525	1010	543	12.2
	Dist.	41,160	10,730	11,318	1161	526	1011	544	12.1
PG6101 (FA)	Gas	69,430	10,040	10,526	1638	742	1101	594	14.6
	Dist.	74,090	10,680	10,527	1704	772	1079	582	15.0
PG7121 (EA)	Gas	84,360	10,480	11,054	2361	1070	998	536	12.7
	Dist.	87,220	10,950	11,550	2413	1093	993	537	12.9
PG7241 (FA)	Gas	171,700	9,360	9,873	3543	1605	1119	604	15.7
	Dist.	183,800	9,965	10,511	3691	1672	1095	591	16.2
PG7251 (FB)	Gas	184,400	9,245	9,752	3561	1613	1154	623	18.4
	Dist.	177,700	9,975	10,522	3703	1677	1057	569	18.7
PG9171 (E)	Gas	122,500	10,140	10,696	3275	1484	1009	543	12.6
	Dist.	127,300	10,620	11,202	3355	1520	1003	539	12.9
PG9231 (EC)	Gas	169,200	9,770	10,305	4131	1871	1034	557	14.4
	Dist.	179,800	10,360	10,928	4291	1944	1017	547	14.8
PG9351 (FA)	Gas	255,600	9,250	9,757	5118	2318	1127	608	15.3
	Dist.	268,000	9,920	10,464	5337	2418	1106	597	15.8

Dist.: Distillate

Note:

1) *Increased turbine mass flow drives up compressor pressure ratio, which eventually encroaches on the compressor surge limit*
2) *The higher turbine power may exceed fault torque limits. In many cases, a larger generator and other accessory equipment may be needed.*
3) *High fuel volumes increase fuel piping and valve sizes (and costs). Low- or medium-Btu coal gases are frequently supplied at high temperatures, which further increase their volume flow.*
4) *Lower-Btu gases are frequently saturated with water prior to delivery to the turbine. This increases the combustion products heat transfer coefficients and raises the metal temperatures in the turbine section which may require lower operating firing temperature to preserve parts lives.*
5) *As the Btu value drops, more air is required to burn the fuel. Machines with high firing temperatures may not be able to burn low Btu gases.*
6) *Most air-blown gasifies use air supplied from the gas turbine compressor discharge.*
7) *The ability to extract air must be evaluated and factored into the overall heat and material balances.*

Reference: P-1 of "GE gas turbine performance characteristics" （GER－3567H）: GE Power Systems

As a result of these influences, each turbine model will have some application guidelines on flows, temperatures and shaft output to preserve its design life. In most cases of operation with lower heating value fuels, it can be assumed that output and efficiency will be equal to or higher than that obtained on natural gas. In the case of higher heating value fuels, such as refinery gases, output and efficiency may be equal to or lower than that obtained on natural gas.

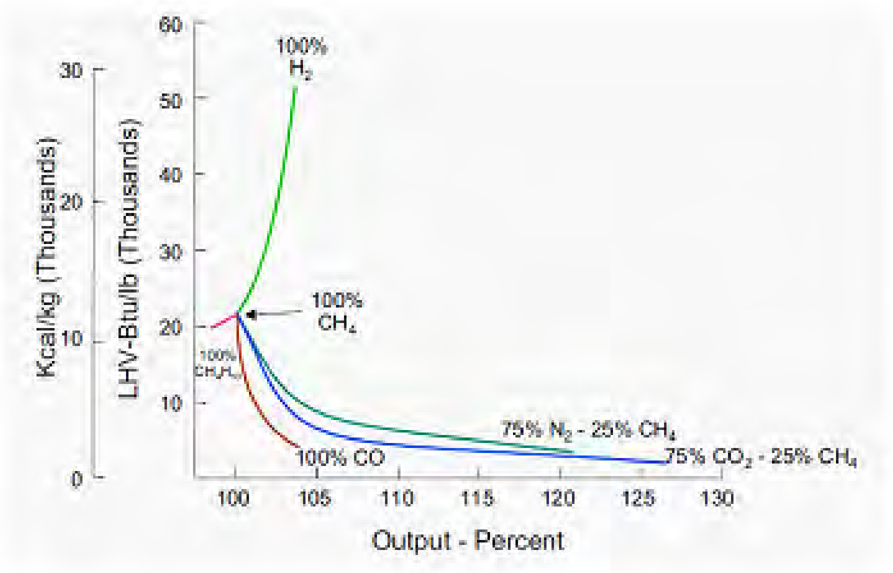


Fig- 38: Effect of fuel heating value on output

Reference: P-11 of "GE gas turbine performance characteristics" （GER－3567H）： GE Power Systems

(5) Fuel Heating

Most of the combined cycle turbine installations are designed for maximum efficiency. These plants often utilize integrated fuel gas heaters. Heated fuel results in higher turbine efficiency due to the reduced fuel flow required to raise the total gas temperature to firing temperature. Fuel heating will result in slightly lower gas turbine output because of the incremental volume flow decrease. The source of heat for the fuel typically is the IP feed-water. Since use of this energy in the gas turbine fuel heating system is thermodynamically advantageous, the combined cycle efficiency is improved by approximately 0.6%.

(6) Diluents Injection

Since the early 1970s, GE has used water or steam injection for NOx control to meet applicable state and federal regulations. This is accomplished by admitting water or steam in the cap area or "head-end" of the combustion liner. Each machine and combustor configuration has limits on water or steam injection levels to protect the combustion system and turbine section. Depending on the amount of water or steam injection needed to achieve the desired NOx level, output will increase because of the additional mass flow. Fig-39 shows the effect of steam injection on output and heat rate for an MS7001EA. These curves assume that steam is free to the gas turbine cycle, therefore heat rate improves. Since it takes more fuel to raise water to combustor conditions than steam, water injection does not provide an improvement in heat rate.

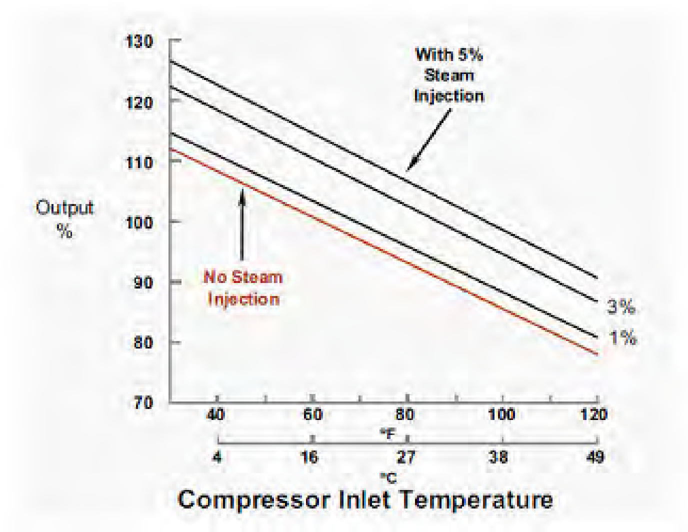


Fig- 39: Effect of steam injection on output and heat rate

Reference: P-12 of "GE gas turbine performance characteristics" （GER－3567H）: GE Power Systems

(7) Air Extraction

In some gas turbine applications, it may be desirable to extract air from the compressor. Generally, up to 5% of the compressor airflow can be extracted from the compressor discharge casing without modification to casings or on-base piping. Pressure and air temperature will depend on the type of machine and site conditions. Air extraction between 6% and 20% may be possible, depending on the machine and combustor configuration, with some modifications to the casings, piping and controls. Such applications need to be reviewed on a case-by-case basis. Air extractions above 20% will require extensive modification to the turbine casing and unit configuration. Fig-40 shows the effect of air extraction on output and heat rate. As a "rule of thumb," every 1% in air extraction results in a 2% loss in power.

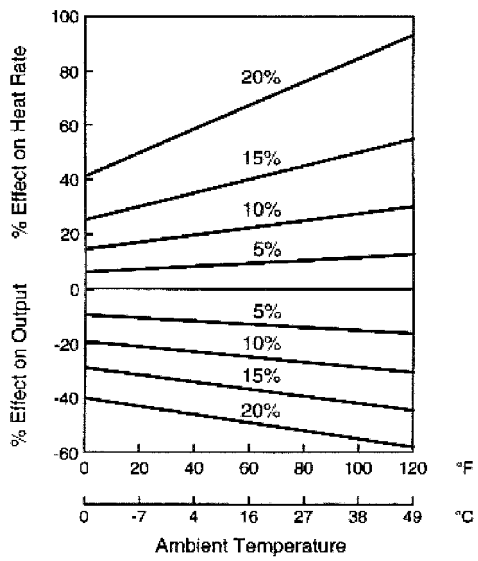


Fig- 40: Effect of air extraction on output and heat rate

Reference: P-12 of "GE gas turbine performance characteristics" （GER－3567H）: GE Power Systems

(8) Performance Enhancements

Generally, controlling some of the factors that affect gas turbine performance is not possible. The planned site location and the plant configuration (such as simple- or combined-cycle) determine most of these factors. In the event additional output is needed, several possibilities to enhance performance may be considered.

(9) Inlet Cooling

The ambient effect curve (see Fig-35) clearly shows that turbine output and heat rate is improved as compressor inlet temperature decreases. Lowering the compressor inlet temperature can be accomplished by installing an evaporative cooler or inlet chiller in the inlet ducting downstream of the inlet filters. Careful application of these systems is necessary, as condensation or carryover of water can exacerbate compressor fouling and degrade performance. These systems generally are followed by moisture separators or coalescing pads to reduce the possibility of moisture carryover. As Fig-41 shows, the biggest gains from evaporative cooling are realized in hot, low-humidity climates. It should be noted that evaporative cooling is limited to ambient temperatures of 59 F/15 C and above (compressor inlet temperature>45 F/7.2 C) because of the potential for icing the compressor. Information contained in Fig-40 is based on an 85% effective evaporative cooler. Effectiveness is a measure of how close the cooler exit temperature approaches the ambient wet bulb temperature. For most applications, coolers having an effectiveness of 85% or 90% provide the most economic benefit. Chillers, unlike evaporative coolers, are not limited by the ambient wet bulb temperature. The achievable temperature is limited only by the capacity of the chilling device to produce coolant and the ability of the coils to transfer heat. Cooling initially follows a line of constant specific humidity, as shown in Fig-42. As saturation is approached, water begins to condense from the air, and mist eliminators are used. Further heat transfer cools the condensate and air, and causes more condensation. Because of the relatively high heat of vaporization of water, most of the cooling energy in this regime goes to condensation and little to temperature reduction.

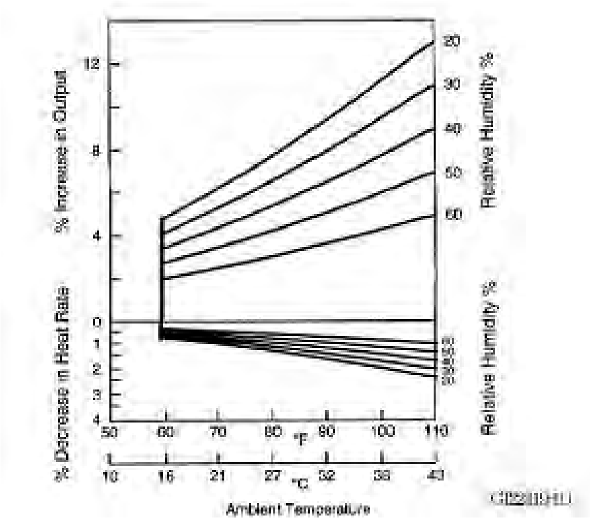


Fig- 41: Effect of evaporative cooling on output and heat rate

Reference: P-13 of "GE gas turbine performance characteristics" （GER－3567H）: GE Power Systems

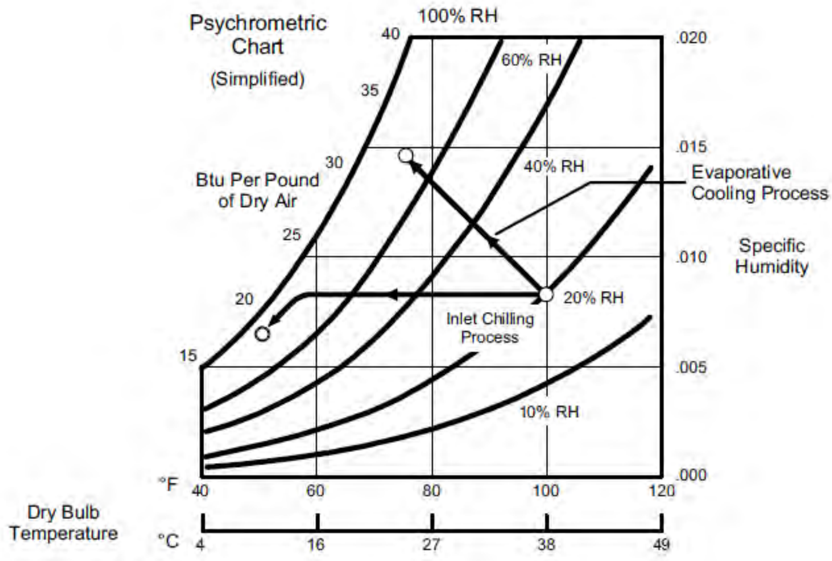


Fig- 42: Inlet chilling process

Reference: P-13 of "GE gas turbine performance characteristics" （GER－3567H）: GE Power Systems

(10) Steam and Water Injection for Power Augmentation

Injecting steam or water into the head end of the combustor for NOx abatement increases mass flow and, therefore, output. Generally, the amount of water is limited to the amount required to meet the NOx requirement in order to minimize operating cost and impact on inspection intervals. Steam injection for power augmentation has been an available option on GE gas turbines for over 30 years. When steam is injected for power augmentation, it can be introduced into the compressor discharge casing of the gas turbine as well as the combustor. The effect on output and heat rate is the same as that shown in Fig-39. GE gas turbines are designed to allow up to5% of the compressor airflow for steam injection to the combustor and compressor discharge. Steam must contain 50 F/28 C superheat and be at pressures comparable to fuel gas pressures. When either steam or water is used for power augmentation, the control system is normally designed to allow only the amount needed for NOx abatement until the machine reaches base (full) load. At that point, additional steam or water can be admitted via the governor control.

(11) Peak Rating

The performance values listed in Table-19 are base load ratings. ANSI B133.6 Ratings and Performance defines base load as operation at 8,000 hours per year with 800 hours per start. It also defines peak load as operation at 1250 hours per year with five hours per start. In recognition of shorter operating hours, it is possible to increase firing temperature to generate more output. The penalty for this type of operation is shorter inspection intervals. Despite this, running an MS5001, MS6001 or MS7001 at peak may be a cost-effective way to obtain more kilowatts without the need for additional peripheral equipment. Generators used with gas turbines likewise have peak ratings that are obtained by operating at higher power factors or temperature rises. Peak cycle ratings are ratings that are customized to the mission of the turbine considering both starts and hours of operation. Firing temperatures between base and peak can be selected to maximize the power capabilities of the turbine while staying within the starts limit envelope of the turbine hot section repair interval.

For instance, the 7EA can operate for 24,000 hours on gas fuel at base load, as defined. The starts limit to hot section repair interval is 800 starts. For peaking cycle of five hours per start, the hot section repair interval would occur at 4,000 hours, which corresponds to operation at peak firing temperatures. Turbine missions between five hours per start and 800 hours per start may allow firing temperatures to increase above base but below peak without sacrificing hours to hot section repair. Water injection for power augmentation may be factored into the peak cycle rating to further maximize output.

(12) Performance Degradation

All turbo machinery experiences losses in performance with time. Gas turbine performance degradation can be classified as recoverable or non-recoverable loss. Recoverable loss is usually associated with compressor fouling and can be partially rectified by water washing or, more thoroughly, by mechanically cleaning the compressor blades and vanes after opening the unit. Non-recoverable loss is due primarily to increased turbine and compressor clearances and changes in surface finish and airfoil contour. Because this loss is caused by reduction in component efficiencies, it cannot be recovered by operational procedures, external maintenance or compressor cleaning, but only through replacement of affected parts at recommended inspection intervals.

Quantifying performance degradation is difficult because consistent, valid field data is hard to obtain. Correlation between various sites is impacted by variables such as mode of operation, contaminants in the air and humidity, fuel and diluents injection levels for NOx. Another problem is that test instruments and procedures vary widely, often with large tolerances.

Typically, performance degradation during the first 24,000 hours of operation (the normally recommended interval for a hot gas path inspection) is 2% to 6% from the performance test measurements when corrected to guaranteed conditions. This assumes degraded parts are not replaced. If replaced, the expected performance degradation is 1% to 1.5%. Recent field experience indicates that frequent off-line water washing is not only effective in reducing recoverable loss, but also reduces the rate of non-recoverable loss.

(13) Verifying Gas Turbine Performance

Once the gas turbine is installed, a performance test is usually conducted to determine power plant performance. Power, fuel, heat consumption and sufficient supporting data should be recorded to enable as-tested performance to be corrected to the condition of the guarantee. Preferably, this test should be done as soon as practical, with the unit in new and clean condition. In general, a machine is considered to be in new and clean condition if it has less than 200 fired hours of operation. Testing procedures and calculation methods are patterned after those described in the ASME Performance Test Code PTC-22-1997, “Gas Turbine Power Plants.” Prior to testing, all station instruments used for primary data collection must be inspected and calibrated. The test should consist of sufficient test points to ensure validity of the test set-up. Each test point should consist of a minimum of four complete sets of readings taken over a 30-minute time period when operating at base load. Per ASME PTC-22-1997, the methodology of correcting test results to guarantee conditions and measurement uncertainties (approximately 1% on output and heat rate when testing on gas fuel) shall be agreed upon by the parties prior to the test. One generalization that can be made from the data is that machines located in dry, hot climates typically degrade less than those in humid climates.

(14) Relation between Gas Turbine Inlet Temperature and Output

The output and thermal efficiency changes in the gas turbine because gas turbine inlet temperature changes due to the change of fuel flow. Moreover, even if keeping the temperature of gas turbine inlet in constant, the output changes according to the inlet temperature and atmospheric pressure. Thus, when seeking an individual gas turbine output, it is necessary to define these conditions. It is necessary to use the turbine inlet temperature properly when using long or short time, because the turbine inlet gas temperature affects directly to the life of the material being used for hot parts such as turbine blades and combustor. The turbine inlet temperature is different from materials and cooling structure, etc. which has been adopted by each respective manufacturer. "JIS B0218: terms for thermal power generation – Gas Turbine and its auxiliary equipments" defined the output of gas turbine as shown in Table-21 and Fig-43.

Table- 21: Definition of rated output stipulated in JIS B0128

Rated Output	The guaranteed output at the generator terminals in operations of a gas turbine in the predetermined conditions.
Standard Rated Output	The rated output when a turbine is operated in the relative standard conditions (i.e. the total temperature of air at the compressor inlet flange is 15°C, total pressure is 1.033kgf/cm^2.abs. (101.3kPa), relative humidity is 60% and static exhaust pressure at the turbine exhaust flange is 1.033kgf/cm^2.abs. (101.3kPa))
Site Rated Output	The rated output of a gas turbine plant in the installation site conditions (such as the atmospheric pressure, atmospheric temperature, pressure loss, and so forth). The rated outputs are classified into the base rating output and peak rating output according to applications of gas turbines.
Permitted Output	The rated output which was reported at its location at given ambient temperature of gas turbine.
Base Operation Mode	The operation mode of gas turbine at the inlet temperature when the standard rated output was determined.
Peak Operation Mode	The operating mode which is aimed to increase output by keeping the inlet temperature higher than the standard rated output.

Peak Load Rated Output	The rated output corresponding to the operation mode depending on the annual operating hours exceeds 500 and less than 2,000 and the average annual starting times exceeds 100 times and less than 50 times.
Base Load Output	The rated output corresponding to the operation mode depending on the annual operating hours exceeds 6,000 and less than 8,760.
Short Time Rated Output	The rated output which can be obtained continuously during predetermined period.
Limit Output	The maximum output at the generator terminal which is determined by the condition other than combustion gas temperature such as shaft strength, capacity of the auxiliary machines).
Output Performance Diagram	The output curve which shows the change in response to ambient temperature.
Corrected Output	The output of generator terminal which is obtained by modifying to the value at comparative standard conditions or given conditions from the output measured at any atmospheric conditions.

Reference: Terms for Thermal Power Facility-Gas Turbine JIS B0128-2010: Japanese Industrial Standard

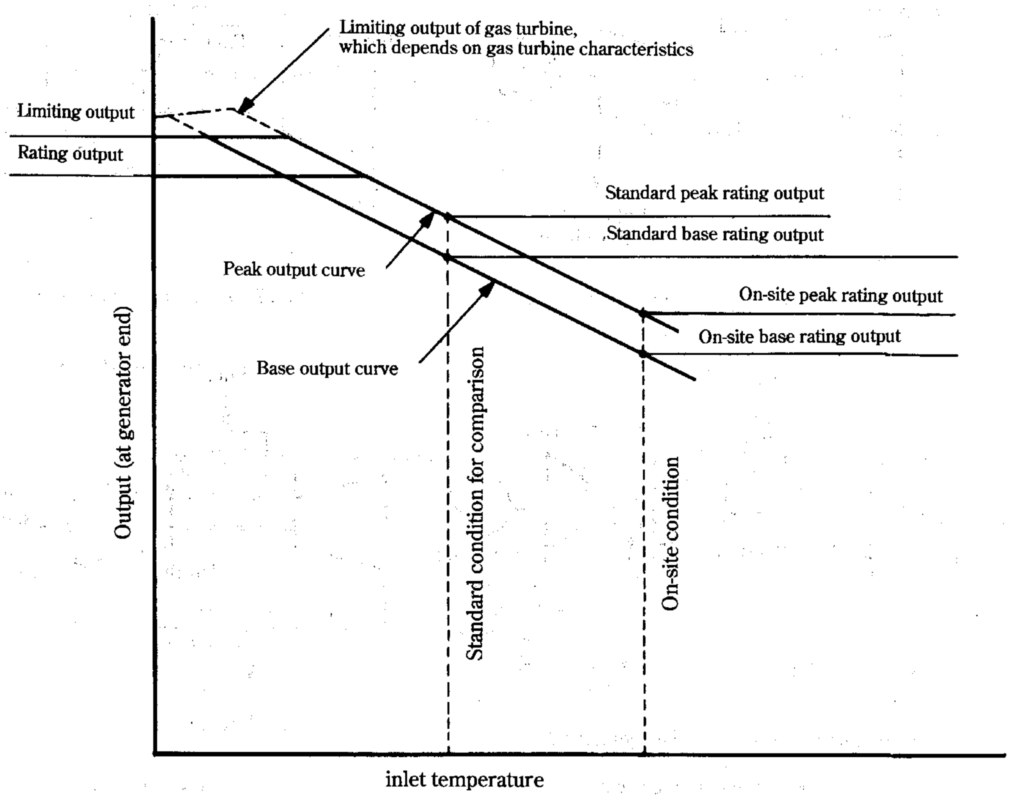


Fig- 43: Relation between gas turbine inlet temperature and output

Reference: P-394 Handbook for Thermal and Nuclear Power Engineers English Ver. 7 2008 TENPES

Unless otherwise expressly agreed upon certain conditions foe applying the delivery between purchaser and supplier, the rated output of gas turbines must be clarified for a combination of the class and the range of average starting times as shown in Table-22. At this time, the manufacturer must indicate the type, interval and extent of the inspection and maintenance required for the relevant operation mode.

Table- 22: Operation mode

Class		Range	
A	Annual operating hours : 500 hours or less	I	Annual average starting times : 500 and more
B	Annual operating hours : 2,000 hours or less	II	Annual average starting times : less than 500
C	Annual operating hours : 6,000 hours or less	III	Annual average starting times : less than 100
D	Annual operating hours : 8,760 hours or less	IV	Annual average starting times : less than 25
—	—	V	Non-stop continuous operation except planned outage for maintenance and inspection during certain period

Reference: 4.4.1 and 4.4.2 of JIS B8042-2-2001

Article 37. Material for auxiliary facilities of gas turbine

1. “The **pressure part**” stipulated in Article37-1 of design technical regulation must be considered the part which is exposed inside the pressure of exceed 0MPa.
2. “The material which have **stable chemical composition and mechanical strength**” stipulated in Article37-2. of design technical regulation must be the material which is excellent in welding performance, strain strength, ductility, toughness and hardness etc. and it may use the materials listed in **Appendix-1-“ferrous material”** and **Appendix-2-“no-ferrous material”** as satisfied”.

3. Required Calculated Thickness of Pipe or Tube

(1) In case of more than 127mm outside diameter

$$t = \frac{Pd}{2\sigma_a \eta + 2\kappa P} + \alpha$$

t	: minimum thickness of steel pipe (if there is negative allowance for steel pipe dimension, actual thickness shall not be below this thickness)	:mm
P	: maximum operation pressure (it shall be 0.7MPa if it is less than o.7MPa)	:MPa
d	: outside diameter of pipe or tube	:mm
α_a	: allowable tensile stress of material	:N/mm^2
η	: efficiency of longitude joint of welded pipe	:—
κ	: According to Table-24	:—
α	: According to Table-23	:mm

(2) In case of not greater than 127mm outside diameter

$$t = \frac{Pd}{2\sigma_a + P} + 0.005d + \alpha$$

t	: minimum thickness of steel pipe	:mm
P	: maximum operation pressure	:MPa
d	: outside diameter of pipe or tube	:mm
α_a	: allowable tensile stress of material	:N/mm^2
α	:1mm, (however, it may apply 0mm for the expanded stub which thickness at the point of stub length plus 25mm greater than equal to the value in Table-25)	:mm

(3) Factors

Table- 23: Minimum thickness

Outside diameter of pipe or tube	Thickness (mm)
$d \leq 38.1$	2.3
$38.1 < d \leq 50.8$	2.6
$50.8 < d \leq 76.2$	2.9
$76.2 < d \leq 101.6$	3.5
$101.6 < d \leq 127$	4.0

Reference: 6.7.2 of JIS B8201-2005 “Stationary steel boilers-Construction”

Table- 24: “κ” value (according to ASME)

Material	Temperature (°C)						
	350 or less	480	510	535	565	590	620 and above
Ferrite steel	0.4	0.4	0.5	0.7	0.7	0.7	0.7
Austenite steel	0.4	0.4	0.4	0.4	0.4	0.5	0.7
Carbon steel	0.4	—	—	—	—	—	—

Reference: 6.7.4 of JIS B8201-2005 “Stationary steel boilers-Construction”

Table- 25: Corrosion allowance

Kind of pipe	Outside diameter (mm)	Minimum value of α (mm)
Screw type	d <34	1.65
	$34 \leq d$	Equal to the height of thread
Non- screw type	d <114.3	1.65
	$114.3 \leq d$	0

Reference: 6.7.4 of JIS B8201-2005 “Stationary steel boilers-Construction”

Article 38. Structure of gas turbine, etc.

1. The **“rotational speed when emergency governor works”** stipulated in Article 38-1 of design technical regulation must include the rotation over-speed which is boosted more than that the emergency governor worked.

2-1. The facility which **“shall not occur abnormal wear, transformation and over-heat”** stipulated in Article 38-2 of design technical regulation must be the equipment which has the following necessary equipments for safety. However, it is not necessary to provide the device stipulated in item-2-2, if the isolation equipment is provided and stop safely when the main oil pump outlet pressure drop. Moreover, it is not necessary to provide the device stipulated in item-2-2 for which is not necessary to provide the device stipulated in item-2-2, if it has the bearing which is capable to stop safely when lubrication oil supply is stopped.

2-2. The bearing which is used air as lubricant must have the construction and function set forth in the next issue, notwithstanding the provisions of the preceding paragraph.

(1) The structure which does not stop lubrication air supply to the bearing during operation of the gas turbine
(2) The structure or function which is taken measure to shorten in contact with the shaft and bearing sufficiently at the range of start-stop or slow rotation in order to reduce friction.
(3) The function to prevent the inclusion of foreign matter into bearing.
(4) The function to cool down by air, etc.
(5) The function to detect abnormality of bearing and stop safely.

2-3. Bearing

Photo-21, 22, 23 24 and 30 shows the typical journal bearing which supports rotor as main bearing. The bearing body is separated in two horizontal planes, the lubricant oil is force feed into lower half and the frictional heat is removed with them. The bearing connected to pedestal through a sphere with upper housing and deal with the movement of the rotor. The contact surface with the rotor is covered by white metal alloy (Babbitt metal) which is mainly composed of tin. This alloy is applied to the bearing, because it has a less coefficient of friction, fit well and is easy to repair because of the low melting temperature.
The pad bearing which has excellent stability is applied to, if the occurrence of pressure pulsation attributed to the oil film is concerned. This bearing has a construction which end surface is separated in several segments (Pads). The bearing shown as Photo-23 is the one type of it and it is called the double tilting pad bearing. The back of the pad itself is dressed in sphere and has simple construction. The thrust bearing is responsible for maintaining the longitudinal position of the rotor and is an important mechanism in maintaining a predetermined value of the stationary and rotating parts clearance. The Mitchell type, Kingsbury type or Taper-land type are mainly applied to, however, every types are common to being considered to formulate oil wedge film. Fig-44~47 and Photo-27, 28, 29 show the plain image of each Mitchell type and Taper-land type. The varnish formation as shown in Photo-31 and 32 must be avoided.

The photo-26 shows typical double roller bearing for small gas turbine.

Photo- 21: GT journal bearing (MHI)

http://www.tradekorea.com/e-catalogue/ddmtl/product-detail/P00255195/MHI_M501F_M501G_Gas_Turbine_Bearing.html

Photo- 22: GT journal bearing

http://www.tradekorea.com/e-catalogue/ddmtl/product-detail/P00255195/MHI_M501F_M501G_Gas_Turbine_Bearing.html

Photo- 23: Double tilting pad bearing

http://bohong-bearing.en.made-in-china.com/product/DbSmLUKxYEHw/China-Radial-Sliding-Tilting-Pad-Thrust-Bearing.html

Photo- 24: GT tilting pad bearing

http://www.ec21.com/product-details/GAS-TURBINE-TILTING-PAD-Bearing--4354378.html

Photo- 25: Double tilting pad bearing

http://www.zhouwa.com/en/product_view.asp?id=95

Photo- 26: Double roller bearing

http://japanese.balljointbearings.com/china-nu_3192_nu29_500_cylindrical_roller_bearings_for_gas_turbines_with_high_rotation_speed-312765.html

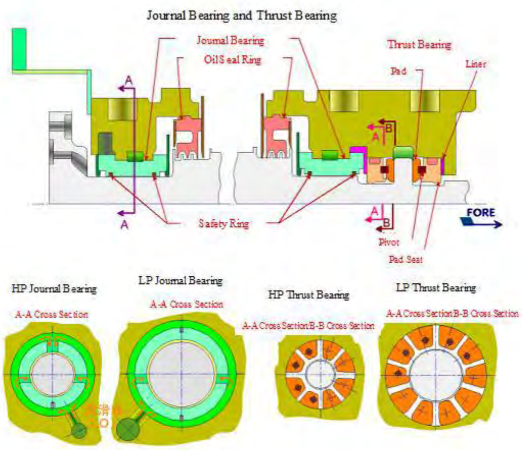


Fig- 44: Turbine bearings

http://www004.upp.so-net.ne.jp/hyoshi/ship/t-plant/t-bearing.gif

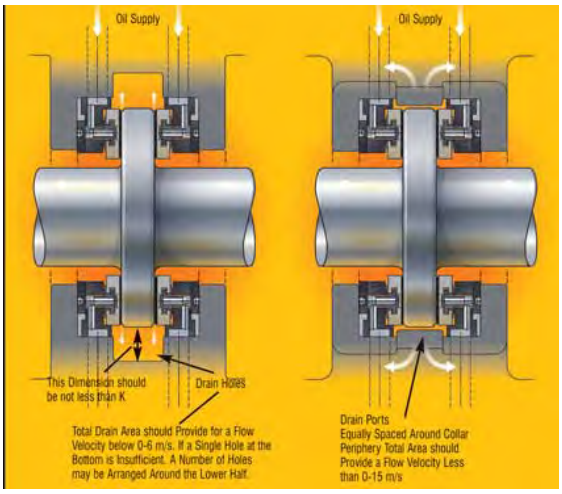


Fig- 45: Thrust bearing

http://media.noria.com/sites/archive_images/Backup_200607_Lube101Fig2.jpg

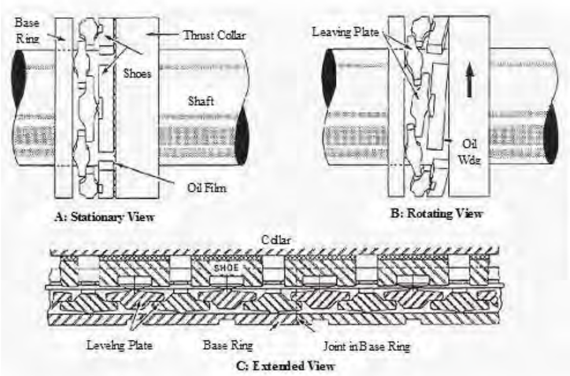


Fig- 46: Kingsbury thrust bearing

http://www.tpub.com/engine3/en33-20.htm

Photo- 27: Kingsbury thrust bearing

http://www.marunda.com.sg/power/images/stories/products/waukesha/tilting_pad_thrust.gif

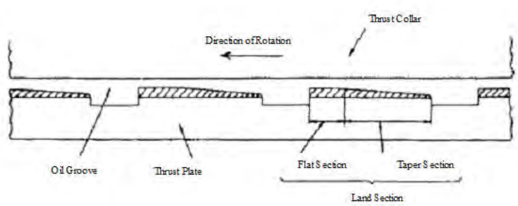


Fig- 47: Taper-land thrust bearing

Reference: P-78 of Journal (No.574: Jul. /2004): TENPES

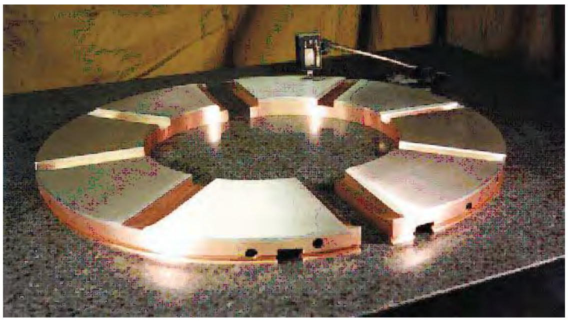


Photo- 28: Taper-land thrust bearing

http://www.mdaturbines.com/wp-content/uploads/2010/01/RenewalPartsMaintenance_Brochure.pdf

Photo- 29: Gas turbine thrust bearing
http://gallery.photo.net/photo/8814191-md.jpg

Photo- 30: Gas turbine journal and thrust bearing.
http://www.power-technology.com/contractor_images/turbine-technology2/4-bearing.jpg

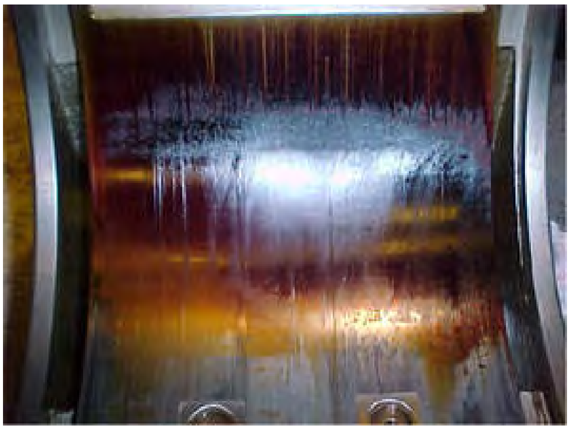


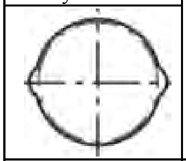
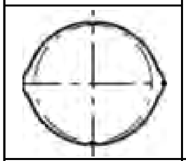
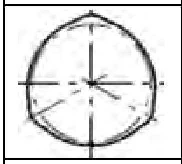
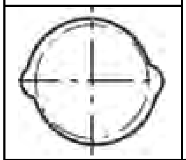
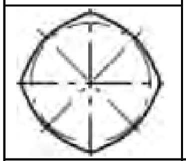
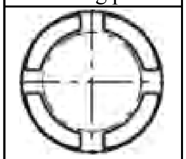
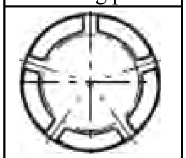
Photo- 31: Varnish formation on GT bearing
http://www.clarustechnologies.com/fluid_intelligence/power_generation.html

Photo- 32: Varnish formation on GT bearing
http://www.realservices.com/Spotlight/Ferrography-Power-Plant.htm

2-4. Clearance Adjustment of Turbine Bearing and Other Parts

(1) The type and application criteria of journal bearing are recommended as shown in Table-26.

Table- 26: Bearing bore configuration selection table

Bore shape	Peripheral speed	Surface pressure 1MPa=1N/mm^2	Sommerfield number	Stiffness/ damping	Relative costs	Applications
Cylindrical 	0…30 (35)m/s	0.2…4.5 (5) Mpa	0.5…10	● ●●●●●	●	Gearboxes Steam tudbines Electric motors Generators
Lemon bore 	25…70 (80)m/s	0.2…3.5 (4) Mpa	0…1.5	●● ●●●●	●●	Gearboxes Steam tudbines Electric motors Generators
3 Lobe 	30…90 (100)m/s	0.1…3.0 (3.5) Mpa	0…1.0	●●● ●●●	●●	General information: Small shaft diameter at high speeds Turbochargers
Offset halves 	20…90 (100)m/s	0.2…3.5 (4.0) Mpa	0…2.0	●●● ●●●●	●●	Gearboxes High-speed pumps Expansion turbines Refrigeration turbines Machine tool spindles
4 Lobe 	30…90 (100)m/s	0.1…2.0 (2.5) Mpa	0…1.0	●●● ●	●●	Gearboxes High-speed pumps Expansion turbines Refrigeration turbines Machine tool spindles
4 Tilting pads 	30…100 (120)m/s	0…2.5 (3.0) Mpa	0…1.0	●●●● ●●●●	●●●●	Gearboxes Steam turbines Single shaft compressors
5 Tilting pads 	30…100 (120)m/s	0…3.0 (3.5) Mpa	0…1.0	●●●●● ●●●●	●●●●	Turbo gear boxes Turbo compressors Steam turbines Gas turbines

http://www.johncrane.co.uk/PDFs/12115TiltingPadJournal_web%5B1%5D.pdf

2-5. Alignment

It is important to design the bearing alignment so that the assembled rotor becomes the most stable situation during operation since the position of bearing pedestal during operation.

The rotor-coupling is the joint which couple each rotor in order to transmit the torque generated by the generator to the turbine blades. The carved into the edge of the rotor flange are mainly applied, however, if the method to fit disk with shrink-fit method, coupling joint shall be the shrink-fit method. The torque may be capable to transmit by flange friction; however, it will be necessary shear strength of bolts in increasing torque to transmit. In addition, even if the instantaneous torque is applied several times of normal situation, it is necessary to prevent disconnection bolt and phase shift at coupling surface as when the transmission torque steady reclosing time or asynchronous inputs.

2-6. Turbine Lubrication Oil

The lubrication oil for turbine is required important role and performance over the range, for instance, lubrication of turbine, lubrication of generator, cooling and sealing. Moreover, turbine oil is required to maintain long term quality unlikely other lubrication oil while over 10years by replacing parts of them "called make-up". The required performance of lubrication oil used for steam turbine, gas turbine and hydro turbine is characterized according to following Table-27, although the standard of fortified turbine oil is stipulated in JIS K2213. Currently, from the small units of 100MW to latest 1000MW super-critical large units have been driving. The operation condition of turbine oil for latest steam turbine has become more severe conditions due to the hot steam with temperature about 600°C. The appropriate lubrication oil for steam turbine which is added corrosion inhibitors, antifoam to main phenol antioxidants and removed to the limit to impurity in order to improve the oxidation stability by combined with hydro-cracked based oil shall be selected.

Table- 27: Required performance of turbine oil

	Oxidation stability	Thermal stability	Anti corrosion	Off foaming	Anti sludging	Resistance for extreme pressure
Steam turbine	○	○	○	○	−	Δ
Gas turbine	○	*	○	○	−	Δ
Hydro turbine	○	−	○	○	*	Δ

(*):Particularly important *Δ:in case when speed reducer is equipped*

The recommended turbine oil for gas turbine is organized in Table-28, 29, 30 and 31. The reference web site of turbo oil manufacture is as follows.

(1) Idemitsu: http://www.idemitsu.co.jp/lube/select/industrial/turbine.html
(2) Showa Shell: http://www.showa-shell.co.jp/products/lub/product/tap1-0001.html
(3) Nikko-Nisseki: http://www.noe.jx-group.co.jp/business/lubricants_e/pdf/guidesheet/ind-3503-0812.pdf
(4) Mobil: http://www.matuyasv.com/katarogu/Mobil%20DTE%20800%20Series.pdf

Table- 28: Recommended gas turbine oil grade for gas turbine

Grade	ISO Viscosity Grade	JIS Standard
32	ISO VG 32	JIS K2213 Turbine Oil Type-2
46	ISO VG 46	JIS K2213 Turbine Oil Type-2
56	ISO VG (56)	—
68	ISO VG 68	JIS K2213 Turbine Oil Type-2
100	ISO VG 100	JIS K2239 Bearing Oil

Table- 29: Turbine oil for gas turbine

Items		Daphne Turbine Oil				
		32	46	56	68	100
Density	(15 ^{o}C)g/cm^3	0.8652	0.8660	0.8672	0.867	0.872
Hue	ASTM	L0.5	L0.5	L0.5	L0.5	L1.0
Flash Point	^{o}C	218	234	242	246	276
Kinetic viscosity (mm^2/s)	@40^{o}C	31.27	45.47	56.09	68.00	98.56
	@100^{o}C	5.365	6.927	7.950	9.260	11.67
Viscosity index		105	108	109	112	107
Pour point	^{o}C	-20	-27.5	-27.5	-25.0	-12.5
Acid value	mgKOH/g	0.10	0.09	0.10	0.09	0.09
Copper corrosion	100^{o}Cx3h	1(1A)	1(1A)	1(1A)	1(1A)	1(1A)

Table- 30: Recommended turbo oil of Idemitsu Kosan Co. Ltd.

(1)	(GEK 32568F) Daphne super turbine oil FX	ISO-VG-32	This is applicable to the gas turbine GE 7000 series, 9000 series which bearing temperature rise up to 500^{o}F (260^{o}C).
(2)	Daphne super turbine oil ME	ISO-VG-32	This is designed to clear the standard MS-MA-CL003 as gas turbine lubrication oil of MHI.
(3)	Daphne super turbine oil MG	ISO-VG-32	This is designated to clear the standard MS04-MA-CL005 as gas turbine lubrication oil. A highly innovated long-life turbine oil blended hydrogenation paraffinic base oil with various additives such as antioxidant, rust inhibitor, antifoam agents.
(4)	α Turbine oil HF	ISO-VG-32, ISO-VG-46	This is high-temperature long-life turbine oil which can be used to bearing of steam turbine and gas turbine. In addition, it is classified flammable liquids which have flash point more than 250 ^{o}C.
(5)	Daphne super turbine oil HT	ISO-VG-46, ISO-VG-68	This turbine oil can be used to bearing of high heat load for gas turbine and compressor which bearing temperature rise up to 500^{o}F (260^{o}C).

Table- 31: Recommended application of BP turbo oil for GT system

Gas Turbine Manufacturer Model	Application				BP Turbo Oil				System Package Manufacturers
	Mecha. Drive	Elec. Gen.	Comb. Cycle	Marine	2380	2197	274	2389	
General Electric Co. -USA									AEG Kanis-West Germany
LM100	●	●		●	●	●		●	ASEA Stal Laval-Sweden
LM350	●				●	●		●	Curtiss Wright-USA
LM500	●		●	●	●	●		●	Dresser Rand-USA
LM1500	●	●		●	●	●		●	European Gas Turbines
LM1600	●	●	●	●	●	●		●	Flat Avio-Italy
LM2500	●	●	●	●	●	●		●	GE Gas Turbine Ltd.-UK
LM4000	●	●	●		●	●		●	Hitachi-Japan
LM5000	●	●	●	●	●	●		●	Ingersoll Rand-USA
LM6000	●	●	●		●	●		●	IHI-Japan
									Johon Brown Engg. Ltd.-UK
									Kverner Energy-Norway
									MTU Moteren und Turbine-Union
									Norwalk Turbo. Inc.-USA
									Nuovo Pignone Turbotecnica-Italy
									Penske-USA
									Stewert & Stevenson Service Inc.-USA
									Sulzer Brothers
									Thomassen Int. IBV-The Netherlands
									Tomassen Steward & Stevenson Int.
									Toshiba-Japan
									Western Engine Co.-USA
Honeywell									Comercio e Industrial Induco-Brazil
(Garrett) -USA									Hibiya Engineering-Japan
831-500	●	●			●				Kongsberg-Norway
IE831-800	●	●			●				ONAN-USA
IM831-800	●	●		●	●				Shinko Engineering-Japan
IME831-800		●		●	●				Stewert & Stevenson Service Inc.-USA
ME831-800		●		●	●				
IM831-1600	●	●			●			●	

Gas Turbine Manufacturer Model	Application: Mecha. Drive	Application: Elec. Gen.	Application: Comb. Cycle	Application: Marine	BP Turbo Oil: 2380	BP Turbo Oil: 2197	BP Turbo Oil: 274	BP Turbo Oil: 2389	System Package Manufacturers
Kawasaki Heavy Ind. -Japan									DMT Corp.-USA
Gas Turbine									Engine Power Co.-USA
S1A, B, T		●			●				Kawasaki Heavy Ind.-Japan
S2A		●			●				Morrison Knudsen-USA
A3A		●			●				Detroit Engine & Turbine-Australia
S5A, B		●			●				Gas Turbine SA-S Africa
M1A, T		●			●				
Generator Set									
LGP 200 (S1B-02)		●			●				
GP 200 (S1A-02)		●			●				
GP 250 (S1A-02)		●			●				
GP 500 (S1T-02)		●			●				
GP 750 (S2A-01)		●			●				
GP 1000		●			●				
GP 1250 (M1A-01)		●			●				
GP 1250S (M1A-01S)		●			●				
GP 1500 (M1A-03)		●			●				
GP 1750 (M1A-06)		●			●				
GP 3500 (M1T-06)		●			●				
GP 4000 (M1T-23)		●			●				
GPC 15 (M1A-13)		●			●				
GPCC 15 (M1A-13CC)		●					●		
GPC 30 (M1T-13)		●					●		
KTF 25		●			●				
KTF 35		●			●				
GP 2000 (M1T-01)		●			●				
GP 2500 (M1T-01S)		●			●				
GP 3000 (M1T-03)		●			●				
GP 60 (S3A-01)		●			●				
GP 20 (S5A-01)		●			●				
GPC 20 (M1A-23)		●					●		
SK30 (RROlympus)		●			●	(1)			
SK60 (2-RR Olympus)		●			●	(1)			
Olympus, TM3B (RR Olympus)					●	(1)			
Spey SM1A (RR Spey)		●			●	(1)			
Tyne RM1C (RR Tyne)		●			●	(1)			
Super KTF25 (LYC TF25)	●	●			●	(1)			
Super KTF35 (LYC TF35)	●	●			●	(1)			

Note: MGP Series (Mobile version) and TGP Series (Trailer version) are also available incorporating the above GP models.
(1) Approval pending.

Gas Turbine Manufacturer Model	Application				BP Turbo Oil				System Package Manufacturers
	Mecha. Drive	Elec. Gen.	Comb. Cycle	Marine	2380	2197	274	2389	
Orenda Division									None known other than Orenda Division
Hawker Siddeley - Canada									
OT 270	●	●						(2)	
OT 270R		●						(2)	
OT 2100	●	●						(2)	
OT 370	●	●						(2)	
OT 390	●	●						(2)	
(2) Lubricant type changed from mineral oil (MIL-L-60681) to 3cSt synthetic turbo oil. Changeover from mineral oil to synthetic oil requires drain/flush procedures and may require replacement of elastomers and/or oil scavenge hoses. Procedure are tailored to engine serial n8umbers and will require coodination with the manufacturer.									
Platt & Whitney -Canada									Ebara
ST6A & B	●	●		●	●		●		
ST6J	●	●		●	●		●		
ST6K & L	●			●	●		●		
ST6L	●	●		●	●			●	
ST6T									
CFT4C-3F	●	●	●	●	(3)				
SPW 901A	●			●	●				
SPW 124	●			●	●				
SPW 127					●				
(3) Consult engine manual for oil recommended for each engine model.									
Rolls Royce Ltd. -UK									ASEA Stal Lavel-Sweden
Avon 1533, 1534, 1535	●	●			●	(1)			Cooper Rolles, Inc-USA
SPEY	●	●	●		●	(1)			Creusot Loire-France
SPEY SM 1A				●	●	(1)			Curtiss Wright-USA
SPEY SM 1C				●	●	(1)			Dresser Inc.-USA
SPEY SM 2C				●	●	(1)			GEC Gas Turbine-UK
Tyne RM1A, 1C				●	●	(1)			Ingersoll rand-USA
RB 211	●	●	●	●	●	(1)			Kawasaki heavy Inc.-Japan
Olympus	●				●	(1)			Pratt &Whitney Canada
Olympus TM3A, B, C				●	●	(1)			R12-UK
SK15 (Avon 1535)		●	●		●	(1)			Stewart & Steavenson Services, Inc-USA
SK15 HE (SPEY)		●	●		●	(1)			Sulzer Escher Wyss Ltd.-Swizzerland
SK25 (RB 211)		●	●		●	(1)			Westinghouse Electric-USA
SK30 (Olympus)	●	●	●		●	(1)			
SK40 (2 Olympus)		●			●	(1)			
SK50 (2 RB 211)		●	●		●	(1)			
SK55 (Olympus 593)		●			●	(1)			
SK60 (2 Olympus)		●	●		●	(1)			
SK110 (2 Olympus 593)	●			●	●	(1)			
TRENT EconoPac	●	●	●		(4)	(1)			
TRENT WR-21				●	(4)	(1)			
(1) Approval pending.									
(4) BPTO 2380 and/or BPTO 2197 approval pending.									

Gas Turbine Manufacturer Model	Application				BP Turbo Oil				System Package Manufacturers
	Mecha. Drive	Elec. Gen.	Comb. Cycle	Marine	2380	2197	274	2389	
Rolles Roys									Centrax Ltd-UK
(Allison) -USA									Creusot Loire-France
250-K	●				●				Cullen DDA-Canada
501-D, F, KB	●	●	●	●	●	●			Dresser Rand
570K	●	●	●	●	●				Enerson GM-USA
571-K	●	●	●	●	●				Hitachi Zosen-Japan
									IHI-Japan
									Ingersoll Rand-USA
									Lawless DDA-USA
									Mitsubishi Heavy Industries
									NATCO-USA
									Penske-USA
									Pratt & Whitney Canada
									Stewart & Steavenson Srevices Inc.-USA
									Turbo Systems Int.-USA
									Western Engine Co.-USA
									Westinghouse Electric-USA
									William and Lane-USA
Solar Turbine Inc. -USA									Solar Turbine Inc.-USA
									ABB Power Generation
Saturn	●	●			●	●			
GSE-1000		●			●	●			
GSC-1200		●			●	●			
MD-1200	●				●	●			
CS-1200	●				●	●			
Centaur	●	●	●		●	●			
GSE-4000		●			●	●			
GSC-4000		●			●	●			
MD-4000	●	●			●	●			
CS-4000	●				●	●			
11, 21 & 31C			●		●	●			
Taurus	●	●	●	●	●	●			
Mars	●	●	●		●	●			
GSP-10000		●			●	●			
GSE-10000, 12000		●			●	●			
GSC-10000, 12000		●			●	●			
MD-10000, 12000	●				●	●			
CS-10000	●				●	●			
T12000	●	●			●	●			
T14000	●	●			●	●			
!!, 21 & 31M			●		●	●			

Caution: Check operations manual for each model to insure it is compatible for use with MIL-PRF-23699 lubricants.

Gas Turbine Manufacturer Model	Application				BP Turbo Oil				System Package Manufacturers
	Mecha. Drive	Elec. Gen.	Comb. Cycle	Marine	2380	2197	274	2389	
Textron, Lycoming Div.-USA									Kawasaki Heavy Ind. -Japan
TF 09	●	●		●	●			●	Lycoming-USA
TF 12	●	●		●	●			●	Norwalk Turbo Inc.-USA
TF 14	●	●		●	●			●	Turbo Systems Int.-USA
TF 15	●	●		●	●			●	
TF 25 (Super KTF 25)	●	●		●	●			●	
TF 35 (Super KTF 35)	●	●		●	●			●	
TC 35	●	●		●	●			●	
TF 40	●	●		●	●			●	
TC 40	●	●		●	●			●	
Turbomeca-France									Turbomeca-France
Alize	●				(3)				IHI-Japan
Artouste	●			●	●			●	
Astagaz		●			●		●	●	
Astazoj	●	●		●	●		●	●	
Bastan VI, VII		●			●		●	●	
Bastangaz	●	●			●		●	●	
Makila T1	●	●		●	●		●	●	
Oredon	●	●			(3)				
Palouste	●				(3)				
Turmo III CA, IV A-B-C	●				●		●	●	
(3) Consult engine manual for oil recommended for each engine model.									
United Technologies Corp.									ASEA Stal Lavel-Sweden
Pratt & Whittney-USA									Ebara
FT3C/GG3C	●	●		●	●				Man GHH
FT4A/GG4A	●	●		●	●				Pratt & Whitney Canada
FT4C/GG4C	●	●		●	●				Prvni Brnenska Strojima
FT12A/GG12A	●	●		●	●				Turbo Power
TP4--2	●	●			●				
TP2-2	●	●			●				
TSP-2, -4, -8 (FT4C)			●		●				
FT8/GG8	●	●	●	●		(1)			
(1) Approval pending.									

【Reference Standard】			
1.	JIS K2213	1983	Turbine oils
2.	ISO 6743-Part5		Turbine oils
3.	ISO/CD 8068	2006	Petroleum products and lubricants -- Petroleum lubricating oils for turbines (categories ISO-L-TSA and ISO-L-TGA) -- Specifications
4.	DIN51515 Part-1	2001	Lubricants and governor fluids for turbines - Specifications - Part 1: L-TD for normal service; Specifications
5.	DIN51515 Part-2	2004	Lubricants and governor fluids for turbines - Part 2: L-TG for higher temperature service, Specifications
6.	HTGD 90117	2009	ABB/Alstom: Lubricating and control oil for turbines
7.	GEK 28143A		GE: Hydrocarbon Base Lubricating Oil Recommendations For Gas Turbines
8.	GEK 32568f		GE: Lubricating Oil Recommendation for Gas Turbines with Bearing Ambients Above 500^{o}F(260^{o}C)
9.	GEK 46506D		GE: Turbine Lube Oil (Recommended Properties & Maintenance Practices)
10.	GEK 101941A		GE: Lubrication oil recommendations with antiwear additives for gas turbines with bearing ambient above 500^{o}F(260^{o}C)
11.	GEK 107395A		GE: Lubricating oil recommendations single shaft STAG units with bearing ambient above 500^{o}F(260^{o}C)
12.	NS04-MA-CL001		MHI: Lubricating Oil Recommendations for Steam and Low-Temperature Gas Turbine Applications
13.	TLV 9013-04		Siemens: List of approved turbine oils
14.	TLV 9013-05	2010	Siemens: Turbine oil specification (turbine oils with higher thermal stability)

2-7. Lubrication Oil Purifier

In general, the journal bearing is applied to large scale steam turbine. It is essential to provide lubrication oil purifier to maintain oil purity and oil cooler to prevent abnormal wear and over-heat of bearing. In general, it is recommended to provide oil purifier equipment to maintain **oil purity below NAS-7grade** as shown in Table-31, 32, 33 and 34.

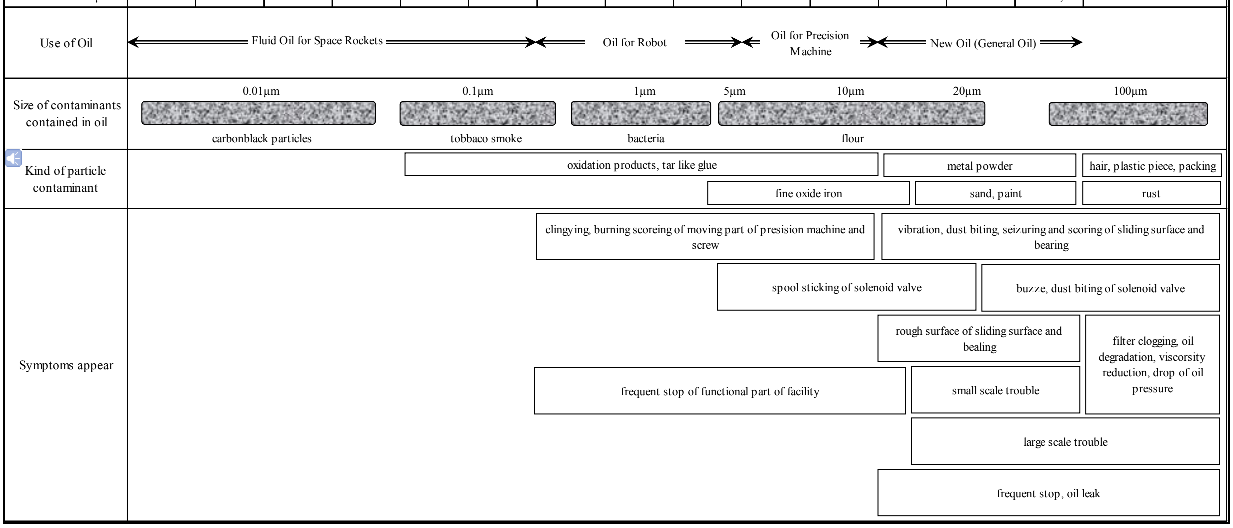
Table- 32: NAS 1638 Contamination classification system

Class	Maximum Particles/100ml in Specified Size Range (µm)				
	5~15	15~25	25~50	50~100	≥100
00	125	22	4	1	0
0	250	44	8	2	0
1	500	89	16	3	1
2	1,000	178	32	6	1
3	2,000	356	63	11	2
4	4,000	712	126	22	4
5	8,000	1,425	253	45	8
6	16,000	2,850	506	90	16
7	32,000	5,700	1,012	180	32
8	64,000	11,400	2,025	360	64
9	128,000	22,800	4,050	720	128
10	256,000	45,600	8,100	1,440	256
11	512,000	91,200	16,200	2,880	512
12	1,024,000	182,400	32,400	5,760	1,024

The broad concept of oil purity of lubrication oil or fluid oil for hydraulic equipment, relation with trouble to appear and general scope of application is shown as below in order to recognize grade7 of NAS grade.

Table- 33: NAS Grade and symptoms appearing in oil administration

	NAS Grade														
	00	0	1	2	3	4	5	6	7	8	9	10	11	12	Irregular Class
5~15µm	125	250	500	1,000	2,000	4,000	8,000	16,000	32,000	64,000	128,000	256,000	512,000	1,024,000	
15~25µm	22	44	89	178	356	712	1,425	2,850	5,700	11,400	22,800	45,600	91,200	182,400	
25~50µm	4	8	16	32	63	126	253	506	1,012	2,025	4,050	8,100	16,200	32,400	
50~100µm	1	2	3	6	11	22	45	90	180	360	720	1,440	2,880	5,760	
more than 100µm	0	0	1	1	2	4	8	16	32	64	128	256	512	1,024	



The replacement table to replace with old and new oil contamination of ISO is shown as below.

Table- 34: Equivalent APC sizes relating to calibration method

Standard	Particle Sizes					
ISO 11171 Size (μm)	<4	<6	<14	<21	<38	<70
ISO 4402 Size (μm)	<1	<5	<15	<25	<50	<100

It is organized the comparison of standards regarding oil contamination in the following Table-20.

Table- 35: Comparison of standards

ISO4009 -1991	No. of particle over 10μ	ACFTD (mg/l)	MIL Standard	NAS Grade	SAE-T490
26/23	140,000	1,000			
25/23	85,000		1000		
23/20	14,000	100	700		
21/18	4,500			12	
20/18	2,400		500		
20/17	2,300			11	
20/16	1,400	10			
19/16	1,200			10	
18/15	580			9	6
17/14	280		300	8	5
16/13	140	1		7	4
15/12	70			6	3
14/12	40		200		
14/11	35			5	2
13/10	14	0.1		4	1
12/9	9			3	0
11/8	5			2	
10/8	3		100		
10/7	2.3			1	
10/6	1.4	0.01			
9/6	1.2			0	
8/5	0.6			00	
7/5	0.3		50		
6/3	0.14	0.001			
5/2	0.04		25		
2/0.8	0.01		10		

【Reference Standard】			
1.	JIS B9933	2000	Hydraulic fluid power－Fluids－Code for defining the level of contamination by solid particles
2.	NAS1638	2001	National Aerospace Standard-- Contamination Classification System
3.	ISO 4402	1991	Hydraulic fluid power -- Calibration of automatic-count instruments for particles suspended in liquids -- Method using classified AC Fine Test Dust contaminant
4.	ISO4406	1999	Hydraulic fluid power -- Fluids -- Method for coding the level of contamination by solid particles
5.	ISO 11171	1999	Hydraulic fluid power -- Calibration of automatic particle counters for liquids

2-8. Fire-fighting System

(1) Enclosure

The following enclosures must be provided in a given place.

1) Enclosure to cover gas turbine and/or driven machine;
2) Ventilation and purge equipment for enclosure;
3) Fire protection device.

The enclosure for outdoor must be so that no dust enter and weatherproof. No dust must enter from the seams of roof or walls of the enclosure. The panel must be designed so that no increase in moisture and corrosion in side the panel occur as much as possible. The material of panel must be non–hygroscopic and non-flammable, and those which insects and small animals can not invade. The enclosure must be designed so that maintenance work on site is easy to conduct.

(2) Fire Protection Extinguishing Equipment

The fire extinguishing equipment must be run on an all operating conditions which may happen in the whole enclosure. The fire extinguishing agents such as Holon which generates ozone must not be used. In order to prevent fire spread, the sop sequence must provide the stop of ventilation fans, closing of fire protection dampers and release of fire extinguishing agent. Although the release of fire extinguishing agent must be done automatically, the agent must be released after warning to warm people that situation waiting in a moment to escape to outside. The safety equipment which does not release extinguishing agents and manual device while the humans are in the enclosure must be provided. The manual control station must be placed on both sides of the enclosure. In the event of fire, appropriate concentration of extinguishing agent must be maintain until the temperature of the gas turbine is cooled down below the ignition temperature of combustible fluid may be present in the enclosure (such as lubricant, hydraulic oil and liquid fuel) .

The measures for gas turbine disaster is prepared and enhanced by the design standard of gas turbine and the associated provisions of NFPA (National Fire Protection Association) because there is no detailed provision. The features of them are as follows;

1) The gas –based fire extinguishing agent must be released “throughout (Total Flooding Systems)” inside of the enclosure. (compartment)
2) The concentration of extinguishing agent must be maintained in a certain time and the “extended release (extend discharge)” must be done in order to prevent re-ignition corresponding to the hot “deep fire”.
3) The dampers existing in the said compartment must be closed fully and the fan must be off as well as the interlock must have unit trip at fire when releasing firefighting agent. Assuming the special nature of firefighting equipment for the combined generation main equipment, the comparison of the suitability of various extinguishing agents is shown in Table-35.

Table- 36: Suitability of various extinguishing agents

Fire extinguishing agent and principle		Halon1301	CO_2	powder	foam
Fire extinguish target compartment	Release method	Negative catalytic effect by combustion reaction	By oxygen blocking and cooling effects	Negative catalytic and oxygen blocking effects	By oxygen blocking and cooling effects
Gas turbine compartment	throughout	O	O	x	x
Fuel gas compartment	throughout	O	O	x	x
Gas turbine starting equipment	throughout	O	O	O	x
#2 bearing of gas turbine	local	O	Δ	O	x
Bearing for steam turbine	local	O	Δ	O	x
Bearing for generator	local	O	Δ	O	x
Main oil tank and aux. facility	local	O	Δ	O	O
Seal oil unit	local	O	Δ	O	x
Notes		—	It must be used after checking that no one.	There is pollution of equipment after releasing agent.	Flat vertical shape object is inadequate.

Note: O: appropriate, Δ: possible, x: suspect

Reference: P-80 of Journal (No.448: Jan. /1994): TENPES

When adopting the CO^2 fire extinguishing system same gas type fire extinguishing system as the halon fire extinguishing system, it is necessary to pay attention for the secondary safety measures at releasing agent in the view point of the respect for human life. In light of this, as an alternative method instead of Halon fire extinguishing,

1) It can be ensured safety during fire fighting and accidental release.
2) It can be measured to deep fire of gas turbine.
3) It can be provided equivalent measure for disaster on multi axis.

The Co_2 fire extinguishing system is recommended to the gas turbine enclosure for entire area release and the powder fire extinguishing system is recommended to the local release such as bearing from the above reason.

Table- 37: Specification of flame detector

Type of agent	Compartment to be detected	Type	Numbers	Setting Temperature (°C)
CO_2	Gas turbine compartment	Thermocouple	3	210
	#1 bearing	Thermocouple	2	430
	Fuel gas compartment	Spot type fixed temperature detector	2	120
	Starting equipment room	Spot type fixed temperature detector	2	120
Powder	#2 bearing of gas turbine	Spot type fixed temperature detector	2	120
	Steam turbine bearing	Spot type fixed temperature detector	6	150/120
	Generator bearing	Spot type fixed temperature detector	6	120
	Main oil tank and aux. equipment	Spot type fixed temperature detector	5	80
	Seal oil unit	Spot type fixed temperature detector	2	80

Reference: P-82 of Journal (No.448: Jan. /1994): TENPES

(3) Gas Leak Detector

1) When using gas fuel for gas turbine;
2) When using flammable fluid for driven machine;
3) When operating gas turbine in hazardous locations.

The appropriate equipment to alert the invasion of leaked gas into enclosure or gas leakage in the enclosure when reaching to a given concentration respectively and to provide stop operation must be provided. The detector must be placed without loss of its performance by the large amount of air flow to remove heat. The gas detector must alert when it detects given concentrations (typically explosive limit (LEL) 5%~20%).

(4) Fire Detector

The time constant compensated heat detector must be provided as the fire detector. Moreover, it is recommended the optical (UV or FIR) type or smoke detector. The fire detector must be run on an entire range of all operation conditions which may happen within the enclosure. The actual application of flame detection is shown in Table-36.

(5) Ventilation and Purge Equipment

The forced draft ventilation (cooling) or purge equipment which keeps inside of enclosure positive or negative pressure in order to ventilate and purge 100% under the most severe weather and load conditions must be provided. The adequate ventilation must be done so that the equipments in the enclosure are not damaged by the heat. The purge air must be enough flow and be distributed around gas turbine and everywhere in the enclosure so that the gas concentrations of dead-spot is exceed explosive limit. Furthermore, the sufficient dilution ventilation and purge must be applied to lower part of the enclosure when the fuel gas is heavier than air and/or spontaneous combustion temperature of mixture is low. The ventilation equipment must be provided the air filter and muffler if necessary. The ventilation equipment must be designed so that it can be operated satisfactory over the specified entire temperature range to avoid excessive cooling at low temperatures. The exit of ventilation and purge air from enclosure must be flange. The damper to prevent leakage of fire extinguishing agents must be provided to each opening.

3-1. The "**minimum rotation speed which can be adjustable**" stipulated inArticle38-1 of design technical regulation means the minimum one of the range of rotation speed which is determined according to the speed variation in case other than the gas turbine combined with the induction generator, the minimum rotation speed which can be generated at the frequency of the induction generator is connected to the grid in case the gas turbine combined with the induction generator.

3-2. "**The case being taken sufficient measure**" stipulated in Article38-3-2 of design technical regulation means the case which has been demonstrated sufficient safety by the measure to reduce resonance factor at over second vibration mode.

3-3. Harmful Vibration during Operation

The "**harmful vibration during operation**" stipulated in Article 33-1 of design technical regulation means the case when maximum total amplitude of vibration occur on main bearing and shaft around it and when total amplitude exceeded the warning value listed as following Table-37 of steam turbine and coupled with other rotor which rated output exceed 400MW.

Table- 38: Warning value of vibration

Measuring Point	Rated Rotation Speed	Warning Value	
		Rotation Speed ＜ Rated Rotating Speed	Rated Rotating Speed ≦Rotation Speed
Bearing	3,000rpm or 3,600rpm	0.075mm	0.062mm
	1,500rpm or 1800rpm	0.105mm	0.087mm
Rotor	3,000rpm or 3,600rpm	0.15mm	0.125mm
	1,500rpm or 1800rpm	0.21mm	0.175mm

Reference: Article 24 of "Interpretation technical regulation for thermal power facility": NISA of METI Japan

(1) The evaluation standard for vibration is stipulated as the vibration velocity according to the IEC60045-1, 2, 3 and is stipulated within 2.8mm/s as good vibration at the steady state and rated speed. The shaft vibration is kept in regular expression "more than twice of the bearing vibration", and omitted from the standard of evaluation.

(2) The idea to evaluate the vibration of turbine as full amplitude of the bearing or shaft is established in Japan and the upper limit of alarm for operation is stipulated in JIS with reference to JESC T0003-2000（Rules of Steam Turbine for Power Generation：JEAC 3703）. Although there is no stipulation about the stop of turbine when the vibration increase, it is recommended to stop or automatically stop steam turbine when the total amplitude of shaft exceed the twice of alarm value according to JESC T0003-2000（Rules of Steam Turbine for Power Generation：JEAC 3703） as shown Fig-48.

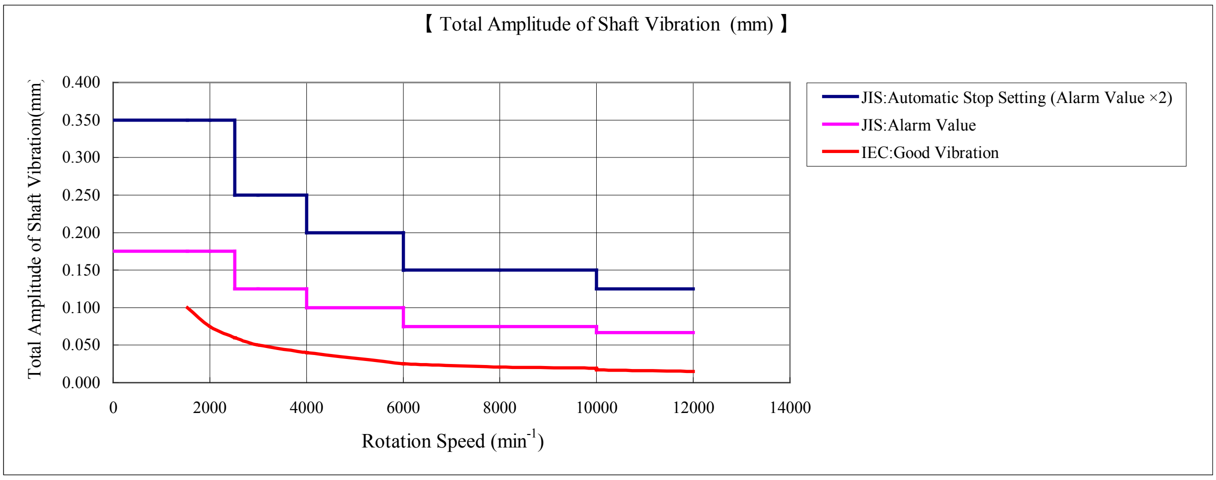


Fig- 48: Allowable value of vibration

(3) Allowable value of gas turbine vibration to be controlled

The axial vibration of a gas turbine in operation is evaluated as shown in Fig-49.

Zone A: The vibration of newly commissioned machines would normally fall within this zone.

Zone B: Machines with vibration within this zone are normally considered acceptable for unrestricted long term operation.

Zone C: Machines with vibration within this zone are normally considered unsatisfactory for ling term continuous operation. Generally, the machine may be operated for a limited period in this condition until a suitable opportunity arises for remedial action.

Zone D: Vibration values within this zone are normally considered to be of sufficient severity to cause damage to the machine.

The evaluation formulas for the border between Zones C and D are as follows;

$$ZoneB/C = S(p-q) = \frac{9000}{\sqrt{N}}$$

$$ZoneC/D = S(p-q) = \frac{13200}{\sqrt{N}}$$

ISO-7919-4: Mechanical Vibration of Nom-reciprocating Machines—
Measurements on Rotating Shafts and Evaluation Criteria—Part4: Gas Turbine Sets

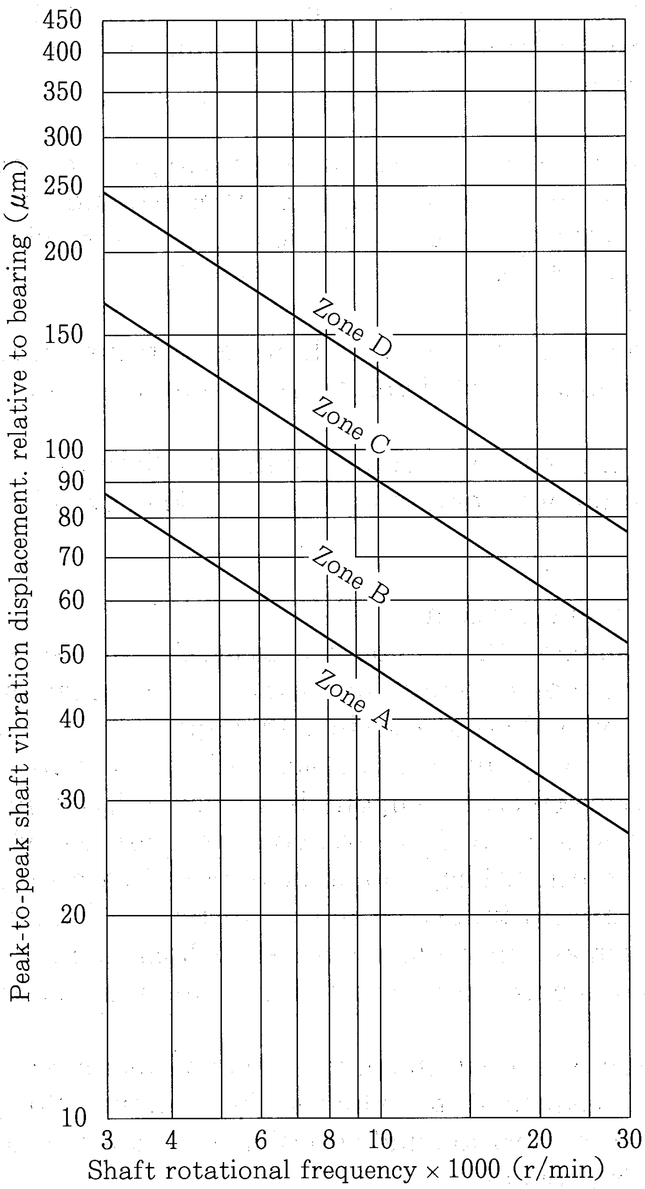


Fig- 49: Shaft vibration evaluation zones

3-4. Natural Frequency JIS B8042-3,

The vibration may affect the operational safety and may cause damage to equipment. The disproportionate is known the transverse source of excitation of rotating machinery. The rotor speed at the resonance condition is called the critical speed and must be design separated from the rated speed. The packager must confirm that it meets the requirement of the rotor dynamics according to the standards which is applied to the machine.

3-5. Rotor Coupling

The rotor coupling must have enough capacity to transmit the maximum continuous torque based on maximum output which may occur. In case for generation use, the rotor coupling for generator must have enough capacity to withstand even the worst conditions of generator failure, unless the type of coupling is the shear-pin. The rotor coupling must be taken a dynamic balance of each individual component and be taken a dynamic balance of assembly. The coupling between coupling and shaft must be designed and manufactured to be able to transmit power at least equal to the maximum continuous rated torque of coupling.

The length of the coupling space must be enough for removing the bearings and seals without removing the casing of gas turbine body. If it is not possible, it must be considered to minimize the number of parts to be removed so that not to remove the driven machines. The typical construction is shown in Photo-33, 34, 35.

Photo- 33: Coupling with splines

http://www.indiamart.com/company/715287/products.html

Photo- 34: Load Couplings with shear pin arrangement for gas turbines rated 16 MW at 1500 rpm

http://www.euroflex.co.in/wnew.html

Photo- 35: Coupling with spline for a solar gas turbine application

http://www.euroflex.co.in/wnew.html

3-6. Field Balancing

The International Standards Organization, ISO, published Standard 1940/1 “Balance Quality Requirements of Rigid Rotors”, which has been adopted by the American National Standards Institute, ANSI, as S2.19-1975, “Balance Quality Requirements of Rotating Rigid Bodies.” It has also been adopted by BRITISH Standards as BS6861: Part 1 and by GERMAN Standards as VDI2060. ISO 1940/1 requires an understanding of balancing and its terminology if the standard is to be understood and used properly. The steam turbine shall be designated to **maintain imbalance less than G2.5.** as shown Table-38, Table-39 and Fig-50, and the adjustment method is designated.

If there is imbalance on the rotor, the field balancing shall be adjusted by balancing weight depending on the modal chart.

Table- 39: Grade of good balancing

(mm/s)

Grade of good balancing	G0.4	G1	G2.5	G6.3	G16	G40	G100	G250	G630	G1600	G4000
Upper limit of good balancing	0.4	1	2.5	63	16	40	100	250	630	1600	4000

Reference: JIS B0905

Table- 40: Balance quality grades for various groups of representative rigid rotors

Balance Quality Grade	Product of the Relationship ($e_{per} \times \omega$) mm/s	Rotor Types / General Examples
G4000	4000	• Crankshaft/drivers of rigidly mounted slow machine diesel engines with uneven number of cylinders
G1600	1600	• Crankshaft/drivers of rigidly mounted large two-cycle engines
G630	630	• Crankshaft/drivers of rigidly mounted large four-cycle engines • Crankshaft/drivers of elastically mounted machine diesel engines
G250	250	• Crankshaft/drivers of rigidly mounted fast four-cylinder diesel engines
G100	100	• Crankshaft/drivers of fast diesel engines with six or more cylinders • Complete engines (gasoline or diesel) for cars, trucks and locomotives
G40	40	• Car wheels, wheel rims, wheel sets, drive shafts • Crankshaft/drivers of elastically mounted fast four-cycle engines with six or more cylinders • Crankshaft/drivers of engines of cars, trucks and locomotives
G16	16	• Drive shafts (propeller shafts, cardan shafts) with special requirements • Parts of crushing machines • Parts of agricultural machinery • Individual components of engine (gasoline or diesel) for cars, truck and locomotives • Crankshaft/drivers of engines with six or more cylinders under special requirements
G6.3	6.3	• Parts of process plant machines • Marine main turbine gears (merchant service) • Centrifuge drums • Paper machinery rolls, print rolls • Fans • Assembled aircraft gas turbine rotors • Flywheels • Pump impellers

Balance Quality Grade	Product of the Relationship ($e_{per} \times \omega$) mm/s	Rotor Types / General Examples
		• Machine-tool and general machinery parts • Medium and large electric armatures (of electric motors having at least 80mm shaft • height) without special requirements • Small electric armatures, often mass produced, in vibration insensitive applications and/or with vibration-isolating mountings • Individual components of engines under special requirements
G2.5	2.5	• Gas and steam turbines, including marine main turbines (merchant service) • Rigid turbo-generator rotors • Computer memory drums and discs • Turbo-compressors • Machine-tool drives • Medium and large electric armatures with special requirements • Small electric armatures not qualifying for one or both of the conditions specified for small electric armatures of balance quality grade G6.3 • Turbine-driven pumps
G1	1	• Tape recorder and phonograph (gramophone) drives • Grinding-machine drives • Small electric armatures with special requirements
G0.4	0.4	• Spindles, discs and armatures of precision grinders • Gyroscopes

Note:

1) *$\omega = 2\pi n/60 \approx n/10$, if n is measured in revolutions per minute and ω in radians per second.*
2) *For allocating the permissible residual unbalance to correction planes, refer to "Allocation of U_{per} to correction planes."*
3) *A crankshaft/drive is an assembly which includes a crankshaft, wheel, clutch, pulley, vibration clamper, rotating portion of connecting rod, etc.*
4) *For the purposes of this part of ISO1940-1, slow diesel engines are those with a piston velocity of less than 9m/s; fast engines are those with a piston velocity of greater than 9m/s.*
5) *In complete engines, the rotor mass comprises the sum of all masses belonging to the crankshaft/drive descried in note 3 above.*

Reference: JIS B0905-1992 "Rotating machines-Balance quality requirements of rigid rotors"

ISO 1940-1-2003 "Mechanical vibration – Balance quality requirements of rigid rotors"

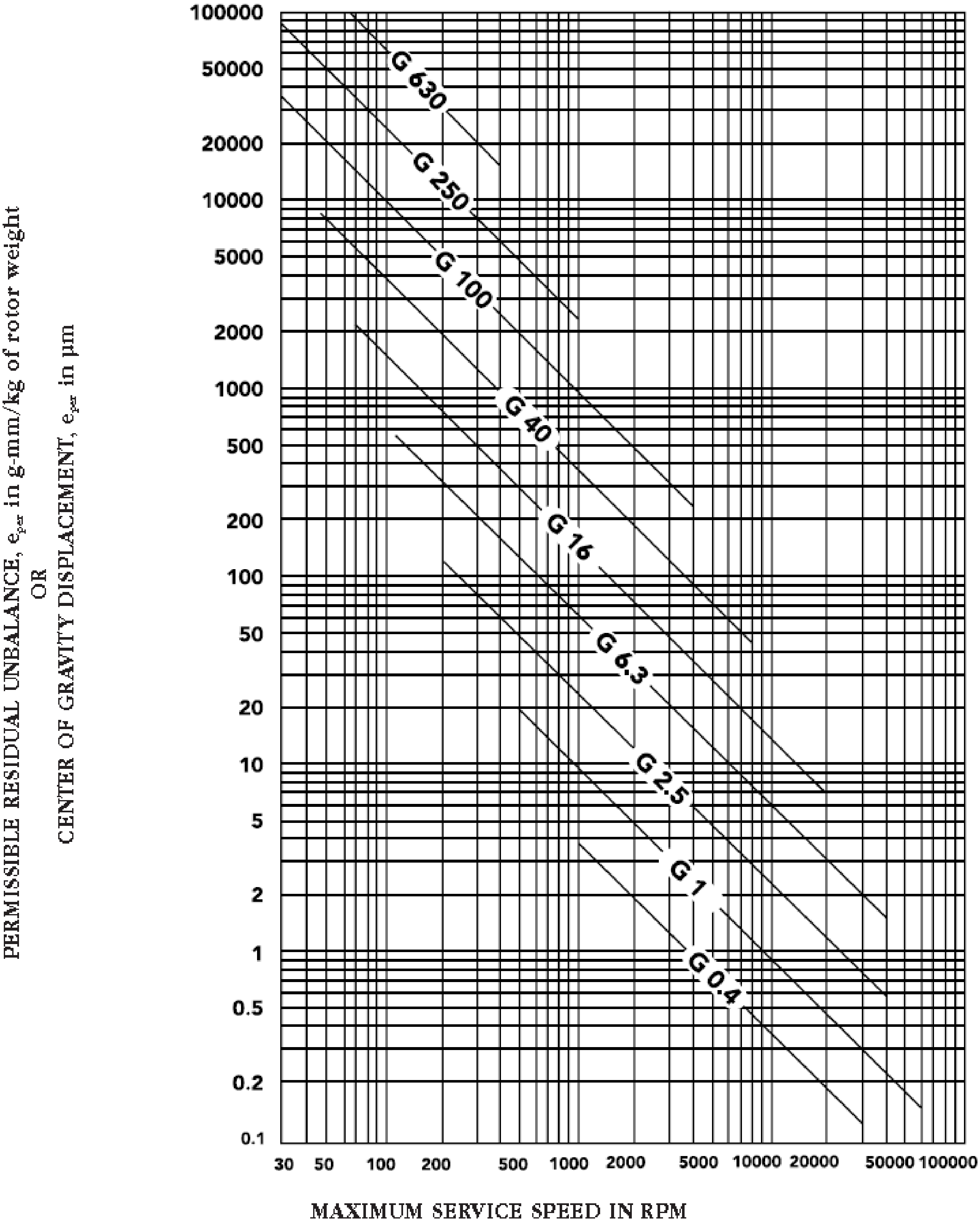


Fig- 50: Maximum permissible residual imbalance

4-1. The **"safety structure"** stipulated in Article 38-4 of design technical regulation must be conformed to the following article of this guideline mutates mutandis.

(1) The vessel and piping which belong to gas turbine auxiliary facility (except for working air heater) must be pursuant to Article 23-1 "Structure for boiler, etc." , Article23-2 "Allowable stress of material",

Article-23-4 “Body of vessel”, Article 23-5 “Rectangle header”, Article 23-6 “Head for vessel”, Article 23-7 “Flat head plate of vessel”, Article23-8 “Dished cover plate with flange for vessel”, Article 23-9 “Tube sheet for vessel”, Article 23-10 “Pipe and stub”, Article 23-11 “Flange” of this technical guideline except the specific for boiler.

(2) The vessel and piping which belong to working air heater must be pursuant to Article 23-1 “Structure for boiler, etc.” , Article23-2 “Allowable stress of material”, Article-23-4 “Body of vessel”, Article 23-5 “Rectangle header”, Article 23-6 “Head for vessel”, Article 23-7 “Flat head plate of vessel” of this technical guideline except the specific for boiler. The air heater (except which is applied casting pipe) must be pursuant to Article 23-10 “Pipe and stub” except for casting pipe, item-5 in case of casting pipe, item-7 incase of other pipe.

(3) The gas turbine and its auxiliary facility must be withstood hydrostatic testing according to the provision Article 23-3 “Hydrostatic test” of the technical guideline for boiler. However, it is not necessary to conduct hydraulic test for the gas turbine casing in case of its one or both end is open, if it is conforming to any of following provisions.

1) Those which have experience of the hydrostatic testing in case of the gas turbine casing which has same material and structure of such models.
2) Those which were confirmed by such as the strength calculation that withstood 1.5 times of maximum operation pressure by hydraulic pressure testing.

4-2. Casing

(1) Barrel Type

Generally, the casing for heavy duty gas turbine can be split in upper and lower vertically and be divided into parts as shown in Photo-36, 37, 38, 39. The bearings supporting the rotor is supported by the radial strut type support at compressor side (cold side) and the tangential strut type at turbine side (hot side) and especially the structure to avoid misalignment due to heat expansion is considered by means of absorbing heat expansion at exhaust side.

Turbine exhaust gases is discharged backward circularly at high speed. The diffuser to expand and slow-down the annular flow of the exhaust gas gradually is provided usually in the wake part as shown in Fig-51 and Photo-40.

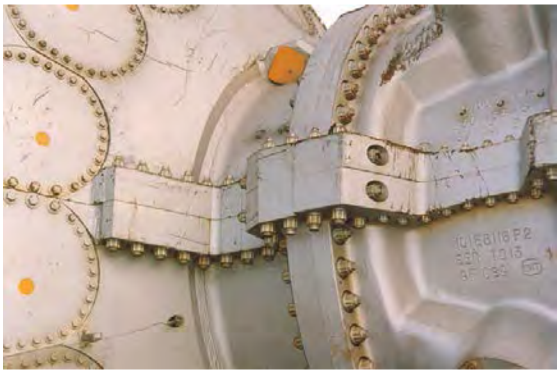


Photo- 36: GT barrel type casing

http://www.cividalespa.com/img/lav5_z.jpg

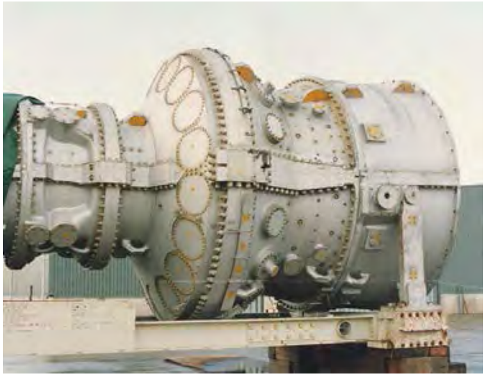


Photo- 37: GT barrel type casing

http://www.cividalespa.com/img/lav5_z.jpg

Photo- 38: GT barrel type casing

http://it.geenergyeurope-pressroom.com/files/pictures/9FB_Belfort.JPG

Photo- 39: GT barrel type casing

http://www.cividalespa.com/img/lav5_z.jpg

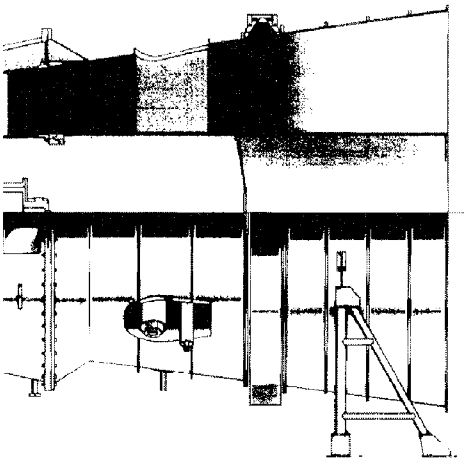


Fig- 51: Exhaust diffuser

Reference: P-77 of Journal (No.578: Nov. /2004): TENPES

Photo- 40: Exhaust diffuser

http://www.atcoem.com/Products/Gas-Turbine-Applications/Diffusers

(2) Ring Type

The aero-space jet engine or aero-diverted type gas turbine has a construction to avoid horizontal joints in order to reduce weight of casing mainly by the ring-shaped casing as shown in Fig-52 and Photo-41.

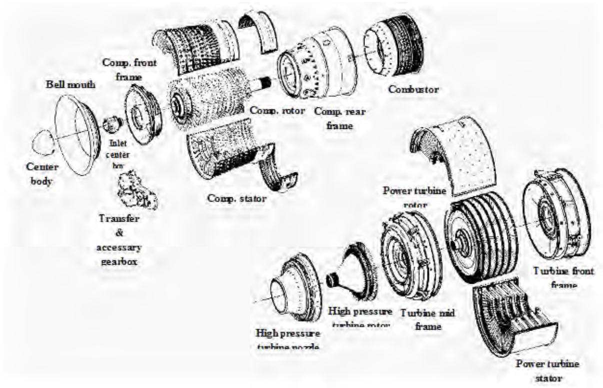


Fig- 52: Ring type casing

http://www.fas.org/man/dod-101/navy/docs/swos/eng/dd234ag.gif

Photo- 41: Ring type casing

http://www.businessfacilities.com/blog/uploaded_images/GEengine-763893.jpg

4-3. Combustor

The fuel is injected into the compressed air and combustion is carried out. Typically the combustion chamber is called "combustor". There are several types such as the donut -shaped "annular type as shown in Fig-53(a)" combustor is used mainly in aircraft engine, the "cannular type as shown in Fig-53(b), Fig-55 and Photo-42" combustor which placed on circumference of the cylindrical combustor, in addition, "silo type as shown in Fig-59 and Photo-46" combustor which is used for large power generation. Annular type is suitable for aircraft engine which is capable to overhaul the ring type components on a regular basis while reducing weight, because it cannot overhaul for intact. On the other hand, the cannular type is suitable for power generation which would like to shorten a little down time, because the decomposition combustor can be replaced separately as shown in Photo-42, 43, 44, although the distribution of temperature tends to occur and to increase the weight of the introduction to the turbine portion of the combustor. The silo type of construction which has the large silo outside of the turbine is suitable for the combustion of low BTU gas because it is capable to take relatively long time for combustion. On the other hand, it is hard to adopt latest gas turbine which has high gas temperature because there is prone to the introduction of the temperature distribution of combustion gas.

The structure of the cannular type combustor is mainly that is made of super alloy thin sheet metal. As the combustion gas temperature rise, the cooling air vents to make a cooling air film and cooling air passages inside the double structure of thin sheet metal as shown in Fig-56 and Fig-57 is provided. Moreover, in recent years, while cooling by the steam inside the burner through a double sheet metal structure, the recovered heat is introduced into the bottoming cycle in combined cycle and recovered as electrical output by steam turbine as shown in Fig-54. In case of some of the large silo type or annular type, the heat resistant tile such as ceramics is pasted or the cooling air is abolished or reduced.

The small gas turbines may be employed for different forms of structure at all combustor. The heat exchanger to heat exchange with the discharge air from compressor and turbine exhaust gas (regeneration heat exchanger) may be employed.

About combustion, the response to the recent trend toward low emission by burning while keeping the flame temperature will be pre-mixed air and fuel, “premixed combustion” is becoming the main stream the method to suppress the generation of NOx. For gas turbine, it is important to suppress the NOx particularly because of the high excess air ratio; combustion temperature is high and has a large amount compared to other internal combustion. It is the technological issue how to control the instable combustion because of the limited combustible air-fuel mixture ratio when reducing the peak of flame temperature and to average the combustor exit temperature distribution as shown in Fig-58.

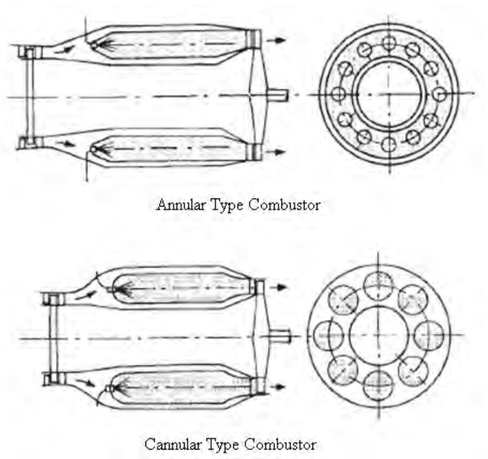


Fig- 53: Annular and cannularr combustor

Reference: P-74 of Journal (No.578: Nov. /2004): TENPES

Photo- 42: Annular type combustor

http://www.pondlucier.com/peakpower/2011/01/11/blackstart/chapter-4-sir-frank-whittle-father-of-the-gas-turbine/

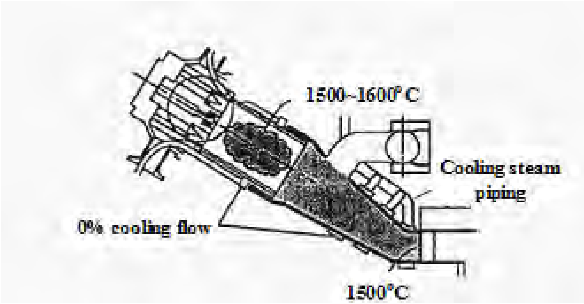


Fig- 54: Steam cooling combustor

Reference: P-74 of Journal (No.578: Nov. /2004): TENPES

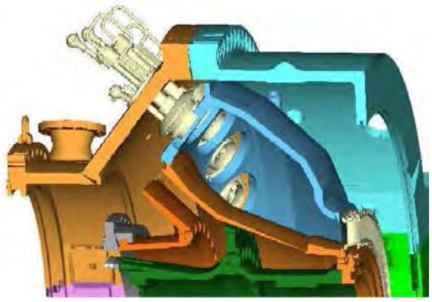


Fig- 55: Typical cross section around combustor

http://www.td.mw.tum.de/tum-td/de/forschung/themen/thermo_osci_annular

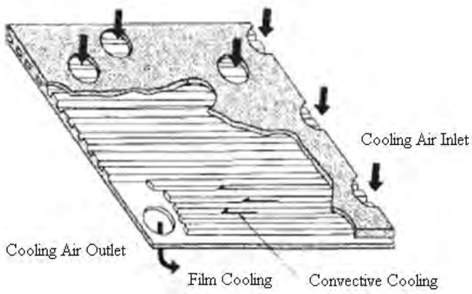


Fig- 56: Cooling construction of laminated wall of combustor (MHI)

Reference: P-74 of Journal (No.578: Nov. /2004): TENPES

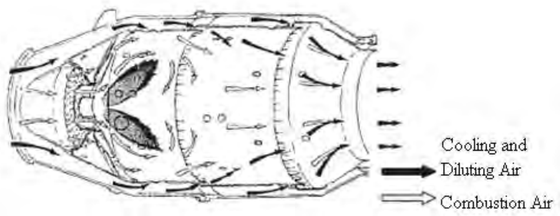


Fig- 57: Air-flow in the combustor

Reference: P-74 of Journal (No.578: Nov. /2004): TENPES

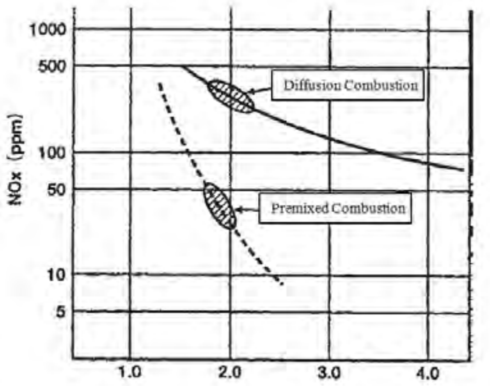


Fig- 58: NOx vs air ratio, stable combustion range

Reference: P-75 of Journal (No.578: Nov. /2004): TENPES

Photo- 43: Combustor and transition piece

http://www.manufacturer.com/cimages/product/www.alibaba.com/0404/e/10920857_Gas_Steam_Turbine_Compressor_Replacement_Parts.jpg

Photo- 44: Transition piece

http://www.powert6herm.in/products2.html

Photo- 45: Laser drilling of combustor

http://www.laico.com/co6mpany-laser-five-axis-machining.html

Photo- 46: Silo type combustor

http://i01.i.aliimg.com/photo/v0/107017675/Gas_Turbine_Combustion_Chamber_Parts.jpg

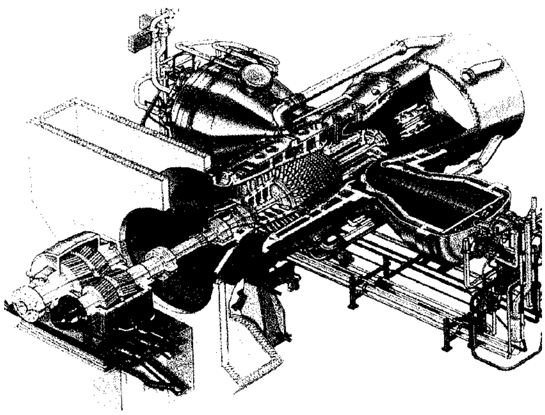


Fig- 59: Silo type combustor (Siemens-V64.3)

Reference: P-74 of Journal (No.578: Nov. /2004): TENPES

4-4. Rotor

It is usual construction to overlap discs and fix them by one or more bolts through them repeatedly for the rotor of axial turbine as shown in Photo-48, 50 and Fig-61. The consolidation by bolting and integration by welding is performed as shown in Photo-47, 49, 51, 52. The Christmas-tree type groove is applied to receive and distribute the centrifugal force in order to fix robust and heavy blades compared with the compressor, although the outer periphery of the disc is engraved with grooves to put in blades like the compressor as shown in Photo-53 and Fig-60.

Photo- 47: Gas turbine rotor assembly

http://www.siemens.com/press/pool/de/pressebilder/2009/photonews/300dpi/PN200909/PN200909-01_300dpi.jpg

Photo- 48: Assembling of gas turbine disc

http://www.siemens.com/press/pool/de/pressebilder/2009/photonews/300dpi/PN200909/PN200909-10_300dpi.jpg

Photo- 49: GT rotor before assembling

http://www.energy.siemens.com/us/en/power-generation/gas-turbines/sgt6-8000h.htm

Photo- 50: Siemens SGT6-4000F

Reference: P-43 of Journal (No.645: Jun./2010): TENPES

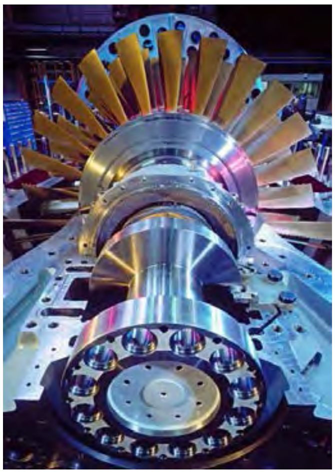


Photo- 51: Compressor rotor head

http://www.hegerguss.de/eisengiesserei/eisengiesserei-produkte-img/turbinen-rotor.jpg?PHPSESSID=793dbdf929f051b8738a736ff9d59b72

Photo- 52: Compressor rotor head

http://it.geenergyeurope-pressroom.com/files/pictures/_CPV0080.jpg

Photo- 53: Curvic disc for turbine

http://www.amcprecision.com/images/GasTurbine.jpg

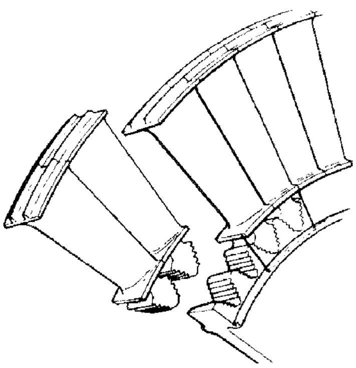


Fig- 60: Christmas-shaped root of turbine blade

Reference: P-77 of Journal (No.578: Nov. /2004): TENPES

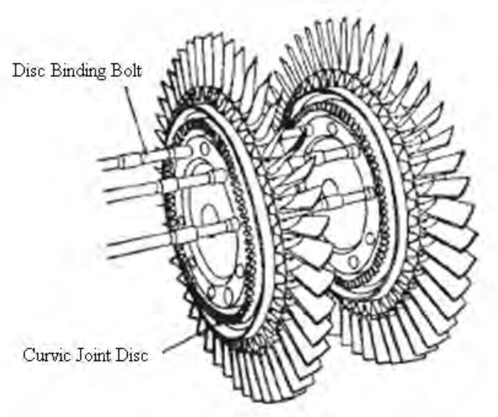


Fig- 61: Curvic disc for turbine

Reference: P-76 of Journal (No.578: Nov. /2004): TENPES

4-5. Disc

The structure of the multi-stage axial compressor is overlapped discs by bolting or welding and formed to rotor as shown in Photo-54, 55, 56, and is generally put blades in the outer periphery of the disc as shown in Fig-62 and 63. Therefore, the carved grooves to insert blades are cut on the disc in advance as shown Fig-64..

Photo- 54: Disc and blade for compressor

http://www.zimbio.com/pictures/-xliux-ZTHC/German+Economy+Showing+Signs+Recovery/dsE8V9DTQz0

Photo- 55: Disc and blade for gas turbine

http://www.siemens.com/press/pool/de/pressebilder/2009/photonews/300dpi/PN200909/PN200909-02_300dpi.jpg

Photo- 56: Disc and blade for compressor

http://www.utilities-me.com/pictures/gallery/WEB_95643757_GAS_TURBINE_2.jpg

Photo- 57: Curvic disc for compressor

http://www.j-airtec.co.jp/img/disc_sum.jpg

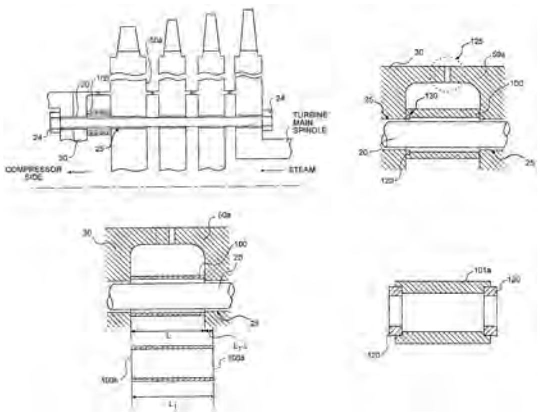


Fig- 62: Binding bolts for compressor

http://www.freepatentsonline.com/6991429-0-large.jpg

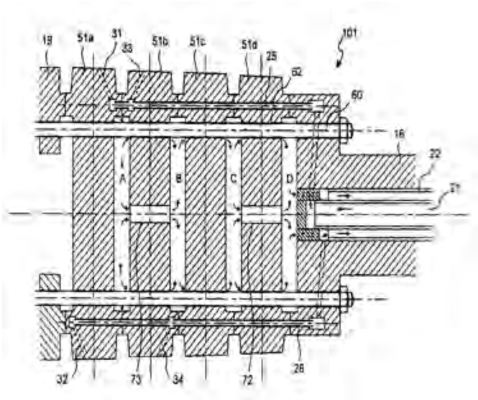


Fig- 63: Binding bolts for compressor

http://www.freepatentsonline.com/7114915-0-large.jpg

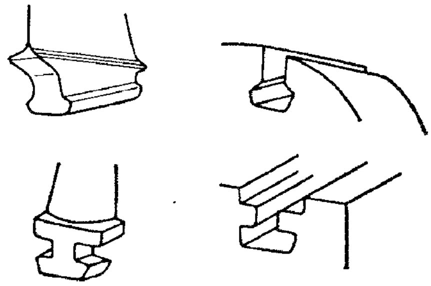


Fig- 64: Root of compressor blade

Reference: P-73 of Journal (No.578: Nov. /2004): TENPES

4-6. Turbine Blade

There are two types for gas turbine, one is axial flow type and centrifugal type same as the compressor, and is applied depending on the capacity. The multistage axial flow type is usually employed for large capacity machines. The basic structure of axial multi-stage consist of a pair of vanes to produce a speed-up flow and blades to convert it into rotational energy, the energy of the high temperature and high pressure combustion gas will be gradually expanded, accelerated and removed as rotation energy. Sometimes the vane located at the entrance of the first stage of the turbine is called "nozzle" from the purpose to create such an accelerated flow as shown in Fig-65. The gas turbine are exposed to high pressure hot gas leaving the combustor, or convert the direction of gas effusion, or receiving on the blades because the kinetic energy in the rotating blades under the very harsh thermal and mechanical conditions. Thus, its structure may be to say that a complicated structure which combines the following three at the same time.

1) The cooling structure for reducing the temperature of ht part below the allowable value.
2) The structure and strength to withstand the centrifugal force or force receiving from gas.
3) The flexible structure which can be tolerated large thermal changes associated with start-stop.

In particular, the measure is taken by avoiding a direct hit of hot gas by means of forming a layer of air on the surface of the blade as shown in Fig-66, lowering the temperature of the material by means of suppressing thermal conductivity by coating with low thermal conductivity material such as ceramic as shown in Fig-67. On the other hand, the measure is taken by lowering the temperature of the metals themselves by means of passing through a complicated path in the inside of blade as shown in Fig-68. The extracted air from intermediate stage or final stage of air compressor parts is utilized for this cooling air. The outside connection pipes go and back between the compressor and turbine, and it is designed in advance that appropriate amount of air flow inside a turbine depending on the proper pressure balance as shown in Fig-69. The progress of the gas turbine technology is the history of the development of material which can withstand high temperature and the development of cooling technology as shown in Fig-70. A variety of materials and cooling methods has been adopted, although the current exhaust gas temperature level is 1,500^{o}C which is exceeds the melting point of normal metal and.

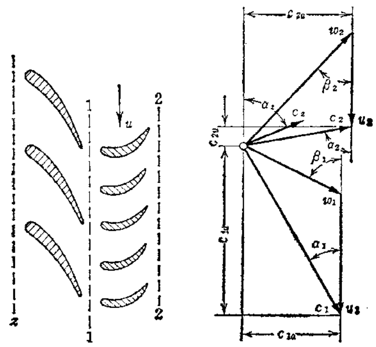


Fig- 65: Velocity triangle of blade and vane

Reference: P-75 of Journal (No.578: Nov. /2004): TENPES

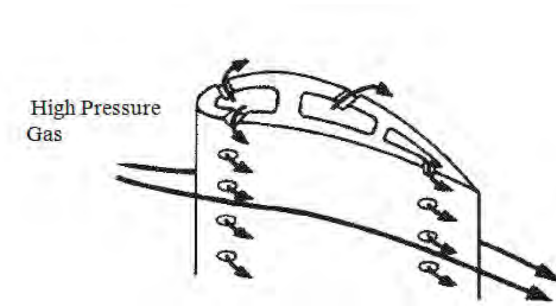


Fig- 66: Film cooling

Reference: P-75 of Journal (No.578: Nov. /2004): TENPES

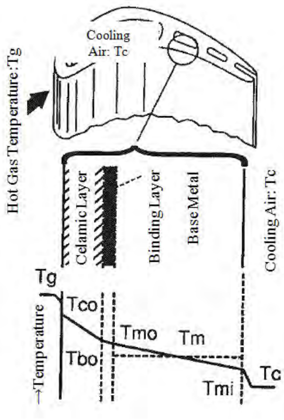


Fig- 67: Ceramic coating for turbine blade

Reference: P-75 of Journal (No.578: Nov. /2004): TENPES

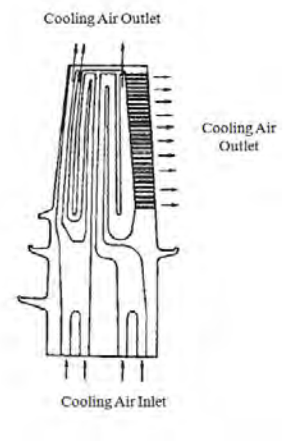


Fig- 68: Construction of air cooling blade

Reference: P-75 of Journal (No.578: Nov. /2004): TENPES

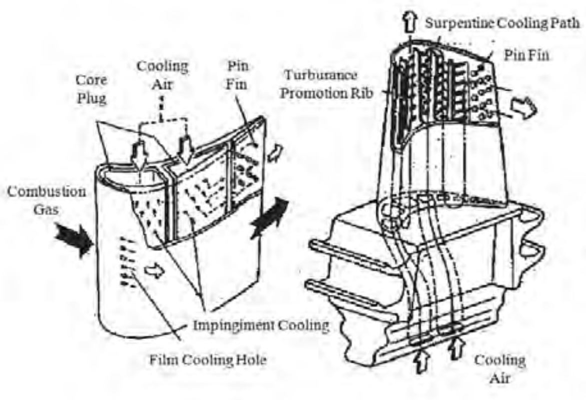


Fig- 69: Cooling system of turbine blade

Reference: P-76 of Journal (No.578: Nov. /2004): TENPES

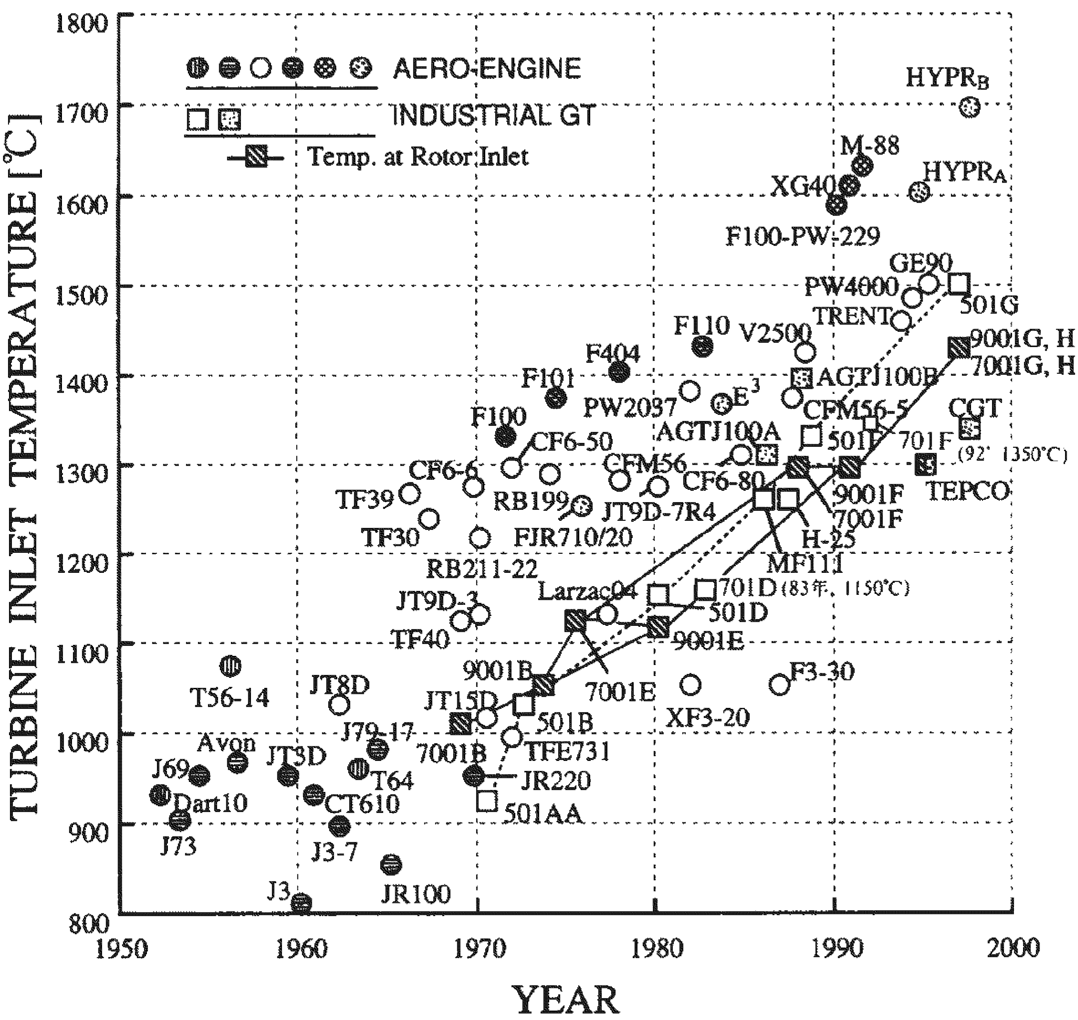


Fig- 70: Progress of turbine inlet temperature

Reference: P-76 of Journal (No.578: Nov. /2004): TENPES

The latest typical cooling method of gas turbine for generation is shown in Fig-71, 72, 73, 74. The blades and vanes which have complicated internal passage for cooling air are recently often produced by precision casting, single crystal casting and laser drilling as shown in Photo-58, Fig-75 Photo-59.

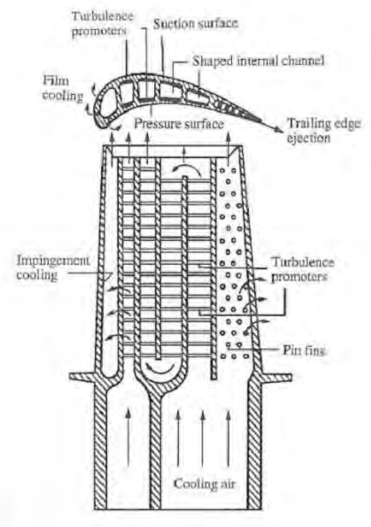


Fig- 71: Air cooling blade

http://www.ligrani.com/Research/Groups/internalcooling.html

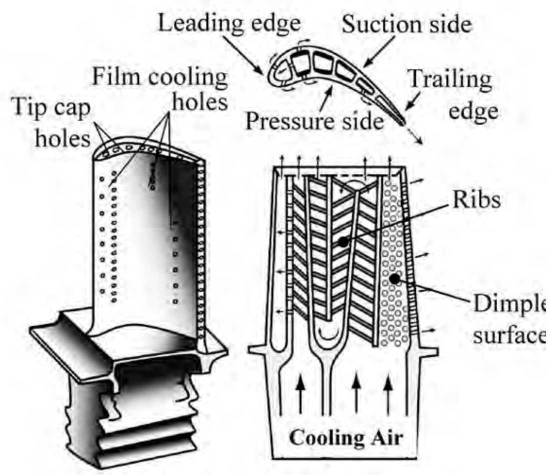


Fig- 72: Air cooling blade

http://www.mmlab.mech.tuat.ac.jp/mmlab/fig/fig_01_b.jpg

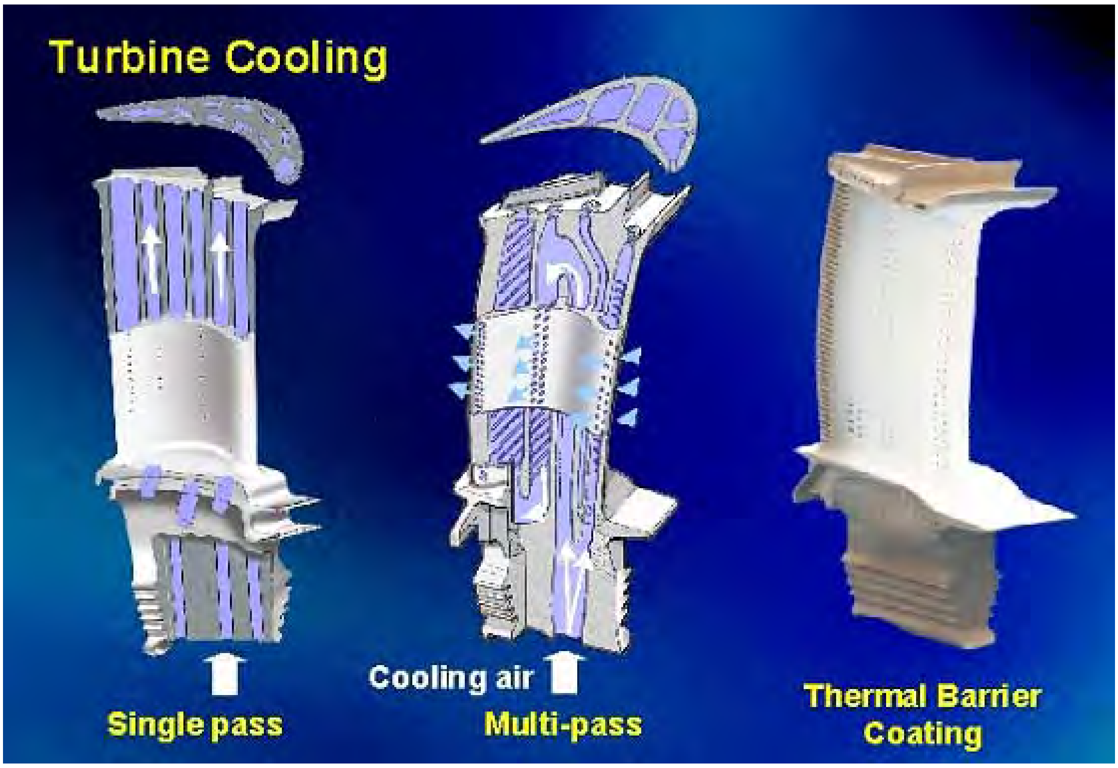


Fig- 73: Air-cooling Blade

http://ligrani.com/Research/Groups/internalcooling_files/int-cooling-1.jpg

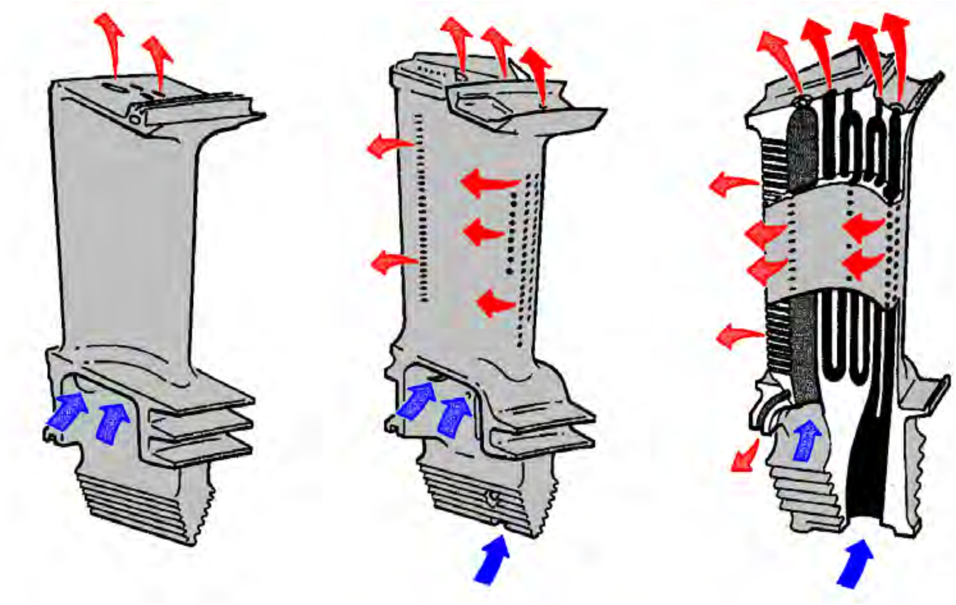


Fig- 74: Air-cooling blade

http://www.tpg.unige.it/research/blade_cooling.jpg

Photo- 58: Lost wax casting of blade

http://www.amtonline.com/print/Aircraft-Maintenance-Technology/A-Tour-of-Turbine-Engine-Parts-Facility/1$12676

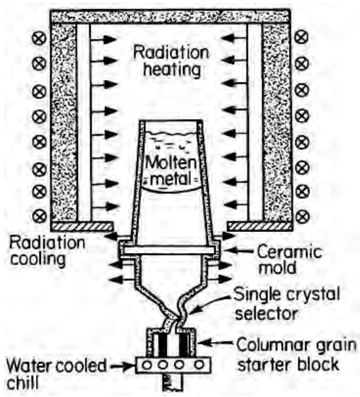


Fig- 75: Single crystal casting

http://www.nap.edu/openbook.php?record_id=10291&page=67

Photo- 59: Laser drilling of GT blade

http://ro.dmg.com/ino/lieferprogramm_09/images/content/ultrasonic/mb_r_lasertec50powerdrill.jpg

4-7. Turbine Nozzle and Vane

There are some types of the construction of turbine nozzle and vanes. One is the type which the inner and outer peripheries and wings are formed a cylindrical annular passage as shown in Photro-62, the second is the segment type which several nozzles and vanes are integrated as shown in Photo-61 and the third is single item type shown in Photo-60.

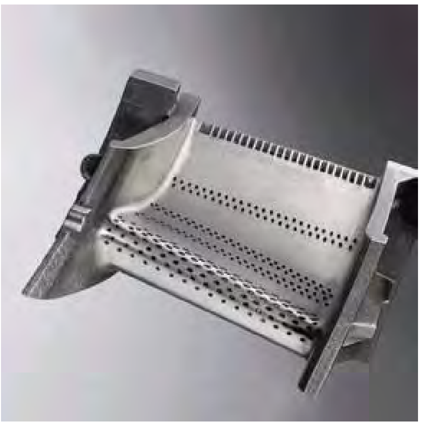


Photo- 60: Laser drilled GT nozzle

http://www.laser-industrial.com/ldex1.jpg

Photo- 61: Gas turbine vane segment

http://farm2.static.flickr.com/1430/886885205_440f5e620a.jpg

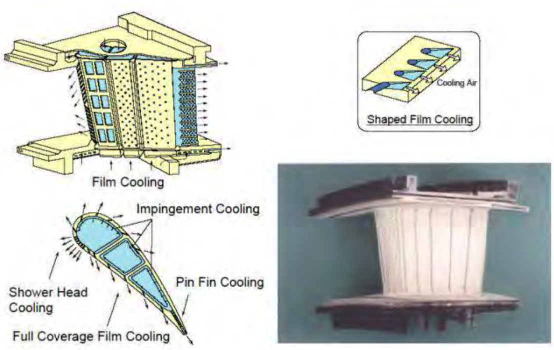


Fig- 76: Gas turbine nozzle with TBC

http://www-tran.mech.eng.osaka-u.ac.jp/research/figure/vane.jpg

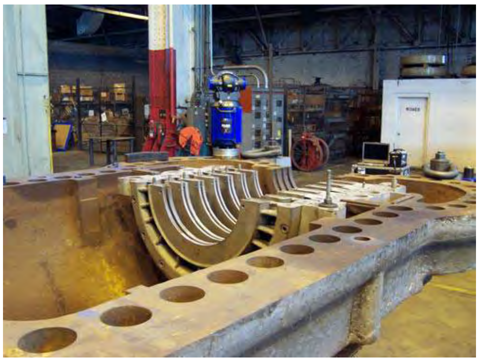


Photo- 62: Gas turbine vane

http://www.power-technology.com/contractor_images/oasis-alignment/5-tracker-turbine.jpg

The nozzle and vanes have been devised to maintain a low temperature of metal by means of passing the cooling air through the nozzles and vanes and forming air layer on the surface of them as shown in Fig-76, 77 and 78.

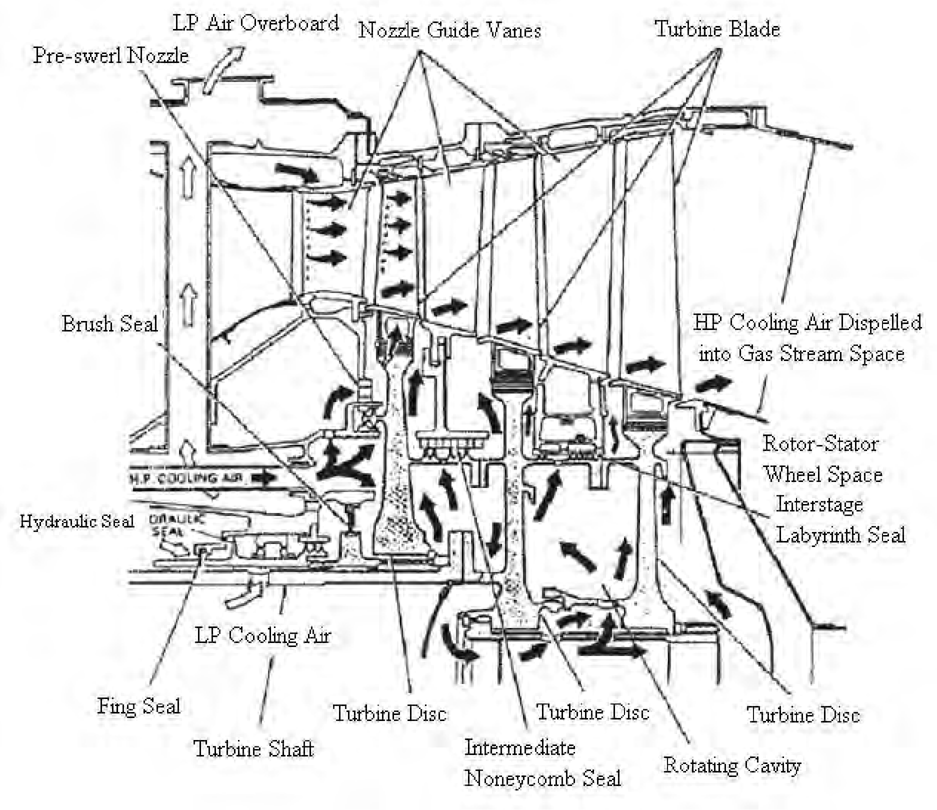


Fig- 77: Air-cooling flow in the gas turbine part

Reference: P-76 of Journal (No.578: Nov. /2004): TENPES

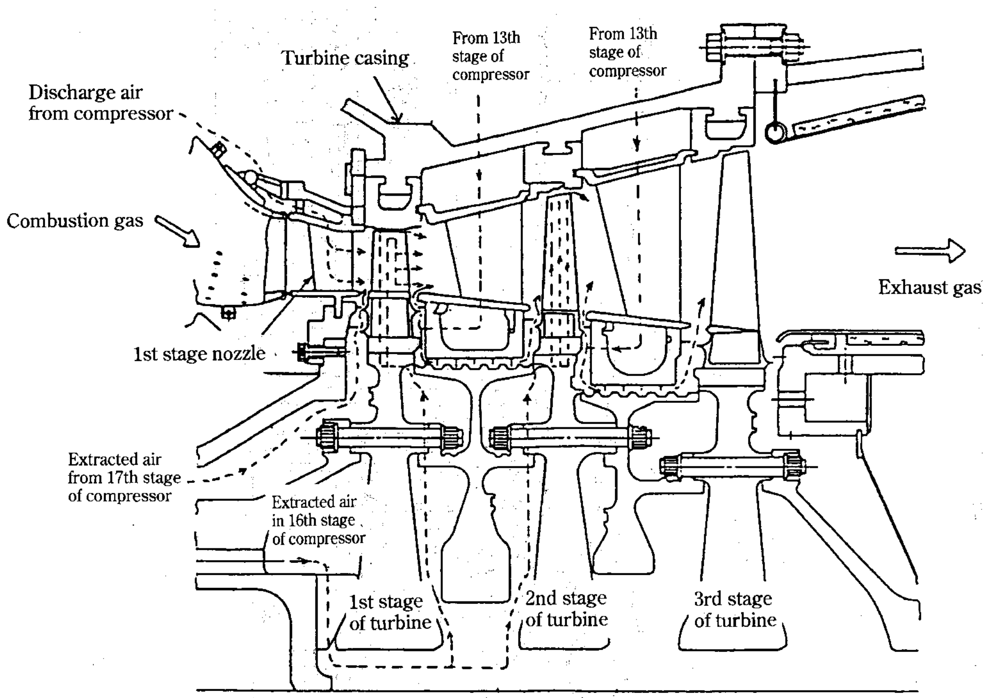


Fig- 78: Construction of gas turbine cooling system (GE)

Reference: P-397 Handbook for Thermal and Nuclear Power Engineers English Ver. 7 2008 TENPES

4-8. Coating

The breakthrough of coating technology is important together with the heat resistant material as shown in Fig-79, Photo-63, 64 and 65. It is capable to obtain high plant efficiency depending on the reduction of amount of cooling air and to prevent temperature rise of base metal by means of applying TBC (Thermal Barrier Coating) to the hot parts. On the other hand, it is necessary durability, adhesion evaluation technique of TBC, because TBC has large range of variation due to the deterioration of durability and quality in use.

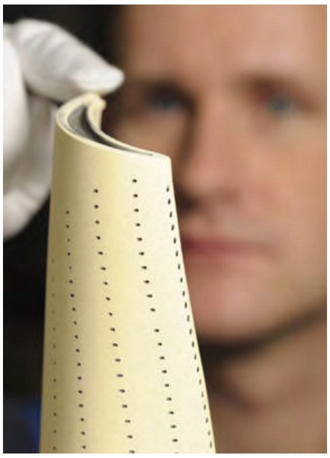


Photo- 63: GT blade with TBC

http://www.siemens.com/press/pool/de/pressebilder/photonews/PN200807/PN200807-05_072dpi.jpg

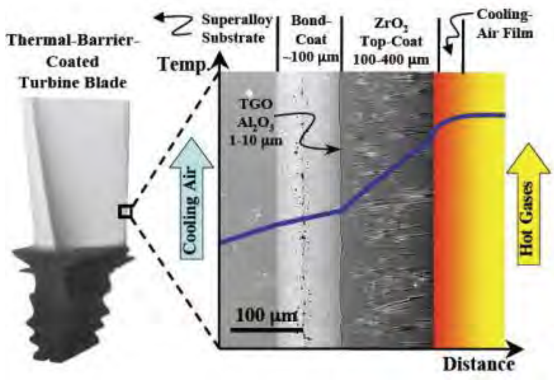


Fig- 79: Cross section of TBC

http://www.matsceng.ohio-state.edu/faculty/padture/padturewebpage/padture/TBC.jpg

Photo- 64: TBC for GT vane

http://nhts.co.id/new/wp-content/uploads/2011/02/tbc.jpg

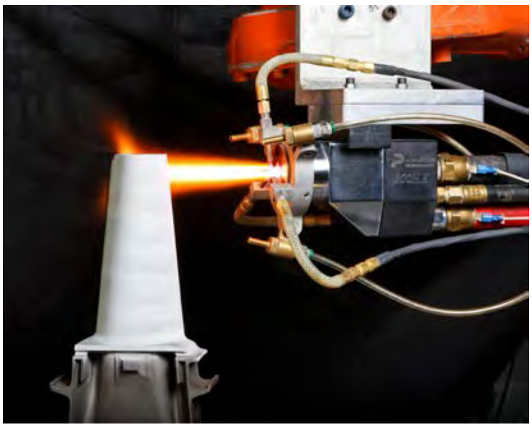


Photo- 65: TBC for GT blade

http://www.progressivesurface.com/casestudy.php?id=12

4-9. Compressor Blade

This is the element to draw and compress the air, and the axial compressor or centrifugal compressor is applied. Typically, the multi stage axial compressor is applied to the high pressure and large capacity gas turbine as shown in Photo-66. The compressor is consist pair of blade which rotates and gives energy to fluid and vane which slow-down and increase pressure by rotation. The annular flow path decreases area as follow the increase in pressure and as the rear. Usually, axial velocity of the air is obtained at intake on the front stage by means of conducting intermediate stage bleed at start-up for axial flow compressor as shown in Fig-80. When the pressure is especially high, “intercooler” may be employed which extract air on the way and cool compressed air by outside cooler and back to passage again.

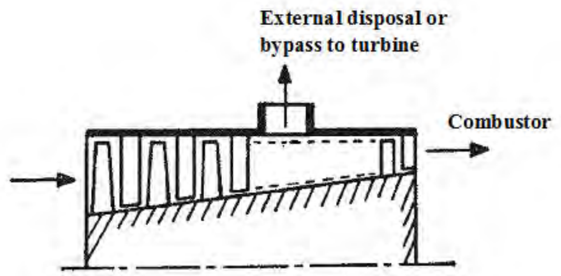


Fig- 80: Concept of air extraction from compressor

Reference: P-72 of Journal (No.578: Nov. /2004): TENPES

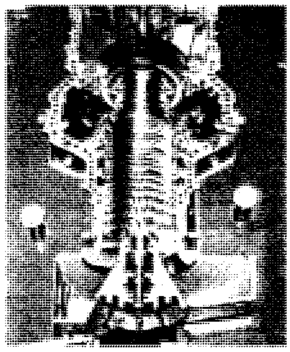


Photo- 66: Axial flow compressor

Reference: P-72 of Journal (No.578: Nov. /2004): TENPES

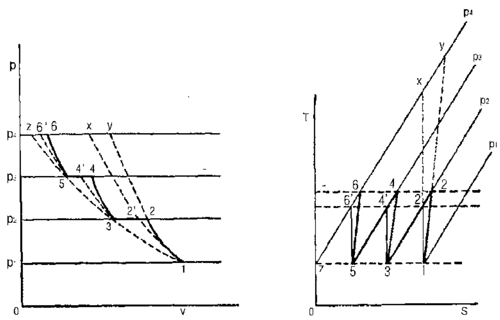


Fig- 81: Concept of 2 stage inter-cooling

Reference: P-72 of Journal (No.578: Nov. /2004): TENPES

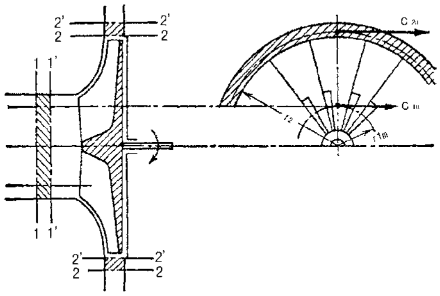


Fig- 82: Centrifugal compressor

Reference: P-73 of Journal (No.578: Nov. /2004): TENPES

Huge potential to reduce power compression is expected as shown in Fig-81 by this. On the other hand, the centrifugal compressor is often employed to small size gas turbine in order to avoid the complexity of starting method and to compact as shown in Fig-82. The principle to raise pressure is same; the energy is given to fluid by rotating impeller and decreasing speed and increasing pressure by the diffuser placed around the blades as shown in Fig-83. In recent years, it comes to employed the complicated shaped blades which is suppressed the overall loss of the blade group or blade by utilizing 3D flow analysis as shown in Fig-84, Photo-67, 68, 69, 70, 71, 72 and 73, because of the development of computer.

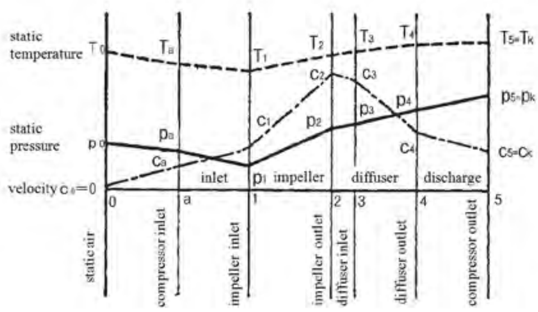


Fig- 83: Variation in the compressor

Reference: P-73 of Journal (No.578: Nov. /2004): TENPES

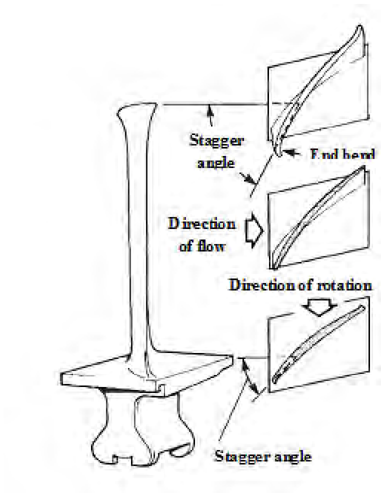


Fig- 84: Compressor blade

Reference: P-73 of Journal (No.578: Nov. /2004): TENPES

Photo- 67: Compressor blade

http://www.periodictable.ru/022Ti/slides/Ti12.jpg

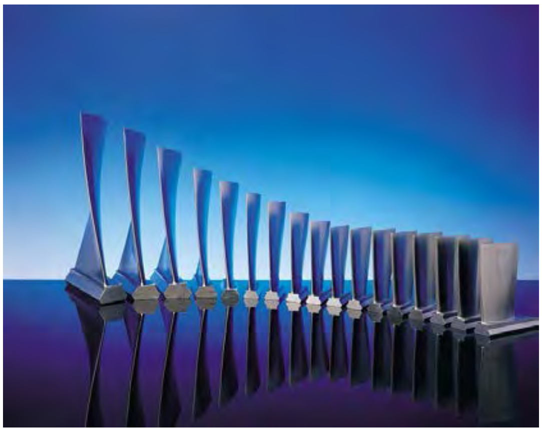


Photo- 68: Compressor blade

http://www.balticnordic.com/images/products/s/25/gas_turbine_compressor_blades_lp_1267727958.jpg

Photo- 69: Compressor blade

http://www.aetsltd.com/Pics/886.jpg

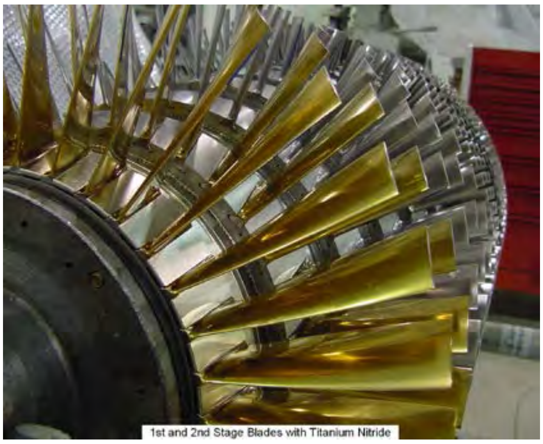


Photo- 70: Titanium blade of compressor

http://www.heyeng.com/compressor.jpg

Photo- 71: Compressor blade

http://www.utilities-me.com/pictures/gallery/turbine%20production.JPG

Photo- 72: Compressor disc and blade

http://www.tpn-gmbh.de/media/2/I1011460/000106.JPG

Photo- 73: Fan blade for jet -engine

http://pic.auairs.com/news/20110325/20110325@19844.jpg

4-10. Compressor Vane

The compressor vane is generally composed by ring-shape diaphragm (diaphragm ring structure) as shown in Fig-85 and Photo-74, 75. The vane has the cross section (wing like) combined with two arcuate shaped like a normal airplane wings, the basic structure to form the shape of the vane is to put a twist in the radial direction gradually considering the difference in peripheral speed of the vane and inner periphery of the periphery.

In case of the axial flow compressor, it is possible to adjust suction air volume by the installed guide vanes which are varied angles in the inlet vane, although the air intake volume is decided depending on the number of revolutions. The compressor with high compression ratio might change the angle of multi-stage vanes in order to improve the aerodynamic integrity of partial load as shown in Fig-86, Photo-76 and 77.

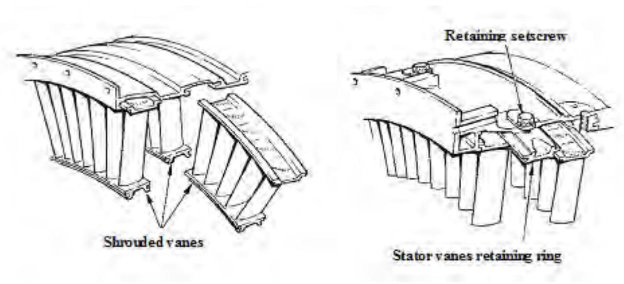


Fig- 85: Diagram for compressor vane

Reference: P-73 of Journal (No.578: Nov. /2004): TENPES

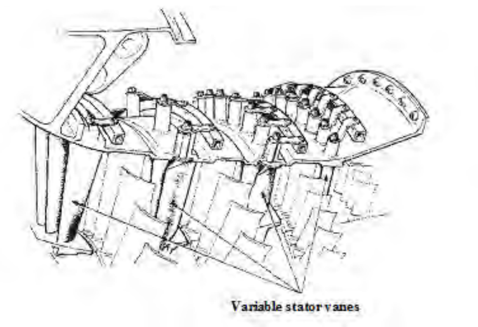


Fig- 86: Valuable vane for compressor

Reference: P-73 of Journal (No.578: Nov. /2004): TENPES

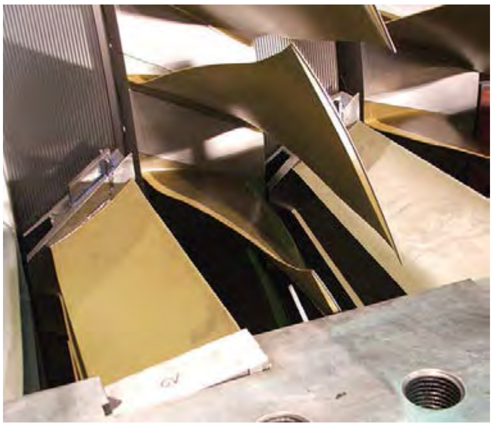


Photo- 74: Compressor vane

http://www.energy.siemens.com/hq/pool/hq/services/power-generation/product-related-services/sgt5-4000f-v94-3a/advanced-compressor-blades-large.jpg

Photo- 75: Compressor vane

http://www.enginehistory.org/G&jJBrossett/JetEngines/403Core%20compressor%20stators.JPG

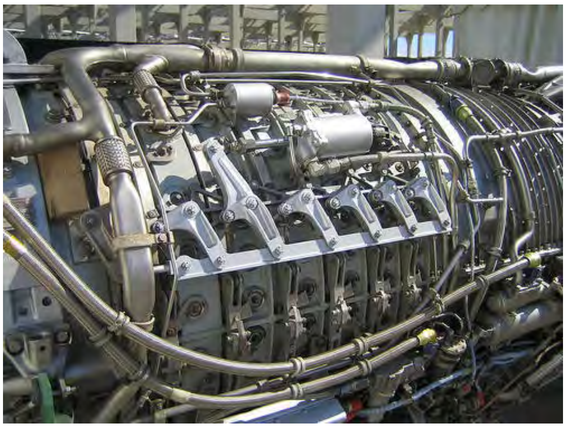


Photo- 76: Valuable vane of compressor

http://farm2.static.flickr.com/1316/847142974_e943c2c99c.jpg

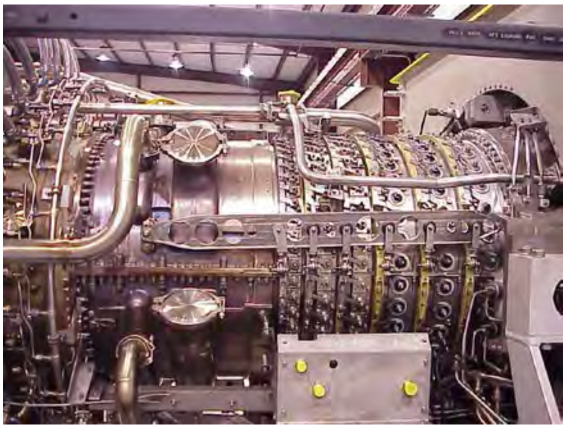


Photo- 77: Valuable vane of compressor

http://2.bp.blogspot.com/_W99vfljlto0/S9XjzJOa-VI/AAAAAAAAAGE/fSoz9MAIAXo/s1600/Gas%2520Turbine%2520Training%2520Pictures%2520060.jpg

Article 39. Speed governing device for gas turbine, etc.

1. The **"Speed governing device for gas turbine, etc."** stipulated in Article39-1 of design technical guideline is the device to control rotation speed of gas turbine to ensure safety of gas turbine.

   The control device is broadly divided into a governor device and a safety device. The governor device regulates the output and speed of the turbine generator, while the safety device stops the turbine generator quickly and safety should it has developed an abnormal condition during operation. The governor device is further divided into a conventional mechanical hydraulic governor and a new-type electro hydraulic governor used for large-capacity turbines. The turbine governor is a device to adjust the turbine rotation speed within a certain range regardless of load. It is consisted by adjusting actuator which moves sensitively depending on the changes of turbine speed and the governor valve which adjust the fuel supply for turbine shown in Fig-89.

   The emergency governor is the emergency stop device to prevent the risk due to over-speed by isolate the fuel to gas turbines immediately as shown in Fig-87. The eccentric bodies (plunger type or ring type) attached to one end of the turbine rotor have slight deviation from the center of gravity of the rotating shaft and centrifugal force works. The plunger or ring is supported in place by spring force when the turbine speed is constant as shown in Fig-88, however, the they act to overcome the sticking force of the spring outward, when rotating speed exceed a certain limit. The turbine governor and the emergency governor are both important devices, the type of them shall be selected reliable ones and the redundancy shall be considered. In addition, the relationship of speed and restrictions shall be organized as follow.

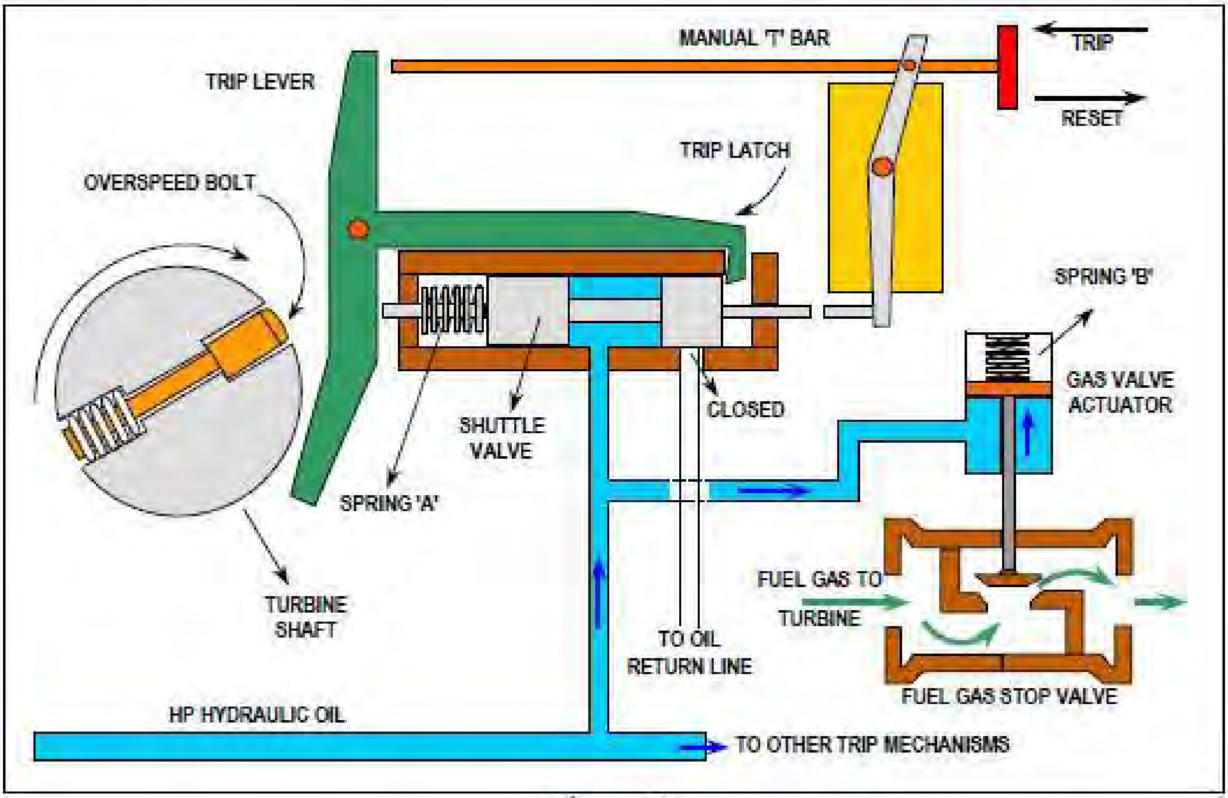


Fig- 87: Typical construction of emergency governor (Over-speed Trip in "Normal" Condition)

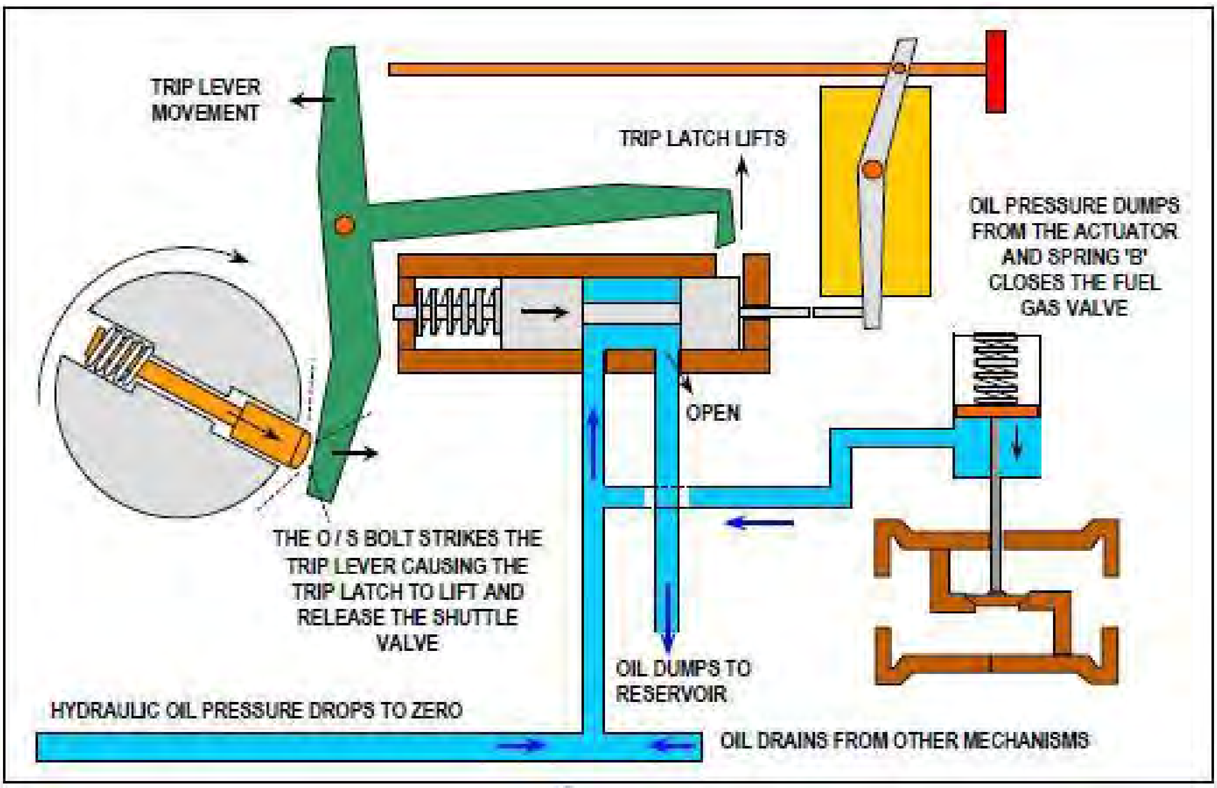


Fig- 88: Typical construction of emergency governor (Over-speed Trip in "Tripped" Condition)

http://articles.compressionjobs.com/articles/oilfield-101/168-gas-turbines-principles-lube-control-systems-overspeed?start=8

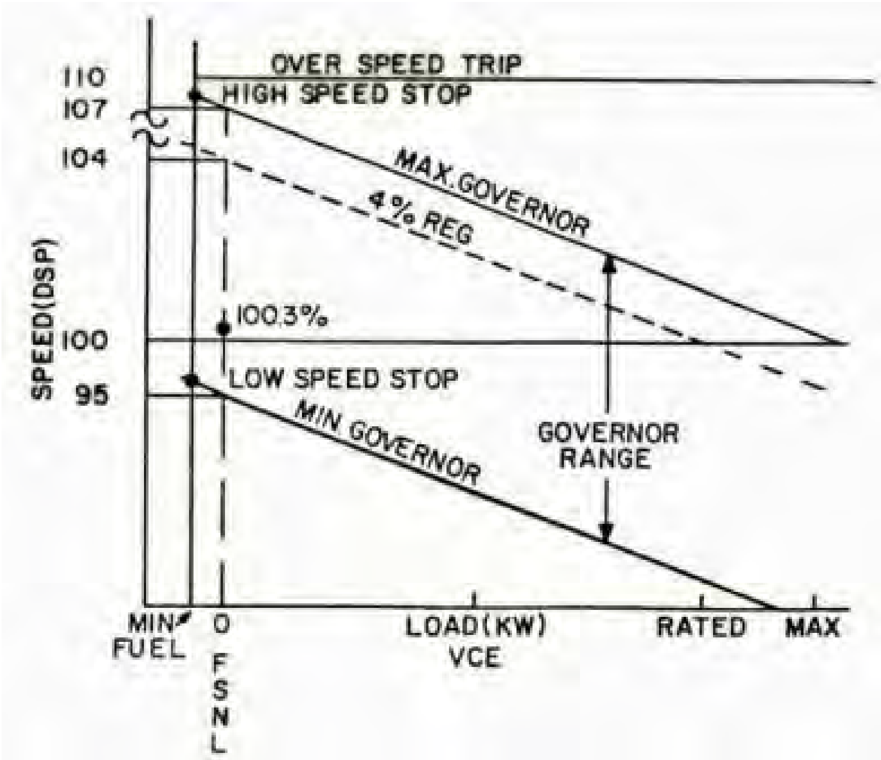


Fig- 89: Typical speed governing

http://automatoes.com/questions/48/what-is-the-difference-of-a-generator-working-in-droop-or-isochronous-isoc-mode

2. Terms Related with Rotation Speed.

The terms related rotation speed is defined as shown in Table-40.

Table- 41: Definition of terms regarding speed

Term	Meaning
rated speed	Design rotation speed at nominal output
maximum continuous speed	Upper limit of rotation speed to operate continuously
over-speed trip setting	Rotation speed which emergency governor operates
instantaneous maximum speed	The rotation speed to reach immediately after suddenly cut off the load when the turbine governor control devices are operated at the rated speed of the load conditions in a given
permanent speed rise	It is called "permanent speed raise at that load" which is automatically stabilized after load isolation when the turbine is operated with rated rotation speed at any load without changing the configuration of the governor.
maximum speed rise	The transient maximum turbine speed in the calculation when the governor does not work but emergency governor work after nominal load interception.
steady state speed regulation, permanent speed change, permanent speed variation, overall speed droop	The speed variation expressed as a percentage of the rated speed when the load is varied from no load to nominal of turbine output without changing the configuration of the governor

Term	Meaning
incremental speed variation, incremental permanent speed variation	R_1(%) is given by: $R_1=(d_n \div d_P)\times(P\div n_r)\times 100$ where $(d_n \div d_P)$: Inclination at Any Output on the Characteristic between Output and Rotation Speed (min^{-1}/kW) P : Nominal Output (kW) n_r : Rated Speed (min^{-1})
maximum momentary speed variation, instantaneous speed change	R_2(%) is given by: $R_2=(n_m-n_r)\div n_r\times 100$ where n_m : Instantaneous Maximum Speed After Load Interception (min^{-1}) n_r : Rated Speed (min^{-1})
Dead band of the speed governing system	The ratio of variation speed with the rated speed without changing of governor valve opening during operation under rated speed.
percentage maximum momentary speed variation	R_m(%) is given by: $R_m=(n_u-n_r)\div n_r\times 100$ where n_u : Raised Speed (min^{-1}) n_r : Rated Speed (min^{-1})
percentage speed variation	R_c(%) is given by: $R_c=(n_c-n_r)\div nr\times 100$ where n_c : Dropped or Raised Speed (min^{-1}) n_r : Rated Speed (min^{-1})
percentage emergency speed variation	R_e(%) is given by: $R_e=(n_e-n_r)\div n_r\times 100$ where n_e : Working Speed of Emergency governor (min^{-1}) n_r : Rated Speed (min^{-1})

3. Instantaneous Maximum Speed

$$n_o = \sqrt{\frac{7.3\times 10^5}{GD^2}\times\left(E_R+\Delta E_1+\Delta E_2+\Delta E_3\right)}$$

n_o	: Maximum speed	(min^{-1})
E_R	: Rotational energy at rated speed $=1.37\times 10^{-6}\times GD^2\times n_r^2$	(kJ)
n_r	: Rated speed	(min^{-1})
GD^2	: Inertia moment of rotating parts of turbine and generator	(kgm^2)
ΔE_1	: The energy flow into turbine during the delay time of valve opening operation after load interception	(kJ)
ΔE_2	: The energy flow into turbine during the time of valve closure after the load interception	(kJ)
ΔE_3	: The energy used to increase speed by the remaining in turbine and steam pipe at the load interception	(kJ)

4. Maximum Speed Rise

$$n_E = \sqrt{\frac{7.3\times10^5}{GD^2}\times\left(E_E + \Delta E_{1E} + \Delta E_{2E} + \Delta E_{3E}\right)}$$

n_E	: Maximum speed (the rotation speed which emergency governor operates)	(min^{-1})
E_R	: Rotational energy at emergency governor operates $=1.37\times10^{-6}\times GD^2\times n_E^2$	(kJ)
GD^2	: Inertia moment of rotating parts of turbine and generator	(kgm^2)
ΔE_{1E}	: The energy flow into turbine during the delay time of valve opening operation after load interception	(kJ)
ΔE_{2E}	: The energy flow into turbine during the time of valve closure after the load interception	(kJ)
ΔE_{3E}	: The energy used to increase speed by the remaining in turbine and steam pipe at the load interception	(kJ)

5. Steady State Speed Regulation

$$R_s[\%] = \frac{n_o - n_r}{n_r}\times100$$

n_o	: The permanent speed rise at no load operation after intercept of rated : output	(min^{-1})
n_r	:Rated speed	(min^{-1})

R_s are generally in the range of 3~5%, ht actual adjustment of R_s=5% at full throttle of governor valve

6. Incremental Speed Variation

$$R_r[\%] = Knp \times \frac{P}{n_r} \times 100$$

Knp	: Inclination at any output point of output-rotation speed characteristic	(min^{-1}/kW)
P	: Nominal output	(kW)
n_r	: Rated speed	(min^{-1})

Table- 42: The incremental speed variation of governor

<table>
<tr><td colspan="2">Type of governor</td><td colspan="3">Mechanical</td><td colspan="3">Electric-hydraulic</td></tr>
<tr><td colspan="2">Nominal output（kW）</td><td>Less than 20,000</td><td>20,000~ 150,000</td><td>More than 150,000</td><td>Less than 20,000</td><td>20,000~ 150,000</td><td>More than 150,000</td></tr>
<tr><td colspan="2">Speed variation ratio（%）</td><td colspan="6">3~5</td></tr>
<tr><td rowspan="2">Incremental speed variation （%）</td><td>0~90（%）of Nominal output</td><td rowspan="2" colspan="4">Maximum Value：No limitation
Minimum Val：40% of steady state speed regulation</td><td colspan="2">2~10</td></tr>
<tr><td>90~100（%）of Nominal output</td><td colspan="2">Less than 12</td></tr>
<tr><td colspan="2">Mean incremental speed variation (1) %within the range 90~100 （%）of nominal output</td><td colspan="4">Less than 15</td><td colspan="2">Less than 10</td></tr>
<tr><td colspan="2">Dead band of speed governing system（%）</td><td>0.4</td><td>0.20</td><td>0.10</td><td>0.15</td><td>0.10</td><td>0.06</td></tr>
</table>

Note-1: In case of partial-arc admission turbine, the mean incremental speed within the range 90~100（%）of nominal output must not exceed 3 times of steady state speed regulation.

Reference: 4.3 of JIS B8101-1991 “General specification for steam turbines”

7. Governor Test

(1) The speed control range: The speed control range of turbine at no-load shall be within ±6% of rated speed. (IEC60045-1 stipulates±5% of rated speed.) If there is special necessity, it can be modified by agreement of the parties. For instance, －5~＋7%.

8. Over-speed Trip Setting of Emergency Governor

(1) Over-speed Trip Setting of Emergency Governor: The maximum speed reached when the emergency governor operates shall not exceed the safety limit of turbine and followers. (JIS stipulates less than 111%

of rated speed and IEC stipulates 110±1% of rated speed.) In case of large scale turbine, it shall be capable to reset before turbine speed drop to rated speed.

1) The maximum momentary speed variation at load interception
2) This means the speed variation reaching momentary when intercepts any load as it has operated at the rated speed under certain condition.
3) The percentage emergency speed variation
4) The percentage emergency speed variation is the maximum speed rise which the maximum momentary speed variation exceeds the over-speed trip setting and reaches to maximum speed. The variation of maximum speed rise shall be less than 120% of rated speed.

9. Over-speed Test

(1) The maximum speed at the over-speed test: When carrying out the over-speed test of rotor in the factory, the test speed shall not exceed 115% of rated rotation speed; duration of test shall be within 2 minutes under no load operation and is limited one time.

10. Speed Governing and Speed Limit

(1) Speed Setting
The automatic speed setting device and selection switch for both manual and automatic must be provided for the control equipment. The range of rotation speed must be quite same and is capable to switch manual with automatic smoothly at any time after reaching the independent speed.

(2) Constant Speed Operation (for power generation)
If there is no other settlement agreement between the parties, no-load speed must be capable to adjust 95%~105% during operation. In case of remote operation, the speed control setting device must be match with those of gas turbine which is operated in parallel. The parties are to agree with the load reduction speed from site rated output to no-load.

(3) Speed Control

1) Transient Performance of Speed Governor (for the generation facility by single-shaft type gas turbine)

In case of steady state, the speed governor must always limit the rotation speed of output shaft within 105% of rated speed. The speed governor for gas turbine to drive generator must not reach the gas turbine speed to trip speed when shedding the load at the possible maximum load. However, this is assumed that the gas turbine is operated at setting rated speed by the speed controller within the range of designed pressure, temperature and calorific value of fuel.

2) Transient Performance of Speed Governor (for the generation facility by dual-shaft type gas turbine)

(a) The speed control must not reach the rotation speed of gas turbine to trip speed when the load is shed at maximum

(b) The manufacturer must provide the information to purchaser about the maximum step up load that can be added to the gas turbine.

3) Dead Zone

The dead zone under rated output must not exceed 0.1% of the rated speed which is the following in maximum power output.

11. Speed Control Stability

(1) Ability

The governor must be capable to perform stable control of following items from no load to maximum output of gas turbine.

1) The rotation speed of gas turbine when the driven machine is operated independently.

2) The amount of energy supplied to the gas turbine when the driven machine is operated with other driven machine in parallel.

(2) System Stability

The system must be stable in the following case.

1) The fluctuation of lasting rotation speed of gas turbine due to the governor and fuel control equipment does not exceed the percentage of the specified rated speed (e.g. 0.12%~0.25% of rated speed), drives the driven machine and supports the load.

2) The fluctuation of lasting heat input (fuel-based energy supply) due to the governor and fuel control equipment does not exceed the 2% of rated output when the driven machine is operated and supporting load stably under rated speed with other driven machine which is operated in parallel.

(3) Over-speed Protection System

If it is not capable to show that it will not raise dangerous over-speed in the aspect of aerodynamics, the over-speed protection device must be provided to each of the independent axis. If the over-speed protection device is electronic type, at least two sets of detector and circuit must be provided.

(4) Setting Value for Over-speed Protection

The main function of the over-speed protection device is to cut off fuel in the vicinity of the combustor by another fuel shut-off valve with main valve. In case of the single-shaft generation facility, the setting value for over-speed protection must not exceed 110% of the synchronous speed. In case of the generation facility for dual-shaft gas turbine, the setting value for over-speed protection must be the higher than the maximum speed which reaching at maximum load rejection for a margin to avoid the malfunction. However, it must not cause excessive stress on the rotor. In case of the generation facility for dual-shaft gas turbine, the setting value for over-speed protection must be 5% higher than the maximum continuous operation speed.

(5) Over-speed Test

The over-speed trip test must be provided. It can be selected either manual or automatic. Whether or not to interrupt the normal operation depends on the agreement between parties.

(6) Additional Over-speed Protection Device

It may be required the additional protection device to prevent over-speed due to the accumulated heat or the large amount of high pressure air or both when the gas turbine has free turbine or heat exchanger. For example, the blow-off valve which is operated by main governor or over-speed trip device or both is may be available for the over-speed protection device.

Article 40. Emergency stop device for gas turbine, etc.

1. "**Immediately**" stipulated in Article 40-1 of design technical regulation means the previous time point when rotation speed exceeded the 1.11 times of the rated rotation speed in case of the rotation speed of gas turbine exceeded the rated rotating speed, 1.16 times of rated speed in case of multi-shaft type gas turbine, for instance appropriated gas turbine, etc. from aircraft and connected with generator, the maximum speed which is verified safe sufficiently. In other case, the time point when abnormal situation occurred.

2-1. "The **over-speed**" stipulated in Article 40-2 of design technical regulation means in case when rotation speed of gas turbine exceeded above rated speed, and "The **other abnormal situation**" mean following situation.

1) internal fault of generator more than 10,000kVA capacity
2) significant temperature rise of exhaust gas

2-2. Safety Equipment

(1) "Flame Monitoring"; the flame directly or indirectly type detector must provided to monitor the burning flame at the appropriate point in the start-up cycle and during subsequent steady-state operation. If the burner is not capable to ignite in time or the burner is misfired during steady-operation, the fuel supply must be stopped.

(2) "Temperature of bearing"; the gas turbine which has journal bearing as main bearing must provide the monitoring device for the bearing metal temperature and discharge oil temperature, it must work alarm and/or stop device if it detects an abnormal temperature.

(3) "Ice Suppression"; The manufacturer must provide the necessary equipment for automatic control when providing the anti-icing system for the gas turbine inlet filter or for compressor bellmouth/1st stage blade bell mouth.

(4) "Inlet Pressure Drop"; the intake system must provide alarm system which will display the pressure difference between the ambient and inlet flange and the trip device, and must work against high pressure difference.

(5) "Back Pressure of Exhaust System"; the manufacture must provide information about maximum permissible back pressure of hole facility if the waste heat is used directly or recovered by HRSG. In order to protect gas turbine from back pressure which exceeds the tolerance, the monitoring device to detect failure must be provided. It may apply either the damper position sensor or the pressure monitoring device according the settlement agreement between the parties. In either case, the devices must work rapidly without failure of gas turbine and equipments.

(6) "Monitoring of Vibration and Axial Displacement"; the monitoring device for vibration and displacement must be provided to alert the axial displacement and vibration levels and to trip the machine if its change is unacceptable.

1) Aero-derivative Gas Turbine

Typically, the seismo-accelerometer (which is capable to display the vibration velocity) must be provided. In case of the gas turbine which has multiple spool casing, the monitoring device with tracking filter may be required to separate the frequency by spool. The monitoring equipment to monitor the axial displacement is not provided for the gas turbine of this type.

2) Industrial Gas Turbine

The axial displacement probe and shaft vibration displacement indicator must be provided. If the manufacturer is capable to show the acceptable level of vibration which does not cause damage due to long term vibration, the mount type acceleration/speed censors may be provide. The final selection must be according to the settlement agreement between the parties.

3) Main Reduction Gear Equipment and Driven Machine Unit

The design of monitoring equipment for the main reduction gear equipment and driven machine unit and the scope of supply is according to the settlement agreement between the parties.

(7) Exhaust Temperature Monitoring System

In order to monitor the exhaust temperature for gas turbine or the inlet temperature of free turbine, a series of thermometer must be provided. In order to detect an asymmetric or uneven temperature distribution by the combustor or turbine nozzle, the sufficient detectors must be provided. If the temperature of a place is deviate from the specific value exceeds the average temperature, it must alert. If it is deviated from greater than the given value, the load reduction, stop or emergency stop must be done.

2-3. Control Unit

(1) General

The gas turbine control system and safety equipment must be designed with “fail-safe” function. When applying that function to the digital control system, this context is as follows.

1) “Digital Instruments”; The digital input instruments (e.g. pressure switch) which is used for gas turbine safety equipment must be designed “ normally open”, and “closed” during gas turbine operation, and “open” again in case of failure.
2) “Analog Instrument Circuit”; the analog instrument (e.g. input from a thermocouple) which is used for gas turbine safety equipment must be always monitored of its circuit breakdown or out of range of input signal.
3) “Digital Control Output Circuit”; the digital output (e.g. relay output) must work “when the power is working”; the all digital outputs must lead process to safe condition.
4) “Analog Control Output Circuit”; the analog control output circuit must always monitor the location of equipment being controlled directly or indirectly, it must generate a signal that leads to a safety level when the location error occurs.

(2) Start-up

The launch control system must be fully automatic including the starting conditions required for turning without manual operation. It is desirable that the start-up sequence cover from single operation until reaching the minimum control operation speed (or until ready to synchronizing in case of power facility). The holding of speed during the start-up preparation, beginning of start-up and start-up process must be provided in the start-up sequence according to the design requirement by manufacturer or the operation requirement by purchaser.

(3) Load Increase

The load increase operation to the necessary level following the start-up must be manual or automatic as specified by the purchaser. In manual operation, the operators increase output to required level by manual. In automatic load increase, the output is increased to setting level automatically without manual operation by operator. The automatic load-up may be carried immediately after completing start-up sequence without additional operation by operator. In any load-up mode, the warm-up may be performed in a period of time at specific load, if necessary. If it is necessary to synchronize a specific network prior to load-up the generator, it may be performed manually or automatically by the requirement by purchaser.

(4) Load Decrease and Stop

The stop operation and load reduction may be manual, semiautomatic or automatic depending on the requirement by purchaser. In manual operation, it is necessary a manual operation to begin each stage. In semiautomatic operation, although some operations are necessary by manual operation such as load reduction, other part is done by automatic sequence. In automatic operation, the operation is run from a single command of operator. However, the basic operation sequence in all cases must be said as below.

1) Stoppage by Control (for power generation)

   a) Load decrease controlling to the nominal zero output remaining synchronized
   b) Breaker opening
   c) Slow-down to idling speed and the cooling time while maintaining combustion (if applicable)
   d) Stop of auxiliary equipment which is not necessary for fuel cut-off and turning
   e) Turning time (if required)
   f) Stop of auxiliary equipment which is remaining after cooling operation of gas turbine such as lubrication oil pump
   g) Reset to start condition

(5) Emergency Safety Equipment

1) The emergency safety equipment must protect gas turbine and associated equipments against danger or imminent damage, and it must detect and work independently with governor if appropriate. In order to keep the longest life of gas turbine, it is not necessary to stop immediately under the certain circumstances; it must be transferred to the following minimum independent speed or minimum load.

   a) Load Shedding for Safety
      a. The control sequence may transfer the gas turbine to minimum load situation, no-load situation (generator breaker open) or independent speed situation according to the fault situation in order to cool-down for a period before stopping the gas turbine by shut-off fuel automatically.
      b. If mutually agreed settlement between the parties, the control sequence may wait the natural recovery during part-load in a certain period, and stop with fuel shut-off if the failure is not recovered according to the failed situation. If it is considered that recovering from failed situation, it may increase load of facility automatically or manually again.
   b) Emergency Stop
      a. The emergency stop must be performed automatically by the gas turbine /process plant protection equipment which is applicable according to the agreement with purchaser, although it is started by manual. This device operates directly the fuel shut-off valve which supplies fuel to gas turbine directly.
      b. The normal turning and stop sequence must continue following the emergency stop from time to time. The automatic re-start is not possible after the manual reset has been done.

(6) Halt by the fire and gas detection

1) The gas turbine must stop automatically by the auto-detection function when the serious failure such as fire or gas leakage is detected. This device must operate fuel shut-off valve and vent valve directly. It stops gas turbine immediately without minimum load or cooling operation.
2) If the gas leakage is found in the enclosure, the all electrical equipment which have not been certified for location-1 must turned off so that it does not an ignition source.
3) When detecting the gas leakage at the ventilation outlet (not at the ventilation inlet), the ventilation fan must continue operation for discharging the remaining gas from enclosure.
4) If the gas is detected at the ventilation inlet, the ventilation fan must be stopped immediately, since the highest potential sources of gas leakage outside the enclosure.

(7) Halt of Generation Facility

The equipment to prevent motoring of generator when closing the fuel shut-off valve on either gas turbine or generator in case for generation use. However, if the phase adjustment operation or the start-up by generator is designated, this does not apply.

(8) Shut-down of Mechanical Drive System

The equipment to cut off the follower automatically from the system that is used in there in order to prevent the rotation of follower or reverse flow during shut down.

(9) Ventilation and Purging

1) Purge of Gas Turbine Enclosure

   The launch control equipment of gas turbine must ensure enough automatic purge time to ensure safety of gas turbine and its downstream equipment. If there is no state regulation, the purge cycle shall be conducted by more than 3 times volume of the suction and exhaust system prior to the start of combustion, including chimney.
2) Purge of Gas Turbine

   When using a highly volatile liquid fuel such as naphtha or gas that density is larger than air, it is required special precautions. The preventive measures must include at least automatically actuated fuel discharge valve, isolation of fuel handling equipment, detector to detect hazardous atmosphere and liquid detector.
3) Special Precautions

   The purge and safety interlock must be incorporated into the automatic launch control unit sequence. It is capable to energize electrical equipments which are not certified for location -1 in the enclosure as long as the inside of enclosure is purged sufficiently and no gas is detected. The all instruments and electrical equipments which work before purge cycle or during purge operation must be authorized for location-1.

2-4. Main Valve

(1) The fuel control valve for speed control device must return to the closed position or lowest position, even in the event the gas turbine stopped due to any reason.

(2) Temperature Limits

The fuel control device must have the priority control function so that gas turbine rated combustion temperature or the fastest gas generator speed not to exceed the limit are likely to reach.

(3) Temperature Limit Stability

The temperature control device and the fuel control device must be capable to control temperature of gas turbine stably when the follower is driven in parallel with other follower; the gas turbine is driven according to the temperature setting in maximum limits for ambient conditions at that time.

(4) The manufacturer is able to apply limits to fuel control device as required, such as the LP gas generator spool speed, the HP gas generator spool speed, the rotation speed of power turbine, the outlet air temperature and pressure of compressor and the exit temperature of power turbine.

http://www.nakakita-s.co.jp/products/plant.html

http://www.controlsouthern.com/section.cfm?id=93&start=11&count=10

Article 41. Pressure relief device for gas turbine, etc.

1. The "**over-pressure**" stipulated in Article 41-1 of design technical regulation means the pressure which exceeds the maximum operation pressure in normal situation.

2. The "**appropriate pressure relief device**" stipulated in Article41-2 of design technical regulation means the appropriate safety valve or safety valve with pilot valve.

Article 42. Instrument equipment for gas turbine, etc.

1-1. The "**instrument device to monitor the operation status**" stipulated in Article42-1 of design technical regulation means the devices to measure following items-1 to item-5 for gas turbine which has bearings to apply lubrication oil, and to measure following item-1 to item -3 for gas turbine which has bearings to apply lubrication air.

(1) rotation speed of gas turbine

(2) discharge pressure of gas turbine compressor, "including the discharge pressure which is calculated by the method to calculate from measured rotation speed of gas turbine"

(3) inlet gas temperature of gas turbine, "including the temperature which is calculated by the method to calculate from measured inlet gas temperature"

(4) lubricating oil pressure at inlet of bearing

(5) lubricating oil temperature at outlet of bearing or metal temperature of bearing

1-2. Other Instrument Devices

Generally, it is recommended to measure and monitor items such as Fig-89 including above mentioned minimum monitoring equipment in order to monitor the normal operation of the gas turbine.

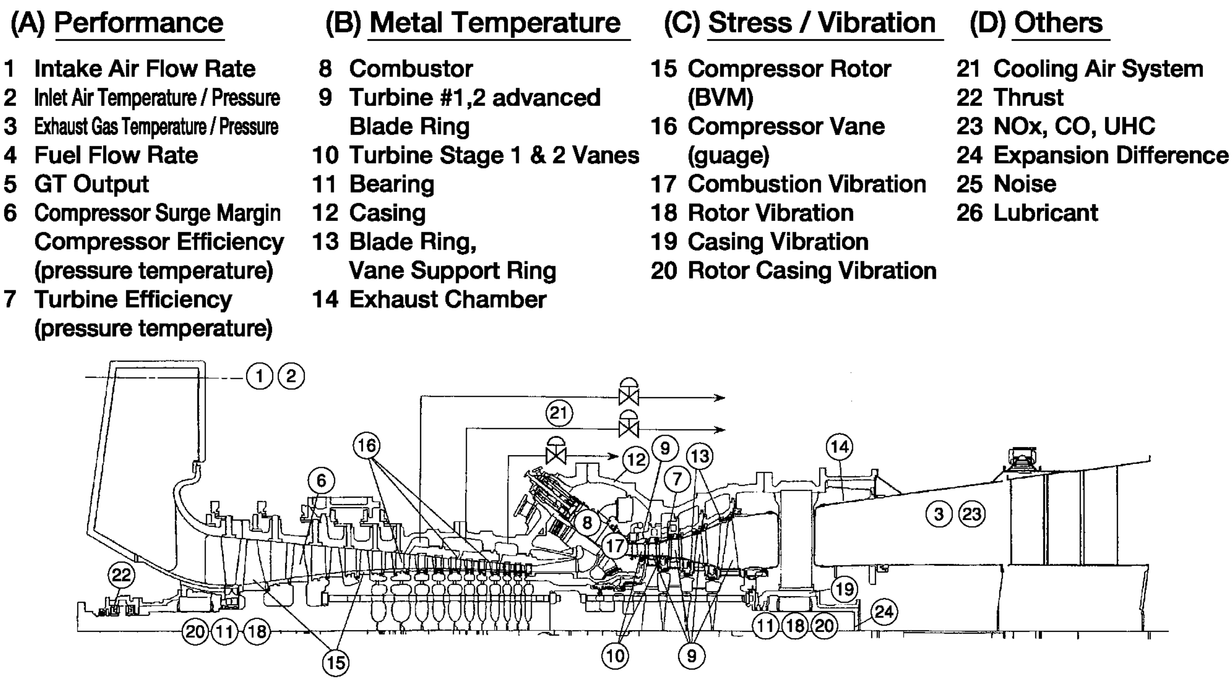


Fig- 90: Typical instrument monitoring items of gas turbine

Reference: P-6 of Literature “Development and in-house shop load test results of M701G2 gas turbine

(MHI Y. /Iwasaki and others): Literature for International Gas Turbine Congress 2003 Tokyo

Chapter-3. Reference International Technical Standards

The reference international standards for designing gas turbine are organized in Table-43.

Table- 43: Reference international standards

Number	Rev.	Title	Content
ISO 1925	2001	Mechanical vibration – Balancing-Vocabulary	—
ISO 1940-1	2003	Mechanical vibration -- Balance quality requirements for rotors in a constant (rigid) state -- Part 1: Specification and verification of balance tolerances	This gives specifications for rotors in a constant (rigid) state. It specifies balance tolerances, the necessary number of correction planes, and methods for verifying the residual unbalance. Recommendations are also given concerning the balance quality requirements for rotors in a constant (rigid) state, according to their machinery type and maximum service speed. These recommendations are based on worldwide experience. This is also intended to facilitate the relationship between the manufacturer and user of rotating machines, by stating acceptance criteria for the verification of residual unbalances.
ISO 1940-2	1997	Mechanical Vibration – Balance quality requirements of rigid rotors – Part-2: Balance errors	Detailed consideration of errors associated with balancing and verification of residual unbalance are given in ISO 1940-2.
ISO 2314	2009	GT-Acceptance tests	This applies to open-cycle gas-turbine power plants using combustion systems supplied with gaseous and/or liquid fuels as well as closed-cycle and semi-closed-cycle gas-turbine power plants. It can also be applied to gas turbines in combined cycle power plants or in connection with other heat-recovery systems. In cases of gas turbines using free-piston gas generators or special heat sources (for example synthetic gas of chemical processes, blast furnace gas), this International Standard can be used as a basis but suitable modifications are necessary. Acceptance tests of gas turbines with emission control and/or power augmentation devices that are based on fluid injection and/or inlet air treatment are also covered by this International Standard and it is necessary that they be considered in the test procedure, provided that such systems are included in the contractual scope of the supply subject to testing. This International Standard does not apply to emission testing, noise testing, vibration testing, performance of specific components of the gas turbine, performance of power augmentation devices and auxiliary systems, such as air inlet cooling devices, fuel gas compressors, etc., conduct test work aiming at development and research, adequacy of essential protective devices, performance of

Number	Rev.	Title	Content
			the governing system and protective systems, and operating characteristics (starting characteristics, reliability testing, etc.).
ISO 2017-1	2005	Mechanical vibration and shock-Resilient mounting systems – Part-1: Technical information to be exchanged for the application of isolation systems	This establishes requirements to ensure the appropriate exchange of information between users, manufacturers and suppliers of vibration sources and receivers regarding the application of isolation systems. The sources and the receivers can be machines, structures, people or sensitive equipment subjected to vibrations and shocks generated by machines, railways, road traffic and other external and internal sources where the vibrations are usually transmitted through the ground to a building. ISO 2017-1:2005 is applicable to the use of new products (source or receiver), and can also be applied to previously installed products when the user wishes to solve a newly arisen vibration problem.
ISO 2954	1975	Mechanical vibration of rotating and reciprocating machinery -- Requirements for instruments for measuring vibration severity	This states the requirements for measuring devices if inaccuracies of measurement are not to exceed a specified value. Devices covered give direct indication or recording of root-mean-square vibration velocity.
ISO 3448	1992	Industrial liquid lubricants -- ISO viscosity classification	This establishes a system of viscosity classification for industrial liquid lubricants and related fluids including mineral oils used as lubricants, hydraulic fluids, and electrical oils and for other applications. The usual method for kinematic-viscosity determination is that specified in ISO 3104. There may be some pure chemicals and naturally occurring products, used as lubricants, which will not fall within the classification.
ISO 3977-1	2007	GT-Procurement –Part-1: General introduction & definitions	—
ISO 3977-2	2007	GT-Procurement –Part-2: Standard reference conditions and ratings	—
ISO 3977-3	2004	GT-Procurement –Part-3: Design requirements	This covers the design requirements for the procurement of all applications of gas turbines and gas turbine systems, including gas turbines for combined cycle systems and their auxiliaries, by a purchaser from a packager. It also provides assistance and technical information to be used in the procurement. It is not intended to deal with local or national legislative requirements with which the installation may be required to conform. This is applicable to simple-cycle, combined-cycle and regenerative-cycle gas turbines working in open systems. It is not applicable to gas turbines used to propel aircraft, road construction and earth moving machines, agricultural and industrial types of tractors and road vehicles. In cases of gas turbines using special heat sources (for example, chemical process,

Number	Rev.	Title	Content
			nuclear reactors, furnace for a super-charged boiler), ISO 3977-3:2004 provides a basis.
ISO 3977-4	2007	GT-Procurement –Part-4: Fuels and environment	This provides guidelines for procurement of gas turbines with consideration of the fuel quality and of the environmental performance. Guidance is given to both the packager and purchaser on what information should be provided with regard to the fuel used by a gas turbine, and with regard to the type of information necessary to quantify the expected environmental impact. Fuel specifications are referenced but not provided.
ISO 3977-5	2006	GT-Procurement –Part-5: Applications for petroleum and natural gas industries	—
ISO/DIS 3977-6	2000	GT-Procurement –Part-6: Combined-cycles	—
ISO 3977-7	2007	GT-Procurement –Part7: Technical information	This specifies the information that needs to be submitted during the proposal and contract stages of a project for the entire scope of supply for which the packager will assume technical and contractual responsibility.
ISO 3977-8:	2007	GT-Procurement –Part8: Inspection, testing, installation and commissioning	This states the principles for systems and procedures to assure the integrity of a packager's product and services. It gives guidance on the inspection, testing, installation and commissioning required for the package and packaged equipment. It outlines the responsibilities between the purchaser and packager for inspection, coordination, reporting and recording.
ISO 3977-9	2004	GT-Procurement –Part9: Reliability, availability, maintainability and safety (RAMS)	—
ISO 4261	1993	Petroleum products -- Fuels (class F) -- Specifications of gas turbine fuels for industrial and marine applications	This sets out the properties of fuels at the time and place of transfer of custody to the user. Does not cover requirements for gas turbine fuels for aviation use. Further information and recommendations for the quality of the fuel entering the turbine combustion chambers (trace metal limits) are provided in annex B. The terminology used and the test methods referred to in these specifications are presented in annex C.
ISO 5348	1998	Mechanical vibration and shock-Mechanical mounting of accelerometers	—
ISO 6249	1999	Petroleum products -- Determination of thermal oxidation stability of gas turbine fuels -- JFTOT method	—
ISO 7919-1	1996	Mechanical vibration of non-reciprocating machines -- Measurements on rotating shafts and evaluation criteria -- Part-1: General Guidelines	Mechanical vibration of non-reciprocating machines -- Measurements on rotating shafts and evaluation criteria -- Part 1: General guidelines
ISO 7919-2	2009	Mechanical vibration -- Evaluation of machine vibration by measurements on rotating shafts --Part-2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min,	Mechanical vibration -- Evaluation of machine vibration by measurements on rotating shafts -- Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min,

Number	Rev.	Title	Content
		1800 r/min, 3000 r/min and 3600 r/min	1 800 r/min, 3 000 r/min and 3 600 r/min
ISO 7919-3	1996	Part-3: Coupled industrial machines	Mechanical vibration -- Evaluation of machine vibration by measurements on rotating shafts -- Part 3: Coupled industrial machines
ISO 7919-4	2009	Part-4: Gas turbine sets	Mechanical vibration -- Evaluation of machine vibration by measurements on rotating shafts -- Part 4: Gas turbine sets with fluid-film bearings
ISO 8044	1999	Corrosion of metals and alloys -- Basic terms and definitions	—
ISO 8068	2006	Lubricants, industrial oils and related products (class L) -- Family T (Turbines) -- Specification for lubricating oils for turbines	This specifies the minimum requirements for turbine lubricants, as delivered. It specifies the requirements for a wide variety of turbines for power generation, including steam turbines, gas turbines, combined-cycle turbines with a common lubrication system and hydraulic (water driven) turbines. This International Standard does not specify the requirements for wind turbines, which are dealt with in ISO 12925-1. Whilst power generation is the primary application for turbines, steam and gas turbines can also be used to drive rotating equipment, such as pumps and compressors. The lubrication systems of these driven loads can be common to that of the turbine. Turbine installations incorporate complex auxiliary systems requiring lubrication, including hydraulic systems, gearboxes and couplings. Depending upon the design and configuration of the turbine and driven equipment, turbine lubricants can also be used in these auxiliary systems. This should be read in conjunction with ISO 6743-5, the classification of different turbine lubricant types. The lubricants considered in ISO 8068:2006 are mineral oils, synthetic lubricants (ester and polyalphaolefin types intended for high-temperature gas turbines), synthetic lubricants (ester and polyalphaolefin types, environmentally acceptable for use in hydraulic turbines) and fire-resistant phosphate-ester type lubricants.
ISO 8216-2	1986	Petroleum products -- Fuels (class F) -- Classification -- Part 2: Categories of gas turbine fuels for industrial and marine applications	This establishes the detailed classification, excluding aircraft fuels. Should be read in conjunction with ISO 8216-0. These fuels are for use in industrial gas turbines and gas turbines derived from aviation turbines that are used in static and marine applications. The classification includes only fuels that are liquid under atmospheric pressure and at their normal storage temperatures.
ISO 8569	1996	Mechanical vibration and shock-Measurement and evaluation of shock and vibration effects on sensitive equipment in buildings	—

Number	Rev.	Title	Content
ISO 9951	1993	Measurement of gas flow in closed conduits -- Turbine meters	This specifies dimensions, ranges, construction, performance, calibration and output characteristics of the turbine meters. Also deals with installation conditions, leakage testing und pressure testing and provides a series of informative annexes A to E including recommendations for use, field checks, and perturbations of the fluid flowing. In many countries, some or all of the items covered are subject to mandatory regulations imposed by the laws of these countries. Where conflicts exist, the mandatory regulations shall prevail.
ISO 10436	2003	Petroleum, petrochemical and natural gas industries -- Steam turbines -- Special-purpose applications	This specifies requirements and gives recommendations for the design, materials, fabrication, inspection, testing and preparation for shipment of special-purpose steam turbines. It also covers the related lube-oil systems, instrumentation, control systems and auxiliary equipment. It is not applicable to general-purpose steam turbines, which are covered in ISO 10436.
ISO 10438-1	2007	Petroleum, petrochemical and natural gas industries -- Lubrication, shaft-sealing and control-oil systems and auxiliaries -- Part 1: General requirements	This Specifies general requirements for lubrication systems, oil-type shaft-sealing systems, dry-gas face-type shaft-sealing systems and control-oil systems for general- or special-purpose applications. General-purpose applications are limited to lubrication systems. These systems can serve equipment such as compressors, gears, pumps and drivers
ISO 10438-2	2007	Petroleum, petrochemical and natural gas industries -- Lubrication, shaft-sealing and control-oil systems and auxiliaries -- Part 2: Special-purpose oil systems	In conjunction with ISO 10438-1, this specifies requirements for oil systems for special-purpose applications. These oil systems can provide lubrication oil, seal oil or both. These systems can serve equipment such as compressors, gears, pumps and drivers.
ISO 10438-3	2007	Petroleum, petrochemical and natural gas industries -- Lubrication, shaft-sealing and control-oil systems and auxiliaries -- Part 3: General-purpose oil systems	In conjunction with ISO 10438-1, this specifies requirements for oil systems for general-purpose applications. These oil systems can provide lubrication oil, but not seal oil and can serve equipment such as compressors, gears, pumps and drivers.
ISO 10438-4	2007	Petroleum, petrochemical and natural gas industries -- Lubrication, shaft-sealing and control-oil systems and auxiliaries -- Part 4: Self-acting gas seal support systems	In conjunction with ISO 10438-1, this specifies requirements for support systems for self-acting gas seals (dry gas seals), for example as described in ISO 10439 and ISO 10440-1. These systems can serve equipment such as compressors, gears, pumps and drivers.
ISO 10441	2007	Petroleum, petrochemical and natural gas industries -- Flexible couplings for mechanical power transmission -- Special-purpose applications	This specifies the requirements for couplings for the transmission of power between the rotating shafts of two machines in special-purpose applications in the petroleum, petrochemical and natural gas industries. Such applications are typically in large and/or high speed machines, in services that can be required to operate continuously for extended periods, are often unspared and are critical to the continued operation of the

Number	Rev.	Title	Content
			installation. By agreement, it can be used for other applications or services. Couplings covered by ISO 10441-2007 are designed to accommodate parallel (or lateral) offset, angular misalignment and axial displacement of the shafts without imposing unacceptable mechanical loading on the coupled machines. It is applicable to gear, metallic flexible element, quill shaft and torsionally resilient type couplings. This covers the design, materials of construction, manufacturing quality, inspection and testing of special-purpose couplings. This does not define criteria for the selection of coupling types for specific applications. This is not applicable to other types of couplings, such as clutch, hydraulic, eddy-current, rigid, radial spline, chain and bellows types.
ISO 10442	2002	Petroleum, chemical and gas service industries -- Packaged, integrally geared centrifugal air compressors	This specifies requirements and gives recommendations for the design, materials, fabrication, inspection, testing and preparation for shipment of constant-speed, packaged, integrally geared centrifugal air compressors, including their accessories, for use in the petroleum, chemical and gas service industries. It is also applicable to gas services other than air that are non-hazardous and non-toxic. It is not applicable to machines that develop a pressure rise of less than 35 kPa above atmospheric pressure, which are classed as fans or blowers.
ISO 10494	2008	GT& GT sets-Measurement of emitted airborne noise-Engineering/survey method	This specifies methods for measuring the sound pressure levels on a measurement surface enveloping a source, and for calculating the sound power level produced by the source. Gives requirements for the test environment and instrumentation, as well as techniques for obtaining the surface sound pressure level from which the A-weighted sound power level of the source and octave or one-third-octave band sound power levels are calculated. This method may be used to perform acceptance tests
ISO 10814	1996	Mechanical vibration -- Susceptibility and sensitivity of machines to unbalance	This gives methods for determining machine vibration sensitivity to unbalance and provides evaluation guidelines. Makes recommendations on how to apply the numerical sensitivity values in some particular cases.
ISO 10816-1	1995	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts --Part-1: General Guidelines	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 1: General guidelines
ISO 10816-2	2009	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts --Part-2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600

Number	Rev.	Title	Content
		3600 r/min	r/min
ISO 10816-3	1998	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part-3: Industrial machines with normal power above 15kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ
ISO 10816-4	2009	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part-4: Gas turbine sets excluding aircraft derivatives	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 4: Gas turbine sets with fluid-film bearings
ISO 10816-5	2000	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts --Part-5: Machines set in hydraulic power generating and pumping plants	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 5: Machine sets in hydraulic power generating and pumping plants
ISO 10816-6	1995	Mechanical vibration- Evaluation of Machine vibration by measurements on non-rotating parts-Part-6: Reciprocating machines with power ratings above 100 kW	This specifies the general conditions and procedures for the measurement and evaluation of vibration, using measurements made on the non-rotating parts of machines with power ratings above 100 kW. Typical examples of application are marine propulsion engines, engines in diesel generator sets, gas compressors and engines for diesel locomotives. Does not apply to machines installed in road vehicles.
ISO 11042-1	2006	GT-Exhaust gas emission-Part-1: Measurement & evaluation	This contains the methods used for the measurement and evaluation of the emission of the exhaust gases from gas turbines and defines appropriate emission terms. Presents requirements for the test environment and instrumentation as well as the accuracy of measurement and correction of data. Does not apply to gas turbines used in aircraft.
ISO 11042-2	2006	GT-Exhaust gas emission-Part-2: Automated emission monitoring	This establishes the monitoring programme and the requirements for the selection and operation of hardware to be used for continuous gas emission measurements. Monitors the concentration and absolute magnitude of specified emissions in the exhaust gas as well as related gaseous components. Requires that the following parameters be continuously monitored: emissions, diluents gases (oxygen, carbon dioxide), exhaust gas flow, fuel consumption and gas turbine performance.
ISO 11086	2006	GT-Vocabulary	This gives terms and definitions used in the field of gas turbines. It applies to open-cycle gas turbines (using normal combustion systems), closed-cycle and semi-closed-cycle and combined-cycle gas turbines.
ISO 11342	1998	Mechanical vibration -- Methods and criteria for the mechanical balancing of flexible rotors	—
ISO 13691	2001	Petroleum and natural gas industries -- High-speed special-purpose gear units	—
ISO 13709	2009	Centrifugal pumps for petroleum, petrochemical and natural gas industries	This specifies requirements for centrifugal pumps, including pumps running in reverse as hydraulic power recovery turbines, for use

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			in petroleum, petrochemical and gas industry process services. This is applicable to overhung pumps, between-bearings pumps and vertically-suspended pumps
ISO 14661	2000	Thermal Turbines for Industrial Applications (Steam Turbines, Gas Expansion Turbines)	—
ISO 19860	2008	GT-Condition and trend monitoring system requirements for gas turbine installations	This applies to data-acquisition and trend-monitoring systems for gas turbine installations and associated systems. ISO 19860:2005 classifies and defines monitoring systems and their technical terms and establishes a system for conversion and validation of measured quantities in order to enable a comparison of the various systems, their features and their performances.
ISO 21789	2009	Gas turbine applications - safety	This covers the safety requirements for gas turbine applications using liquid or gaseous fuels and the safety-related control and detection systems and essential auxiliaries for all types of open cycles (simple, combined, regenerative, reheat, etc.) used in onshore and offshore applications including floating production platforms.
ISO 22266	2009	Mechanical vibration -- Torsional vibration of rotating machinery -- Part 1: Land-based steam and gas turbine generator sets in excess of 50 MW	This provides guidelines for applying shaft torsional vibration criteria, under normal operating conditions, for the coupled shaft system and long blades of a turbine generator set. In particular, these apply to the torsional natural frequencies of the coupled shaft system at line and twice-line frequencies of the electrical network to which the turbine generator set is connected. In the event that torsional natural frequencies do not conform to defined frequency margins, other possible actions available to vendors are defined.
ANSI/API 670	1993	Vibration, Axial-Position, and Bearing-Temperature Monitoring Systems	This provides a purchase specification to facilitate the manufacture, procurement, installation, and testing of vibration, axial position, and bearing temperature monitoring systems for petroleum, chemical, and gas industry services. Covers the minimum requirements for monitoring radial shaft vibration, casing vibration, shaft axial position, and bearing temperatures. It outlines a standardized monitoring system and covers requirements for hardware (sensors and instruments), installation, testing, and arrangement. Standard 678 has been incorporated into this edition of Standard 670.
IEC 60034-1	2010	Rotating electrical machines - Part 1: Rating and performance	This is applicable to all rotating electrical machines except those covered by other IEC standards, for example, IEC 60349. Machines within the scope of this standard may also be subject to superseding, modifying or additional requirements in other publications, for example, IEC 60079 and IEC 60092. The changes with respect to the previous edition are as follows:

Number	Rev.	Title	Content
			- clarification of water coolant temperature, - recognition of IE code, - clarification of the term "tolerances".
IEC 60034-3	2007	Rotating electrical machines - Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines	This applies to three-phase synchronous generators, having rated outputs of 10 MVA and above driven by steam turbines or combustion gas turbines. Provides common requirements as well as specific requirements for air, hydrogen or liquid cooled synchronous generators and supplements the basic requirements given in IEC 60034-1. Gives also the precautions to be taken when using hydrogen cooled generators. The scope of this new edition has been limited with respect to the previous edition
IEC 60045-1	1991	Steam Turbines- Part-1: Specifications	This applies to steam turbines driving generators for electrical power services. Includes provisions relevant to turbines for other applications. Enables a prospective purchaser to be aware of the available options and alternatives and to explain his technical requirements to suppliers. Replaces IEC 60045 (1970).
IEC 61064	1991	Acceptance tests for steam turbine speed control systems	This contains recommendations for the conduct of tests of speed control systems of steam turbines. Applies primarily to constant speed steam turbines but may be applied where appropriate for other types of turbines. The purpose of the tests described in this publication is to verify the criteria guaranteed by the manufacturer and to check compliance with IEC 60045-1.
IEC 60079-0	2007	Explosive atmospheres - Part 0: Equipment - General requirements	This specifies the general requirements for construction, testing and marking of electrical equipment and Ex Components intended for use in explosive atmospheres. Electrical equipment complying with this standard is intended for use in hazardous areas in which explosive gas atmospheres, caused by mixtures of air and gases, vapors or mists, exist under normal atmospheric conditions. The standard atmospheric conditions (relating to the explosion characteristics of the atmosphere) under which it may be assumed that electrical equipment can be operated are:
IEC 60079-1	2007	Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d"	This contains specific requirements for the construction and testing of electrical apparatus with the type of protection flameproof enclosure 'd', intended for use in explosive gas atmospheres. This edition contains significant technical changes with regard to the previous edition. The contents of the corrigendum of September 2008 have been included in this copy.
IEC 60079-2	2007	Explosive atmospheres - Part 2: Equipment protection by pressurized enclosures "p"	This part of IEC 60079 contains the specific requirements for the construction and testing of electrical apparatus with pressurized enclosures, of type of protection "p", intended for use in explosive gas atmospheres. It specifies requirements for

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			pressurized enclosures containing a limited release of a flammable substance. The significant changes with respect to the previous edition are the introduction of the "Equipment protection level concept".
IEC 60034-3	2007	Rotating electrical machines - Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines	This applies to three-phase synchronous generators, having rated outputs of 10 MVA and above driven by steam turbines or combustion gas turbines. Provides common requirements as well as specific requirements for air, hydrogen or liquid cooled synchronous generators and supplements the basic requirements given in IEC 60034-1. Gives also the precautions to be taken when using hydrogen cooled generators. The scope of this new edition has been limited with respect to the previous edition.
IEC 60079-5	2007	Explosive atmospheres - Part 5: Equipment protection by powder filling "q"	This contains specific requirements for the construction, testing and marking of electrical equipment, parts of electrical equipment and Ex components in the type of protection powder filling "q", intended for use in explosive gas atmospheres. The significant changes with respect to the previous edition are: all requirements for third-party certification removed; requirements for external connections added; all requirements for cable glands deleted as they have been transferred to 60079-0; specific requirements for cells and batteries introduced; added relaxation requirements on required faults for fuse-protected equipment and added requirements for instructions.
IEC 60079-6	2007	Explosive atmospheres - Part 6: Equipment protection by oil immersion "o"	This part of IEC 60079 specifies the requirements for the construction and testing of oil-immersed electrical equipment, oil-immersed parts of electrical equipment and Ex components in the type of protection oil immersion "o", intended for use in explosive gas atmospheres. The significant changes with respect to the previous edition are: all requirements for third-party certification removed; added requirements for external connections; collected all marking requirements in the marking clause, and added requirements for instructions.
IEC 60079-7	2006	Explosive atmospheres - Part 7: Equipment protection by increased safety "e"	This part of IEC 60079 specifies the requirements for the design, construction, testing and marking of electrical apparatus with type of protection increased safety "e" intended for use in explosive gas atmospheres. This standard applies to electrical apparatus where the rated voltage does not exceed 11 kV r.m.s. a.c. or d.c. Additional measures are applied to ensure that the apparatus does not produce arcs, sparks, or excessive temperatures in normal operation or under specified abnormal conditions.
IEC 60079-10-1	2008	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres	This is concerned with the classification of areas where flammable gas or vapor or mist hazards may arise and may then be used as a

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			basis to support the proper selection and installation of equipment for use in a hazardous area. It is intended to be applied where there may be an ignition hazard due to the presence of flammable gas or vapor, mixed with air under normal atmospheric conditions, but it does not apply to a) mines susceptible to firedamp;
IEC 60079-10-2	2009	Explosive atmospheres - Part 10-2: Classification of areas - Combustible dust atmospheres	This is concerned with the identification and classification of areas where explosive dust atmospheres and combustible dust layers are present, in order to permit the proper assessment of ignition sources in such areas. The principles of this standard can also be followed when combustible fibers or flying may cause a hazard. This standard is intended to be applied where there can be a risk due to the presence of explosive dust atmospheres or combustible dust layers under normal atmospheric conditions. This first edition of IEC 60079-10-2 cancels and replaces the first edition of IEC 61241-10 published in 2004. The significant technical changes with respect to IEC 61241-10 are:
IEC 60079-11	2006	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i"	This specifies the construction and testing of intrinsically safe apparatus intended for use in an explosive gas atmosphere and for associated apparatus, which is intended for connection to intrinsically safe circuits which enter such atmospheres. The contents of the corrigendum of December 2006 have been included in this copy.
IEC 60079-13	2010	Explosive atmospheres - Part 13: Equipment protection by pressurized room "p"	This gives requirements for the design, construction, assessment and testing and marking of rooms protected by pressurization in: - a room located in an explosive gas atmosphere or explosive dust atmosphere hazardous area that does not include an internal source of a flammable substance; - a room located in an explosive gas atmosphere or explosive dust atmosphere hazardous area that includes an internal source of a flammable substance; - a room located in a non-hazardous area that includes an internal source of a flammable substance.
IEC 60079-14	2007	Explosive atmospheres - Part 14: Electrical installations design, selection and erection	This part of IEC 60079 contains the specific requirements for the design, selection and erection of electrical installations in hazardous areas associated with explosive atmospheres. Where the equipment is required to meet other environmental conditions, for example, protection against ingress of water and resistance to corrosion, additional methods of protection may be necessary. The method used should not adversely affect the integrity of the enclosure. The requirements of this standard apply only to the use of equipment under normal or near normal atmospheric conditions. The significant technical changes with respect to the previous edition are:

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			Equipment Protection Levels (EPLs) have been introduced and are explained in the new Annex I and dust requirements included from IEC 61241 14, Ed. 1.0.
IEC 60079-15	2010	Explosive atmospheres - Part 15: Equipment protection by type of protection "n"	This specifies requirements for the construction, testing and marking for Group II electrical equipment with type of protection, "n" intended for use in explosive gas atmospheres. This standard applies to electrical equipment where the rated voltage does not exceed 15 kV r.m.s. a.c. or d.c. This standard supplements and modifies the general requirements of IEC 60079-0, except as indicated in Table 1. Where a requirement of this standard conflicts with a requirement of IEC 60079-0, the requirement of this standard takes precedence. The significant technical changes with respect to the previous edition are as follows:
IEC/TR 60079-16	1990	Electrical apparatus for explosive gas atmospheres. Part 16: Artificial ventilation for the protection of analyzer (s) houses	This gives the general principles of protection by artificial ventilation. This publication has the status of a technical report.
IEC 60079-17	2007	Explosive atmospheres - Part 17: Electrical installations inspection and maintenance	This gives the general principles of protection by artificial ventilation. This publication has the status of a technical report
IEC 60079-18	2009	Explosive atmospheres - Part 18: Equipment protection by encapsulation "m"	This gives the specific requirements for the construction, testing and marking of electrical equipment, parts of electrical equipment and Ex components with the type of protection encapsulation "m" intended for use in explosive gas atmospheres or explosive dust atmospheres. This part applies only for encapsulated electrical equipment, encapsulated parts of electrical equipment and encapsulated Ex components where the rated voltage does not exceed 11 kV. The significant technical changes with respect to the previous edition are as follows:
IEC 60079-19	2010	Explosive atmospheres - Part 19: Equipment repair, overhaul and reclamation	This gives instructions, principally of a technical nature, on the repair, overhaul, reclamation and modification of equipment designed for use in explosive atmospheres; it is not applicable to maintenance, other than when repair and overhaul cannot be disassociated from maintenance, neither does it give advice on cable entry systems which may require a renewal when the equipment is re-installed. The significant technical changes with respect to the previous edition are:
IEC 60079-20-1	2010	Explosive atmospheres - Part 20-1: Material characteristics for gas and vapor classification - Test methods and data	This provides guidance on classification of gases and vapors. It describes a test method intended for the measurement of the maximum experimental safe gaps (MESG) for gas- or vapor-air mixtures under normal conditions of temperature and pressure so as to permit the selection of an appropriate group of equipment. The tabulated values of chemical and engineering properties of

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			substances are provided to assist engineers in their selection of equipment to be used in hazardous areas. This first edition of IEC 60079-20-1 cancels and replaces the first edition of IEC 60079-1-1(2002), the second edition of IEC 60079-4 (1975), its amendment 1(1995) and its complement: IEC 60079-4A (1970), the first edition of IEC/TR 60079-12 (1978) and the first edition of IEC 60079-20 (1996). It constitutes a technical revision.
IEC 60079-25	2010	Explosive atmospheres - Part 25: Intrinsically safe electrical systems	This contains the specific requirements for construction and assessment of intrinsically safe electrical systems, type of protection "i", intended for use, as a whole or in part, in locations in which the use of Group I, II or III apparatus is required. This standard supplements and modifies the general requirements of IEC 60079-0 and the intrinsic safety standard IEC 60079-11. Where a requirement of this standard conflicts with a requirement of IEC 60079-0 or IEC 60079-11, the requirement of this standard takes precedence. This standard supplements IEC 60079-11, the requirements of which apply to electrical apparatus used in intrinsically safe electrical systems. The installation requirements of Group II or Group III systems designed in accordance with this standard are specified in IEC 60079-14. The significant changes with respect to the previous edition are:
IEC 60079-26	2006	Explosive atmospheres - Part 26: Equipment with equipment protection level (EPL) Ga	This specifies the particular requirements for construction, test and marking for electrical equipment that provides equipment protection level (EPL) Ga. This electrical equipment, within the operational parameters specified by the manufacturer, ensures a very high level of protection that includes rare faults related to the equipment or two faults occurring independently of each other. The contents of the corrigendum of March 2009 have been included in this copy.
IEC 60079-27	2008	Explosive atmospheres - Part 27: Fieldbus intrinsically safe concept (FISCO)	—
IEC 60079-28	2006	Explosive atmospheres - Part 28: Protection of equipment and transmission systems using optical radiation	This explains the potential ignition hazard from equipment using optical radiation intended for use in explosive gas atmospheres. It also covers equipment, which itself is located outside but its emitted optical radiation enters such atmospheres. It describes precautions and requirements to be taken when using optical radiation transmitting equipment in explosive gas atmospheres. The contents of the corrigendum of March 2010 have been included in this copy.
IEC 60079-29-1	2007	Explosive atmospheres - Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases	This specifies general requirements for construction, testing and performance, and describes the test methods that apply to portable, transportable and fixed apparatus for the detection and measurement of

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			flammable gas or vapor concentrations with air. The apparatus, or parts thereof, are intended for use in potentially explosive atmospheres and in mines susceptible to firedamp. This first edition of IEC 60079-29-1 cancels and replaces the first edition of IEC 61779-1 to IEC 61779-5:1998 series and constitutes a technical revision with numerous changes with respect to the previous edition.
IEC 60079-29-2	2007	Explosive atmospheres - Part 29-2: Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen	This gives guidance on, and recommended practice for, the selection, installation, safe use and maintenance of electrically operated group II apparatus intended for use in industrial and commercial safety applications for the detection and measurement of flammable gases complying with the requirements of IEC 60079-29-1.This first edition of IEC 60079-29-2 cancels and replaces the first edition of IEC 61779-6:1999 and constitutes a technical revision with many changes with respect to the previous edition.
IEC 60079-29-4	2009	Explosive atmospheres - Part 29-4: Gas detectors - Performance requirements of open path detectors for flammable gases	This specifies performance requirements of equipment for the detection and measuring of flammable gases or vapors in ambient air by measuring the spectral absorption by the gases or vapors over extended optical paths, ranging typically from one meter to a few kilometers. Such equipment measures the integral concentration of the absorbing gas over the optical path in units such as LFL meter for flammable gases. This standard supplements and modifies the general requirements of IEC 60079-0. Where a requirement of this standard conflicts with a requirement of IEC 60079-0, the requirement of this standard shall take precedence. The contents of the corrigendum of August 2010 have been included in this copy.
IEC 60079-30-1	2007	Explosive atmospheres - Part 30-1: Electrical resistance trace heating - General and testing requirements	This specifies general and testing requirements for electrical resistance trace heaters for application in explosive gas atmospheres. The standard covers trace heaters that may comprise either factory- or field- (work-site) assembled units, and which may be series heating cables, parallel heating cables or heating pads and heating panels that have been assembled and/or terminated in accordance with the manufacturer's instructions.
IEC 60079-30-2	2007	Explosive atmospheres - Part 30-2: Electrical resistance trace heating - Application guide for design, installation and maintenance	This provides guidance for the application of electrical resistance trace heating systems in areas where explosive gas atmospheres may be present, with the exception of those classified as zone 0. It provides recommendations for the design, installation, maintenance and repair of trace heating equipment and associated control and monitoring equipment. It does not cover devices that operate by induction heating, skin effect heating or direct pipeline heating,

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			nor those intended for stress relieving.
IEC 60079-31	2008	Explosive atmospheres - Part 31: Equipment dust ignition protection by enclosure "t"	This is applicable to electrical equipment protected by enclosure and surface temperature limitation for use in explosive dust atmospheres. It specifies requirements for design, construction and testing of electrical equipment. This standard supplements and modifies the general requirements of IEC 60079-0. Where a requirement of this standard conflicts with a requirement of IEC 60079-0, the requirement of this standard shall take precedence. This first edition of IEC 60079-31 has been developed from the first edition of IEC 61241-1 (2004) which it now cancels and supersedes.
IEC 61241-0	2004	Electrical apparatus for use in the presence of combustible dust - Part 0: General requirements	This specifies general requirements for the design, construction, testing and marking of electrical apparatus protected by any recognized safeguard technique for use in areas where combustible dust may be present in quantities that could lead to a fire or explosion hazard. The application of electrical apparatus in atmospheres which may contain explosive gas as well as combustible dust, whether simultaneously or separately requires additional protective measures. The contents of the corrigendum of November 2005 have been included in this copy.
IEC 61241-2-1	1994	Electrical apparatus for use in the presence of combustible dust - Part 2: Test methods - Section 1: Methods for determining the minimum ignition temperatures of dust	This specifies two test methods for determining the minimum ignition temperatures of dust
IEC/ETC 61241-2-2	1993	Electrical apparatus for use in the presence of combustible dust - Part 2: Test methods - Section 2: Method for determining the electrical resistivity of dust in layers	This specifies a test method to determine, by application of a d.c. voltage, the electrical resistivity of a layer of dust. Is to be used in the design, construction, testing and application of electrical apparatus for use in the presence of combustible dust. This publication has the status of a technical report. The contents of the corrigendum of May 1994 have been included in this copy.
IEC 61241-2-3	1994	Electrical apparatus for use in the presence of combustible dust - Part 2: Test methods - Section 3: Method for determining minimum ignition energy of dust/air mixtures	This specifies a method of test to determine the minimum ignition energy of a dust/air mixture by an electrically generated high-voltage d.c. spark. This test method is intended to develop data to be used in deciding whether or not combustible dust/air mixtures are considered to be ignitable with respect to electrical discharge.
IEC 61241-4	2001	Electrical apparatus for use in the presence of combustible dust - Part 4: Type of protection "pD"	This gives requirements on the design, construction, testing and marking of electrical apparatus for use in combustible dust atmospheres in which a protective gas (air or inert gas), maintained at a pressure above that of the external atmosphere, is used to prevent the entry of dust which might otherwise lead to the formation of a combustible mixture within enclosures which do not contain a source of combustible dust.

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IEEE C50.14	1977	Requirement for Combustion Gas Turbine Driven Cylindrical Rotor Synchronous Generators	The requirements in this standard apply to 60 Hz open-ventilated air-cooled cylindrical rotor synchronous generators rated 10,000 kVA and above. All requirements and definitions, except as specifically covered in this standard, shall be in accordance with ANSI C50.10-1977 and C50.13-1977.
IEEE 67	2005	Requirement for Operation and Maintenance of Turbine Generator	This guide covers general recommendations for the operation, loading, and maintenance of turbine-driven synchronous generators that have cylindrical rotors.
ASME B133.1M	1983	Gas Turbine Technology	This provides a comprehensive, alphabetical list of technical terms pertinent to the B133 series of gas turbine procurement standards.
ASME B133.2	1977	Basic Gas Turbines	This presents and describes features that are desirable for the user to specify in order to select a gas turbine that will yield satisfactory performance, availability and reliability. The standard is limited to a consideration of the basic gas turbine including the compressor, combustion system and turbine.
ASME B133.3	1981	Procurement Standard for Gas Turbine Auxiliary Equipment	The purpose of this Standard is to provide guidance to facilitate the preparation of gas turbine procurement specifications. It is intended for use with gas turbines for industrial, marine, and electric power applications. This Standard covers auxiliary systems such as lubrication, cooling, fuel (but not its control), atomizing, starting, heating-ventilating, fire protection, cleaning, inlet, exhaust, enclosures, couplings, gears, piping, mounting, painting, and water and steam injection.
ASME B133.5	1978	Procurement Standard for Gas Turbine Electrical Equipment	This provides guidelines and criteria for specifying electrical equipment, other than controls, which may be supplied with a gas turbine. Much of the electrical equipment will apply only to larger generator drive installations, but where applicable this standard can be used for other gas turbine drives.
ASME B133.6	1978	Procurement Standard for Gas Turbine Rating and Performance	This provides guidelines for the ratings and performance of gas turbines that are developed by the manufacturer to match site conditions that are supplied by the user. When complete site conditions are unavailable, standard conditions may be used.
ASME B133.7M	1985	Gas Turbine Fuels	Gas turbines may be designed to burn either gaseous or liquid fuels, or both with or without changeover while under load. This Standard covers both types of fuel.
ASME B133.8	1977	Gas Turbine Installation Sound Emissions	This presents and describes features that are desirable for the user to specify in order to select a gas turbine that will yield satisfactory performance, availability and reliability. The standard is limited to a consideration of the basic gas turbine including the compressor, combustion system and turbine.

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ASME B133.10	1981	Procurement Standard for Gas Turbine Information to be supplied by user and Manufacturer	This provides a means for rapid communication between the user and manufacturer relative to requests for proposals by the user and the tendering of proposals by the manufacturer. The use of the pre-structured forms contained in this Standard will facilitate the preparation of this information and ensure consistency of submission by the various manufacturers who may be requested to submit proposals. The forms cross-reference the appropriate information contained in the other sections of the Gas Turbine Procurement Standard.
ASME B133.11	1982	Procurement Standard for Gas Turbine Preparation for shipping and Installation	This provides a review of shipping and installation items that should be considered in the preparation of procurement specifications. The shipping sections of this Standard provide guidelines which the user may find helpful in preparing a specification applicable to his specific requirements. In the preparation of the installation and startup sections, it was found that there are a variety of suitable methods to achieve the same ultimate end, as employed by the various manufacturers. Because of this diversity, the user is advised to consult with the manufacturer on his use and interpretation of this Standard. This Standard should be useful in providing guidelines for items that should be included in the user's more detailed specifications, applicable to his specific requirements.
ASME B133.12	1981	Procurement Standard for Gas Turbine Maintenance and Safety	This provides a basis for the exchange of maintenance information between the gas turbine user and manufacturer to permit the user to evaluate and compare bids and to advise the manufacturer of user preferences and requirements regarding maintenance. Information is to be exchanged in the specific areas of maintenance activities and schedules and support services
ASME B133.16	2000	Procurement Standard for Gas Turbine Marine Applications	This provides guidance and criteria for gas turbine systems used in marine applications. It supplements the general gas turbine procurement standards presented in ASME's B133 series. In utilizing this procurement standard, the user should ensure that only those requirements considered necessary for his/her application are utilized. This is a general document and its intent is to cover most marine applications. Therefore, there is an inclusion of data for most varied applications, which may not be applicable to a specific application. Marine applications are defined as gas turbines serving as prime movers for:
ASME PTC22	2005	Gas Turbine: Performance Test Codes	This Code provides directions and rules for conduct and report of results of thermal performances tests for open cycle gas turbine power plants and gas turbine engines, hereafter referred to as gas turbines. The object is to determine the thermal

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			performance of the gas turbine when operating at test conditions, and correcting these test results to specified reference conditions. This Code provides explicit procedures for the determination of correct power output, corrected heat rate (efficiency), corrected exhaust flow, energy, and temperature. Tests may be designated to satisfy different goals, including absolute performance and comparative performance. It is the intent of the Code to provide results with the highest level of accuracy consistent with the best engineering knowledge and practice in the gas turbine industry. In planning the test, an uncertainty analysis must demonstrate that the proposed instrumentation and measurement techniques meet the requirements of the Code.
ASME PTC19.10	1981	Fuel and Exhaust Gas Analysis—Part10	This specifies methods, apparatus, and calculations which are used in conjunction with Performance Test Codes to determine quantitatively, the gaseous constituents of exhausts resulting from stationary combustion sources. The gases covered by this Document are oxygen, carbon dioxide, carbon monoxide, nitrogen, sulfur dioxide, sulfur trioxide, nitric oxide, nitrogen dioxide, hydrogen sulfide, and hydrocarbons. Stationary combustion sources include steam generators, gas turbines, internal combustion engines, incinerators, etc. Included are instrumental methods as well as (normally, wet chemical) methods. The instrumental methods include instruments used for non-continuous or continuous sampling using extractive samples and in-situ type instruments that require no sampling system.
ASTM D2880-03	2010	Standard Specification for Gas Turbine Fuel Oil	This specifies specification for gas turbine, excepting gas turbines used in aircraft, for the guidance of interested parties such as turbine manufacturers and. . .
API 614	2005	Lubrication, Shaft-sealing and Control-oil Systems and Auxiliaries	This specifies general requirements for lubrication systems, oil-type shaft-sealing systems, dry gas face-type shaft-sealing systems and control-oil systems for general- or special-purpose applications. General purpose applications are limited to lubrication systems. These systems can serve equipment such as compressors, gears, pumps and drivers. This part of ISO 10438 is intended to be used in conjunction with ISO 10438-2, ISO 10438-3 or ISO 10438-4, as appropriate.
API 616	2011	Gas Turbine for the Petroleum, Chemical, and Gas Industry Services	This covers the minimum requirements for open, simple, and regenerative-cycle combustion gas turbine units for services of mechanical drive, generator drive, or process gas generation. All auxiliary equipment required for operating, starting, controlling, and protecting gas turbine units are either discussed directly in this standard or referred to in this standard through references to other

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			publications. Specifically, gas turbine units that are capable of firing gas or liquid or both are covered by this standard. This standard covers both industrial and aero-derivative gas turbines.
API 616 Datasheets	2000	Datasheets for API Standard 616, Gas Turbine for the Petroleum, Chemical, and Gas Industry Services	This is a .zip file containing Microsoft Excel Spreadsheets relating to API Standard 616.
API 670	2011	Machinery Protection Systems	This covers the minimum requirements for a machinery protection system measuring radial shaft vibration, casing vibration, shaft axial position, shaft rotational speed, piston rod drop, phase reference, over-speed, and critical machinery temperatures (such as bearing metal and motor windings). It covers requirements for hardware (transducer and monitor systems), installation, documentation, and testing.
API 4158	2008	Development of Research Techniques for Determining the Oxidative Stability of Aircraft Gas Turbine Fuels	The objective of the CRC program described herein was to develop a research technique for determining the oxidative stability (deposit-forming potential) of aircraft gas turbine fuels, the resulting technique to be less complicated and more precise than the Standard Method of Test for Thermal Stability as defined in ASTM Method D1660.
API 4234	2006	An Investigation of Three Synthetic Gas Turbine Lubricants for Oil Aeration and Forming Tendencies	During the past few years, there have been Incidents with aviation gas turbine engines in which the Standard ASTM Designation Test 0892-63 did not correlate properly with engine experience relative to oil aeration or foaming tendencies. It was desired to develop a dynamic test with parameters which simulated the air entrainment and foaming conditions of a modern aircraft gas turbine engine. Participants on the Sub-Panel had developed dynamic testers for their own particular use and volunteered to evaluate three synthetic gas turbine lubricants. The lubricants selected were identified as RAO-19-67, RAO-20-67, and RAO-27-70, and represented a low foam, high foam, and medium to marginal foam lubricant, respectively. These oils were selected from previous dynamic foam tests and were not related to engine service experience. ASTM Method D892-72 - "Foaming Characteristics of Lubricating Oils," is a specification test for aviation oils.
API RP 11PGT	2005	Packaged Combustion Gas Turbines	This recommended practice is intended to cover the minimum requirements for a complete self-sufficient packaged combustion gas turbine prime mover with or without driven equipment for onshore/offshore oil and gas production services
DIN 4341	1979	Gas Turbine Acceptance Tests	—
DIN 4341-1	1979	Gas Turbine Acceptance Tests	—
DIN 4342	1979	Gas Turbines: Standard Reference	—

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		Conditions Standard Power and Performance Data	
DIN EN ISO 21789	2009	Gas Turbine Applications-Safety	This covers the safety requirements for gas turbine applications using liquid or gaseous fuels and the safety-related control and detection systems and essential auxiliaries for all types of open cycles (simple, combined, regenerative, reheat, etc.) used in onshore and offshore applications including floating production platforms.
DIN ISO/CD 19859		Gas Turbine Applications-Requirements for Power Generation	Under development, target publication date: 2014/04/01
DIN ISO/NP 4261		Petroleum Products - Fuels (class F) - Specification of Gas Turbine fuels for Industrial and Marine Applications	—
ISO/TC 192	2010	Gas Turbines	Standardization in the field of all aspects of gas turbine design, application, installation, operation and maintenance, including simple turbine cycles, combined cycle systems, definitions, procurement, acceptance, performance, environment (on the gas turbine itself and the external environment) and methods of test. ISO / TC 192 is responsible for preparing horizontal standards for all types of gas turbines. Work on aero gas turbine engines shall be undertaken in liaison with those technique committees having the primary responsibility.
ISO/TC 192/WG10		Gas Turbine Safety	—
ISO/TC 192/WG4		Joint TC192-TC67/SC6 WG: Gas Turbine	—
ISO/TC 28/SC4/WG5		Gas Turbine Fuels	—
ASTM D4241-83	2003	Standard Practice for Design of Gas Turbine Generator Lubricating Oil Systems (Withdrawn 2008)	1 This practice covers the design of lubricating oil systems for gas turbine driven generator units 1000 kW and larger. 1.1.1 The lubricating oil system is defined as that assembly which utilizes and circulates the turbine generator lubricating oil and furnishes pressurized oil for control and seal functions.
NFPA 37	2010	Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines	This establishes criteria for minimizing the hazards of fire during the installation and operation of stationary combustion engines and gas turbines.
NFPA 56		Standard for the Fire and Explosion Prevention During Cleaning and Purging of Flammable Gas Piping Systems	This is being processed as a Provisional Standard to ensure prompt dissemination of new safety criteria per ANSI's Essential Requirements. See the Next Edition tab for further information along with the Standards Council Decision No. 11-3, Agenda Item 11-3-21
NFPA 59A	2009	Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)	This shall apply to the following: (1) Facilities that liquefy natural gas (2) Facilities that store, vaporize, transfer, and

Number	Rev.	Title	Content
			handle liquefied natural gas (LNG) (3) The training of all personnel involved with LNG (4) The design, location, construction, maintenance, and operation of all LNG facilities 1.1.2 This standard shall not apply to the following: (1) Frozen ground containers (2) Portable storage containers stored or used in buildings (3) All LNG vehicular applications, including fueling of LNG vehicles
NFPA 85	2011	Boiler and Combustion Systems Hazards Code	This shall apply to single burner boilers, multiple burner boilers, stokers, and atmospheric fluidized-bed boilers with a fuel input rating of 3.7 MWt (12.5 million Btu/hr) or greater, to pulverized fuel systems, to fired or unfired steam generators used to recover heat from combustion turbines [heat recovery steam generators (HRSGs)], and to other combustion turbine exhaust systems. 1.1.1 This code shall cover design, installation, operation, maintenance, and training. 1.1.2 This code shall cover strength of the structure, operation and maintenance procedures, combustion and draft control equipment, safety interlocks, alarms, trips, and other related controls that are essential to safe equipment operation. 1.1.3 Coordination of the design and operating procedures of the boiler furnace or HRSG system and any flue gas cleanup systems downstream of the postcombustion gas passes shall be required. Such coordination shall include requirements for ensuring a continuous flow path from the combustion air inlet through the stack.
NFPA 91	2010	Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids	This provides minimum requirements for the design, construction, installation, operation, testing, and maintenance of exhaust systems for air conveying of vapors, gases, mists, and noncombustible particulate solids except as modified or amplified by other applicable NFPA standards. 1.1.2 This standard does not cover exhaust systems for conveying combustible particulate solids that are covered in other NFPA standards (see A.1.1).
NFPA 329	2010	Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases	This provides methods for responding to fire and explosion hazards resulting from the release of a flammable or combustible liquid, gas, or vapor that can migrate to a subsurface structure. Although this recommended practice is intended to address only fire and explosion hazards, other authorities should be consulted regarding the environmental and health impacts and other hazardous conditions of such releases. This recommended practice outlines options for detecting and investigating the source of a release, for mitigating the fire and explosion hazards resulting from the release, and for tracing the release back to its source. The options outlined in this recommended practice are not intended to be, nor should

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			they be considered to be, allinclusive or mandatory in any given situation. If better or more appropriate alternative methods are available, they should be used. The procedures outlined in this recommended practice can apply to hazardous substances other than flammable and combustible liquids that might have adverse human health effects. However, the physical characteristics of the specific hazardous substance released must be understood before any action is taken
NFPA 497	2008	Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas	This applies to those locations where flammable gases or vapors, flammable liquids, or combustible liquids are processed or handled; and where their release into the atmosphere could result in their ignition by electrical systems or equipment. 1.1.2 This recommended practice provides information on specific flammable gases and vapors, flammable liquids, and combustible liquids whose relevant combustion properties have been sufficiently identified to allow their classification into the groups established by NFPA 70, National Electrical Code (NEC), for proper selection of electrical equipment in hazardous (classified) locations. The tables of selected combustible materials contained in this document are not intended to be all-inclusive. 1.1.3 This recommended practice applies to chemical process areas. As used in this document, a chemical process area could be a large, integrated chemical process plant or it could be a part of such a plant. It could be a part of a manufacturing facility where flammable gases or vapors, flammable liquids, or combustible liquids are produced or used in chemical reactions, or are handled or used in certain unit operations such as mixing, filtration, coating, spraying, and distillation. 1.1.4 This recommended practice does not apply to situations that could involve catastrophic failure of or catastrophic discharge from process vessels, pipelines, tanks, or systems. 1.1.5 This recommended practice does not address the unique hazards associated with explosives, pyrotechnics, blasting agents, pyrophoric materials, or oxygen-enriched atmospheres that might be present.

Chapter-4. Reference Japanese Technical Standards

The reference Japanese industrial standards for designing gas turbine are organized in Table-44.

Table- 44: Reference Japanese standards

Number	Rev.	Title	Content
JIS B0128	2010	Glossary of terms for thermal power plants-gas turbine and auxiliary equipment	This defines the terms of gas turbine and ancillary equipments for power plant.
JIS B0153	2010	Glossary of terms used in mechanical vibration and shock	This stipulates terms and definitions for mechanical vibration and shock.
JIS B 0905	2007	Rotating machines ― Balance quality requirements of rigid rotors	This defines the good balance applying the concept of good valance in the eccentricity of modified surface of the rigid rotor.
JIS B0906	2008	Mechanical vibration ― Evaluation of machine vibration by measurements on non-rotating parts―General guidelines	This summarizes general guidelines about measurement and evaluation of the mechanical vibration that is measured at completed non-rotating parts such as bearing housing or non-reciprocating parts if applicable.
JIS B0907	2009	Mechanical Vibration of Rotating and Reciprocating Machinery ― Requirements for Instruments for Measuring Vibration Severity	This stipulates the requirement for severity of mechanical vibration.
JIS B0910	2009	Mechanical vibration of non-reciprocating machines ― Measurements on rotating shafts and evaluation criteria ― General guidelines	This is the basic standard summarized general guidelines about measurement and evaluation of mechanical vibration which were measured by rotating part of finished machine.
JIS B0911	2009	Mechanical vibration ― Susceptibility and sensitivity of machines to unbalance	This stipulates the method how to determine the sensitivity to mechanical vibrations against disproportionate.
JIS B8040	2005	Gas Turbine – Vocabulary	This stipulates basic terms about gas turbine used for power generation, mechanical drive for industrial, oil, gas industry, vessel, distributed energy system, combined cycle, cogeneration and emergency power.
JIS B8041	2000	Gas turbines―Acceptance tests	This is the comparison table corresponding with JIS and international standard.
JIS B8042-1	2001	Gas turbines-procurement―Part1 : General introduction and definitions	This stipulates regulations and standards for guidance primarily for descriptive information required when trying to produce gas turbine and related auxiliaries from the manufacture by the purchaser.
JIS B8042-2	2001	Gas turbines ― Procurement ― Part 2 : Standard reference conditions and ratings	This defines the standard rating conditions and a comparative measure of the gas turbine.
JIS B8042-3	2007	Gas turbines-Procurement-Part 3: Design requirements	This stipulates the necessary requirements for gas turbine design.
JIS B8042-4	2003	Gas turbines-Procurement-Part 4: Fuels and environment	This mainly stipulates guidelines for the provision of technical information on fuel for gas turbine.

Number	Rev.	Title	Content
JIS B8042-5	2001	Gas turbines — Procurement — Part 5 : Applications for petroleum and natural gas industries	This mainly stipulates guidelines for the provision of technical information on package type gas turbine used in drilling, production, refining and transportation of oil, natural gas.
JIS B8042-6	2003	Gas turbines - Procurement - Part 6: Combined cycles	This mainly stipulates guidelines for the provisions of technical information of combined cycle.
JIS B8042-7	2001	Gas turbines — Procurement — Part7 : Technical information	This stipulates about entire supply information which packager is believed responsible to submit as the technical and contractual one at the project estimate phases and contract execution phase.
JIS B8042-8	2001	Gas turbines — Procurement — Part 8 : Inspection, testing, installation and commissioning	This stipulates guidelines for the provisions of inspection, testing, installation and commissioning of package and its ancillary equipments, in addition, responsibility to be decided, adjusted, reported and recorded.
JIS B8042-9	2003	Gas turbines - Procurement - Part 9: Reliability, availability, maintainability and safety	This stipulates standard about information of reliability, availability, maintenanceability and safety which exchange between manufacturer, purchaser, consultant, organizations, and insurance companies.
JIS B8043-1	2000	Gas turbines—Exhaust gas emission—Part 1 : Measurement and evaluation	This stipulates measurement and evaluation method of exhaust emissions and terminology, in addition, stipulates test environment, measurement quality and correction of data.
JIS B8043-2	2000	Gas turbines—Exhaust gas emission—Part 2 : Automated emission monitoring	This stipulates the requirements for selection and operation of monitoring program carried out continuously over the long period and measurement device.
JIS B8044	2001	Gas turbines and gas turbine sets — Measurement of emitted airborne noise— Engineering/survey method	This stipulates how to calculate the sound power level generated from sound source and measuring method of sound level at measuring plane including sound source.
JIS B8045	2001	Gas turbines-Data acquisition and trend monitoring system requirements for gas turbine installations	This stipulates the condition monitoring equipment (data acquisition equipment and trend monitoring equipment)
JIS C60079-0	2010	Explosive atmospheres-Part 0: Equipment-General requirements	This stipulates common rules the general requirements for structure, testing and display of electrical device and Ex component which is used in explosive atmosphere.
JIS C60079-1	2008	Electrical apparatus for explosive gas atmospheres - Part 1: Flameproof enclosures "d"	This stipulates specific requirements for construction and testing of explosion-proof construction "d" which is used in explosive atmosphere.
JIS C60079-2	2008	Electrical apparatus for explosive gas atmospheres - Part 2: Pressurized enclosure "p"	This stipulates requirements for construction and testing of explosion-proof "p" which is used in explosive atmosphere, and for explosion-proof pressure regulation has limited release of flammable material in a container.

Number	Rev.	Title	Content
JIS C60079-6	2004	Electrical apparatus for explosive gas atmospheres - Part 6:Oil immersion "o"	This stipulates requirements for construction and testing of explosion-proof construction "o" of oil filled electric equipments and its parts or Ex. component which may be hazardous by flammable gases or vapors.
JIS C60079-7	2008	Electrical apparatus for explosive gas atmospheres - Part 7: Increased safety "e"	This stipulates specific requirements for design, construction, testing and display of explosion-proof "e" of electric devices which is used in explosive atmosphere.
JIS C60079-10	2008	Electrical apparatus for explosive gas atmospheres - Part 10: Classification of hazardous areas	This stipulates classification of hazardous area where may be hazardous by flammable gases or vapors.
JIS C60079-14	2008	Electrical apparatus for explosive gas atmospheres - Part 14: Electrical installations in hazardous areas (other than mines)	This stipulates specific requirements for design, selection, and installation of electric equipment which is used in explosive gaseous atmosphere other than mining purpose.
JIS C60079-15	2008	Electrical apparatus for explosive gas atmospheres - Part15: Construction, test and marking of type of protection "n" electrical apparatus	This stipulates requirements for construction, testing and display of explosion-proof "n" group-2 of electric devices which is used in explosive atmosphere.
JIS C60079-18	2008	Electrical apparatus for explosive gas atmospheres - Part18: Construction, test and marking of type of protection encapsulation "m" electrical apparatus	This stipulates specific requirements for design, construction, testing and display of resin-filled explosion-proof "m" of electric devices and Ex component which is used in explosive atmosphere.
JIS C60079-25	2008	Electrical apparatus for explosive gas atmospheres - Part 25: Intrinsically safe systems	This stipulates establishment and evaluation intrinsically of safe system used in explosive atmosphere other than mining.
JEAC 3704	2007	Rules for gas turbine for power generation	This stipulates necessary requirements of construction plans for gas turbine and its ancillary facility for power generation and requirement for safety management.
JEAC 3708	2010	Rules for fuel transportation and combustion facility	This mainly stipulates necessary requirements for design, installation, inspection and operation of fuel transportation and combustion facility (facilities from receiving to burner) which is installed in power plant in the view point of security matters in order to deal as diversified boiler fuel.
JEAC 3718	1991	Rules concerning the vibration of steam turbine and generator for power generation	Private standard for fire safety measures for the steam turbine and generator for generation.
NEGA C361	2006	Technical standard for captive power generation facility driven by gas turbine for continuous operation	Private standard for the gas turbine and reciprocating engine generation facility by Nippon Engine Generator Association.
NEGA C362	2006	Testing method of captive power generation facility driven by gas turbine for continuous operation	Private standard for the gas turbine and reciprocating engine generation facility by Nippon Engine Generator Association.
NEGA C363	2006	Performance testing method of captive power generation facility driven by gas turbine for continuous operation before shipment	Private standard for the gas turbine and reciprocating engine generation facility by Nippon Engine Generator Association.

Chapter-5. Reference TCVN

The referenced Vietnamese national standards for designing of gas turbine are organized in Table-45.

Table- 45: Reference TCVN

Number	Rev.	Title	Content
TCVN 2685	2008	Gasoline, kerosene, aviation turbine, and distillate fuels. Determination of (thiol mercaptan) sulfur (potentiometric method)	Tiêu chuẩn này quy định phương pháp xác định lưu huỳnh mercaptan với hàm lượng từ 0,0003% khối lượng đeesn 0,01% khối lượng có trong xăng, dầu hỏa, nhiên liệu tuốc bin hàng không và nhiên liệu trưng cất
TCVN 3172	2008	Petroleum and petroleum products. Determination of sulfur by energy-dispersive X-ray fluorescence spectrometry	Tiêu chuẩn này quy định phương pháp xác định tổng lưu huỳnh trong các hydrocacbon như: nhiên liệu điêzen, naphta, dầu hoả, dầu cặn, dầu gốc bôi trơn, dầu thuỷ lực, nhiên liệu phản lực, dầu thô, xăng (không chì), và các nhiên liệu chưng cất khác.
TCVN 3180	2007	Diesel fuels. Method for calculated cetane index by four variable equation	Chỉ số xêtan tính toán bằng phương trình bốn biến số cung cấp phương thức để đánh giá trị số xêtan của nhiên liệu chưng cất từ các giá trị khối lượng riêng và nhiệt độ chưng cất đo được.
TCVN 5689	2005	Diesel fuel oils (DO). Specification	Tiêu chuẩn này quy định các chỉ tiêu chất lượng cho nhiên liệu điêzen dùng cho động cơ điêzen của phương tiện giao thông cơ giới đường bộ và các động cơ điêzen dùng cho mục đích khác.
TCVN 6371	1998	Mechanical vibration of large rotating machines with speed range from 10 to 200 rev/s. Measurement and evaluation of vibration severity in situ	Tiêu chuẩn này qui định các qui tắc đánh giá rung động của các động cơ chính và các máy khác có khối lượng quay, có công suất lớn hơn 300kW và tốc độ từ 10 đến 200 vg/s
TCVN 6426	2009	Aviation turbine fuels jet A-1. Specifications	Tiêu chuẩn này quy định các chỉ tiêu chất lượng nhiên liệu dùng cho động cơ phản lực tuốc bin của tàu bay sau đây gọi là nhiên liệu phản lực tuốc bin hàng không Jet A-1.
TCVN 6503-1	1999	Gas turbines. Exhaust gas emission. Part 1: Measurement and evaluation	Tiêu chuẩn này thiết lập các phương pháp dùng để đo và đánh giá sự phát tán của các khí thải từ tuốc bin khí và định nghĩa các thuật ngữ về phát tán thích hợp. Tiêu chuẩn đưa ra những yêu cầu về môi trường thử và thiết bị cũng như chất lượng của các phép đo và hiệu chỉnh các dữ liệu đo được
TCVN 6503-2	1999	Gas turbines. Exhaust gas emission. Part 2: Automated emission monitoring	Tiêu chuẩn này thiết lập chương trình quan trắc giám sát và các yêu cầu cho việc lựa chọn và hoạt động của phần cứng dùng để đo liên tục một thời gian kéo dài không giới hạn

Number	Rev.	Title	Content
TCVN 6607	2008	Aviation turbine fuels. Test method for determination of corrosiveness to silver	Tiêu chuẩn này quy định phương pháp xác định xu hướng ăn mòn bạc của nhiên liệu thuốc bin hàng không
TCVN 6627-3	2000	Rotating electrical machines. Part 3: Specific requirements for turbine-type synchronous machines	Tiêu chuẩn này áp dụng cho các máy điện ba pha tuabin, có công suất ra danh định bằng và lớn hơn 10 MVA dùng làm máy phát. Các điều trong tiêu chuẩn này thích hợp áp dụng cho các máy điện dùng làm động cơ đồng bộ hoặc máy bù đồng bộ. Tiêu chuẩn này bổ sung các yêu cầu cơ bản đối với máy điện quay nêu trong TCVN 6627-1:2000
TCVN 6627-8	2000	Rotating electrical machines. Part 8: Terminal markings and direction of rotation of rotating machines	Tiêu chuẩn này áp dụng cho máy điện xoay chiều không có cổ góp, và đề cập đến: a. ghi nhãn đầu ra; b.chiều quay; c. mối liên quan giữa ghi nhãn đầu ra và chiều quay
TCVN 7272	2006	Aviation turbine fuels. Method for determination water separation characteristics by portable speedometer	Phương pháp này áp dụng cho máy đo nhanh loại xách tay dùng ngoài hiện trường và trong thí nghiệm để xác định khả năng nhả nước dạng hấp phụ hoặc nhũ tương của nhiên liệu tuốc bin hàng không khi bơm qua vật liệu kết tụ bằng sợi thuỷ tinh
TCVN 7418	2004	Aviation turbine fuel. Test method for determination of smoke point	Tiêu chuẩn này quy định phương pháp xác định chiều cao ngọn lửa không khói của dầu hoả và nhiên liệu tuốc bin hàng không.
TCVN 7419	2004	Aviation turbine fuel. Test method for determination of acidity	Tiêu chuẩn này quy định phương pháp xác định axit tổng có trong nhiên liệu tuốc bin hàng không từ 0,000 đến 0,100 mg KOH/g.
TCVN 7989	2008	Aviation turbine fuels. Determination of naphthalene hydrocarbons. Ultraviolet spectrophotometry method	Tiêu chuẩn này quy định phương pháp xác định tổng nồng độ của naphtalen, acenaphten, và các dẫn xuất alkyl của các hydrocacbon có trong nhiên liệu phản lực.
QCVN 01:2007/BKHCN	2007	National technical regulation on gasoline and diesel fuel	

Chapter-6. Referenced Literature and Materials

The referenced books, literatures, standards to establishing this guide line are organized as follows.

1. Interpretation of technical regulation for thermal power facility (10/Jul/2007): NISA (Nuclear and Industrial Safety Agency) of METI (Ministry of Economy, Trade and Industry)
2. Outline of alternative system to halogenated fire extinguishing system on Yanai combined cycle power plant No.2 group (Journal No.448: Jan/1994: K. Momota and others): TENPES (Thermal and Nuclear Engineering Society of Japan)
3. Gas Turbine performance and construction (Journal No.578: Nov /2004): TENPES (Thermal and Nuclear Engineering Society of Japan)
4. Mitsubishi Gas Turbine (Journal No.625: Oct /2008: Y. Iwasaki and others): TENPES (Thermal and Nuclear Engineering Society of Japan)
5. Facility for GTCC-Gas Turbine (Journal No.645: Jun./ 2010): TENPES (Thermal and Nuclear Engineering Society of Japan)
6. Latest trends of thermal power generation technology of Tokyo Electric Power Co. (Journal No.655: Dec/2011: Y. Ishimaru): TENPES (Thermal and Nuclear Engineering Society of Japan)
7. GE Gas Turbine Performance Characteristics (GER-3567H): GE Power Systems
8. Handbook for Thermal and Nuclear Power Engineers (7^{th} Revision 2008): TENPES (Thermal and Nuclear Engineering Society of Japan)
9. Terms for Thermal Power Facility-Gas Turbine JIS B0128-2010: Japanese Industrial Standard
10. "Development and in-house shop load test results of M701G2 gas turbine (MHI Y. Iwasaki and others): Literature for International Gas Turbine Congress 2003 Tokyo