(3) Selection of transformer taps

14.2.1 Selection of Transformers

(1) Transformer efficiency is expressed by the following equation:

$$\eta = \frac{n\,p\cos\phi}{n\,p\cos\phi + W_i + n^2 W_c} \times 100\ (\%) \quad \cdots\cdots (1)$$

Where η : Efficiency (%)

n : Load factor

p : Rated capacity (kVA)

$\cos\phi$: Power factor

W_i : Iron loss

W_c : Copper loss

Although a transformer has dielectric and stray-load losses, in addition to the above iron and copper losses, they are difficult to measure and are minute, and as such will be ignored. Also, the ratio of copper loss W_c to iron loss W_i at rated load is called "Loss ratio α".

$$\alpha = \frac{W_c}{W_i} \quad \cdots\cdots (2)$$

The loss ratio is generally 2 to 5 as shown in Table 14-3. However, it may exceed 10 in the energy conservation type transformers as described later.

Table 14–3 Efficiency of 3 Phase High Voltage Medium Capacity Transformer

Primary 6.6/3.3 kV, Secondary 400/200 V

	Company A				Company B			
	Efficiency (%)	Iron loss (kW)	Copper loss (kW)	Loss ratio	Efficiency (%)	Iron lossq (kW)	Copper loss (kW)	Loss ratio
300	98.2	0.9	4.6	5.1	97.9	2.2	4.2	1.9
500	98.27	1.3	7.5	5.8	98.1	2.7	7.0	2.6
750	98.36	2.0	10.5	5.3	98.2	3.2	10.6	3.3
1,000	98.52	2.5	12.5	5.0	98.2	3.5	14.8	4.2
1,500	98.62	4.5	16.5	3.7	–	–	–	–
2,000	98.69	6.0	20.5	3.4	98.3	7.3	27.3	3.7

From equation (1), the transformer efficiency is at maximum when $n = \sqrt{W_i/W_c}$, namely, output when the iron loss is equal to the copper loss at this point. One example of change in efficiency against output is illustrated in Fig. 14-5.

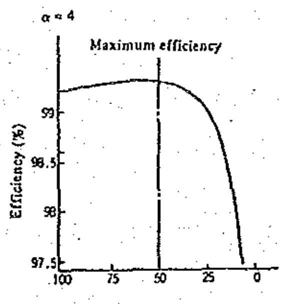
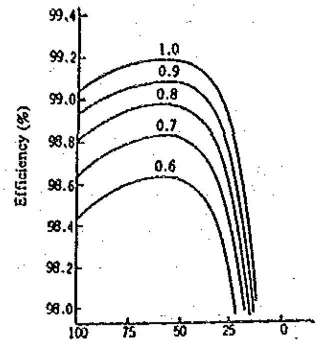


Figure 14–5 Transformer Efficiency (Example)

Also, the transformer efficiency varies with the load power factor in equation (1) and lowering the power factor reduces the efficiency.

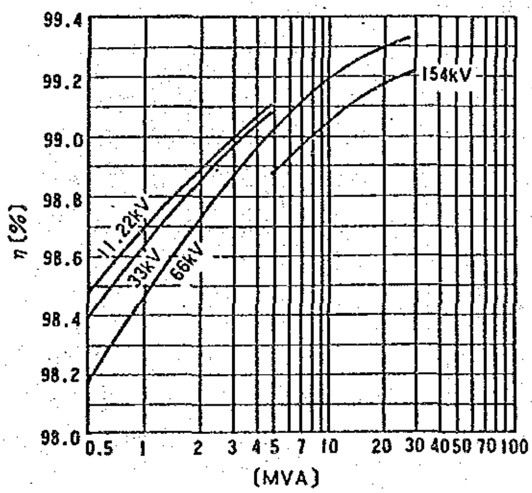
This example is shown in Fig. 14-6.



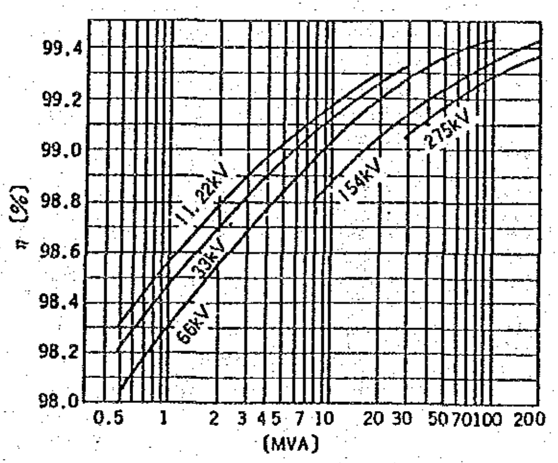
Note: Figure indicates power factor.

Figure 14–6 Relation between Power Factor and Efficiency

The difference of efficiency due to the transformer capacity is shown in Fig. 14-7.



Example of efficiency of 50Hz single oil immersed transformer



Example of efficiency of 50Hz 3 phase oil immersed transformer

Figure 14–7 Example of Efficiency of 50 Hz Transformer

(2) All day efficiency of transformers

Although it is of course important to purchase and operate transformers considering the transformer maximum efficiency point, daily efficiency also must not be neglected because the transformer load varies every hour. Equation (3) is called "all day efficiency".

All day efficiency =

$$\frac{\text{Output energy per day (kWH)} \times 100\%}{\text{Output energy per day (kWh)} + \text{Loss energy per day (kWh)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

If the daily pattern for load fluctuation is almost the same, it would be better to operate transformers so that the all day efficiency is better.

(3) Energy conservation type transformers

Some transformers that use the laser treated plate of silicon steel belt for the core material and employ would core construction are manufactured. They are called conservation type transformers with the iron loss approximately 40% of the conventional types. Anybody purchasing transformers had better keep above for future reference.

14.2.2 Efficient Operation of Transformers

(1) Stopping of light-load transformers

Generally speaking, when there are two or more transformers and each of them has a low load factor, electric power can be saved by stopping low load factor transformers to integrate the load. However, in some cases, loss of transformers with increased load may exceed reduced loss of stopped transformers, causing and adverse effect. Therefore, it is always necessary to confirm by calculating, as shown in the following example.

(Example) When there are two 500 kVA transformers

In the case where each transformer has a load factor of 40% as shown in Fig. 14-8, we will calculate the merit for when one transformer is stopped. We presume the transformer's characteristics to be of company A, specified in Table 14-3.

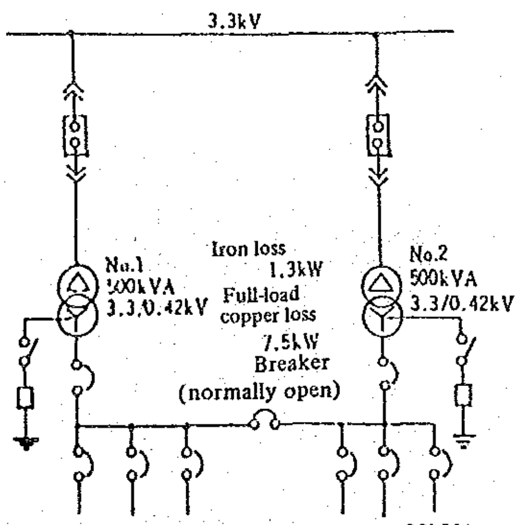


Figure 14–8 Method to Use Two 50 kVA Transformer

At present, for both transformer No.1 and transformer No.2,

Iron loss = 1.3 (kW)

Copper loss = Fuel-load x $(\frac{\text{Load factor}}{100})^2$ = 7.5 x $(\frac{40}{100})^2$ = 1.2 (kW)

Hence,

Total loss = 2 (1.3 + 1.2) = 5 (kW)

After stop of transformer No.1,

Iron loss of transformer No.2 = 1.3 (kW)

Copper loss of transformer No.2 = Full-load x $(\frac{\text{Load factor}}{100})^2$

= 7.5 x $(\frac{80}{100})^2$ = 4.8 (kW)

Total loss = 1.3 + 4.8 = 6.1 (kW)

Stopping one transformer increases the loss by 1.1 kW.

(2) Control of the number of transformers

When transformers with the same rating are operated in parallel, the total loss can be reduced by increasing or decreasing the number of transformers.

Overall loss when N units of transformers are operated in parallel is expressed by the following equation:

$$W_N = N \quad W_i + (\frac{P_L}{N_Q})^2 W_c \quad (kW)$$

Where W_N: Overall loss (kW)

W_i : Iron loss of one transformer (kW)

W_c : Copper loss of one transformer (kW)

P_L : Load capacity (kVA)

N : Number of transformers

Q : Capacity of one transformer (kVA)

Overall loss when (N-1) units of transformers are operated in parallel is expressed by the following equation:

$$P_L < \sqrt{\frac{N(N-1)}{\alpha}} \times Q \text{ (kVA)}$$

Where,

$$\alpha = \frac{W_c}{W_i}$$

α : Loss ratio

For example, when three 500 kVA transformers whose α being 3 are operated

$$\sqrt{\frac{N(N-1)}{\alpha}} \times Q = \sqrt{\frac{3 \times 2}{3}} \times 500 = 707 \text{ kVA}$$

That is, when the load is 707 kVA or below, the energy can be saved by reducing one of the operated transformers to two units.

(3) Stopping of transformers at night and on holidays

In equipment and factories where operation is not performed at night and on holidays, the electric power can be saved by concentrating only loads for which electricity supply cannot be stopped even at night and on holidays, to certain transformers and stopping unnecessary transformers. However, when there is not much difference in electric power between the daytime and at night, there is no merit.

14.2.3 Selection of Transformer Taps

Low-voltage transformers or main power lines have many loads and it is not easy to supply the voltage close to the rating of each load. However, it is important to optimize the transformer taps and endeavour to get as close as possible. Observing how motors are being operated in factories, full-load operations are few and 50% to 80% of the load is generally seen.

Relation between voltage fluctuation and load state of an induction motor is as shown in Table 14-4 and Table 14-5. When all loads for the transformer are motors, it is desirable to select the taps in the light of these.

Table 14–4 Effect of Voltage Fluctuation on Induction Motor

	Voltage fluctuation	
	90% Voltage	110% Voltage
Starting torque, Maximum torque	–19%	+21%
Synchronous speed	Remain unchanged	Remain unchanged
% Slip	+23%	–17%
Full-load speed	–15%	+1%
Efficiency (Full-load)	–2%	Slightly increased
Power factor (Full-load)	+1%	–3%
Full-load current	+11%	–7%
Starting current	–10 ~ –12%	+10 ~ +12%
Full-load temperature rise	+6 ~ +7°C	–1 ~ –2°C
Magnetic noise	Slightly decreased	Slightly increased

Table 14–5 Relation between Voltage Fluctuation and Loading State of Induction Motor

		Voltage fluctuation	
		90% Voltage	110% Voltage
Efficiency	Full load	–2%	Slightly increased
	¾ Load	Remain unchanged	Remain unchanged
	½ Load	+1 ~ +2%	–1 ~ –2%
Power factor	Full load	+1%	–3%
	¾ Load	+2 ~ +3%	–4%
	½ Load	+4 ~ +5%	–5 ~ –6%

14.3 Motors

For motor energy conservation, the countermeasures are mainly classified into the following two cases:

(1) In the case of energy conservation by newly establishing or by greatly remodelling load and motor equipments.

(2) In the case of energy conservation by intensifying the management aspect of the existing equipment or by remodelling in a small scale.

Each of these will be discussed below:

14.3.1 In the Case of Newly Establishing Load and Motor Equipments

Although it applies not only to motor application equipment but also to general equipment, it can be stated that the amount of energy used may be determined to a certain degree at the equipment planning stage. If the equipment capacity is too big or unfit for the load equipment, the energy cannot be used in a rational manner. Matters which should be considered at the planning or introducing stage of newly-establishing equipment are described as follows:

(1) Basic expressions relating to motor-driven force applications

Basic expressions which must first be understood when considering the motor energy conservation are shown in Table 14-6. For reasons of space, the description is omitted, but see the technical books for reference.

Table 14–6 Basic and Practical Expressions Relating to Motor Application

Formulation / Item	Basic expression	Practical expression	Description of symbols
1 Power and torque	$P = \omega T$	$Rk[kW] = P \times 10^{-3}$ $N[rpm] = \frac{60}{2\pi}\omega$ $Tg[kg\text{-}m] = \frac{T}{g} = \frac{T}{9.81}$ $Pk[kW] = \frac{N[rpm]}{973} \times Tg[kg\text{-}m]$	P :Power (watt) Pk:Power (Kilo watt) T :Torque (N-m) Tg:Torque (Gravity unit Kg-m) W :Angular velocity (rad/sec) N :Rotating speed (rpm)
2 Moment of inertia and acceleration torque	$J\frac{d\omega}{dt} = T$	$GD^2 = 4J$ $Tg[kg\text{-}m] = \frac{1}{365} GD^2 \cdot \frac{dN}{dt}$	J :Moment of inertia (kg m²) GD^2: Flywheel effect
3 Acceleration time	$t = \int_0^{\omega_0} \frac{J}{Ta} d\omega[sec]$	$\overline{Ta} = \frac{\int_0^{\omega_0} Ta(\omega)}{\omega_0} d\omega$: $ta[sec] = \frac{1}{365}\frac{GD^2 N_0^2 [rpm]}{P[W]}$	t :Time required for acceleration (sec) ta :Time required for completion of acceleration (sec) Ta: Acceleration torque (Kg-m) $\overline{Ta}$: Mean acceleration torque (Kg-m)

(2) Load condition in the selection of motors

To select an optimum motor, it is necessary to know the load condition.

How a motor must be under various conditions of load, or what to be the allowable conditions are summarized in Table 14-7. When the conditions shown here are clear, it is possible to select the motor and also to select the control equipment to follow it.

Table 14–7 Conditions for Motor Selection

Conditions of load		Motor system		
		DC machine	Induction machine	Synchronous machine
Starting conditions	Necessary frequency for starting		Study heat capacity of motor	
	Necessary starting torque • Moment of inertia of load • Possibility of no-load starting	Application of series motor	Application of wound-rotor type IM Study starting current and time according to the above items	
	Necessity of smooth starting	Acceleration restriction	Reactor starting, soft starter, etc.	Low frequency starting, etc.
Stop conditions	Necessity and its degree of emergency stop (quick stop)	Regeneration system, dynamic braking, etc.	Reversing-phase braking	Brake, etc.
	Necessity of precise stop position	Position control	Difficulty	
	Necessity of holding the stop position	Presence of brake		
Operating conditions	Necessity and its conditions of reverse rotation	Field switching Armature switching	Main circuit switching	
	Rating of load (Continuous, time)	Possibility of reducing frame No. for hourly rating		
	Special function	Restriction is comparatively small.	Restriction is large.	
Speed control	Constant speed or variable speed?	For variable speed	For constant speed Variable speed in conjunction with control equipment	
	Speed control range	Scope of application is large.	Study combination with control equipment.	
	Necessity of speed control	Suitable	Change by amount of slip	Synchronize with the power source frequency.
Ambient conditions, etc.	Temperature and humidity conditions	Study motor construction.		
	Necessity of explosion-proof construction	Possible, but difficult	Possible	
	Whether good atmosphere or not	Problem on brush commutator	Squirrel cage type is for improper circumstance.	Brushless exciting is possible.
	Problem on personnel for maintenance	Maintenance is important.	In the case of brushless, easy maintenance.	
	Power source condition	Problem on higher harmonics and power factor	Starting current large, Delay power factor	Leading power factor is possible.

Although motor systems are classified into DC, induction and synchronous machines in Table 14-8, induction and synchronous machines here are considered to be constant-speed drive systems for commercial power source. A thyristor motor applied to a synchronous machine and a frequency control method applied to an induction machine belong to the DC machines for system.

Main items for selection of motors are described following item (3):

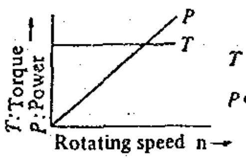
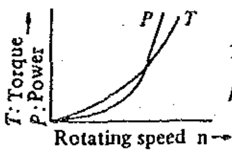
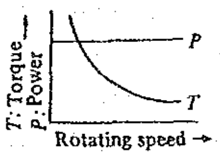
(3) Torque characteristics of load

Motors usually start in a load-coupled state from zero speed, accelerate to a specified speed and enter into a constant speed operation. Since the load has inherent torque characteristics, motors must generate a torque greater than that required by the load over all speed ranges.

Generally, when load and motors are more alike in torque characteristics, motors can be more economically designed.

As examples of typical torque-speed characteristics, there are three types. The first is constant-torque type in which the torque is constant in spite of the speed, the second is torque increasing type in which the torque is in proportion to the speed, its square or cube, and the third is constant-output type in which the necessary torque is in inverse proportion to the speed and torque multiplied by speed is constant. These relations are summarized in Table 14-8.

Table 14–8 Class of Load and Torque Speed Characteristic

Load characteristic		Typical load
Constant torque load	 T = Constant, $P \propto n$	Gravity load, Friction load [Example] Crane, Winding machine, Conveyor, Paper machine, Mixer
Increasing torque load	 $T \propto n^2$, $P \propto n^3$	Fluid load [Example] Blower, Pump
Constant output load	 $T \propto \frac{1}{n}$, P = Constant	Special load [Example] Winder, Constant cutting machine, Log barker

It is generally important in constant-speed motors such as three phase induction and synchronous motors whether starting torque and maximum torque are greater than the torque required by the load. It is also important in synchronous motors whether pull-in torque is greater than the torque required by the load.

(4) GD^2 of the load

The amount of the load GD^2 (Flywheel effect) is related to length of the starting time and the amount of the heating value during starting, so it is an important factor in the selection of motors.

A summing the load torque as T_L (kg·m), the motor torque as T_M (kg·m) and the sum of the flywheel effect for the load and motor as GD^2 (kg·m²),

$$T_M = \frac{GD^2}{375} \cdot \frac{dN}{dt} + T_L \quad \cdots\cdots (1)$$

Accordingly, the starting time is

$$t = \int_0^{No} \frac{GD^2 \cdot dN}{365\,(T_M - T_L)} \text{ second)} \quad \cdots\cdots (2)$$

Where N_o: Rated speed

The needed time for starting is in direct proportion to GD^2. Since motors are unusually warmed when t is long, the allowable GD^2 of the load is determined for any motors. When GD^2 is great, on the contrary, it is necessary to select large motors fitting for it.

When GD^2 of motors: $G_1 D_1^2$, GD^2 of machines: $G_2 D_2^2$ and reduction ratio: $n_1/n_2 = n$ as shown in Fig. 14-9, GD^2 converted to the motor side is:

$$GD^2 = G_1 D_1^2 + \frac{1}{n^2} G_2 D_2^2 \quad \cdots\cdots (3)$$

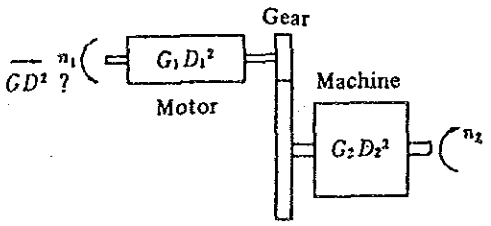


Figure 14–9 Conversion of Flywheel Effect

This result is important because a reducer is, in most cases, used for industrial load.

(5) Time characteristics of the load

Motors are used in various methods of use such as continuous, short-time and intermittent use, etc. and such hour application duty is called "Duty". When electrical machinery and apparatus are used under specified conditions for use, they are designed so that the allowable maximum temperature is not exceeded, and these conditions are called "Rating of machinery and apparatus".

For the ratings, there are rated output, rated rotating speed, rated voltage, rated current, rated frequency, etc., and for the duty, there are various classes such as continuous rating, short-time rating, periodic rating, etc.

A) Continuous rating

For 24 hour continuous operation, we select, of course, motor with a continuous rating.Generally, when continusouly used for more than two or three hours, motors with continuous rating are mostly used because they are nearly the same in price. The motor, while continuously used, is heated from the inside due to copper and iron losses, etc., and at the same time cooled by radiant heat from the surface and opeated at a balanced value between these two.

Assuming the heating value every second: Q, Difference between the motor and ambient temperature (temperature rise value): θ, Heating capacity of motor: C, Heat dissipation coefficient: A,

$$C\frac{d\theta}{dt} + A\theta = Q \quad \cdots\cdots (3)$$

Assuming $\theta = 0$ at $t = 0$,

$$\theta = \frac{Q}{A}(1 - \epsilon^{-\frac{t}{T}}) \quad \cdots\cdots (4)$$

Where, $T = \dfrac{C}{A}$

T in the above equation is called "Thermal time constant". If $t = \infty$ in equation (4), $\theta = Q/A$ and the final temperature rise is determined.

This is graphed in Fig. 14-10. Also, the thermal time constant normally will be as shown in Table 14-9 . Next, when the motor is separated from the power source and stopped, subsituting $Q = 0$ in equation (3) and $\theta = \theta_0$ at $t = 0$,

$$\theta = \theta_0 \epsilon^{-\frac{t}{T}}$$

Where, $T' \doteqdot \dfrac{C}{A'}$

T': Thermal time constant during cooling

A': Heat radiant coefficient during cooling

θ_0: Temperature when cooling starts.

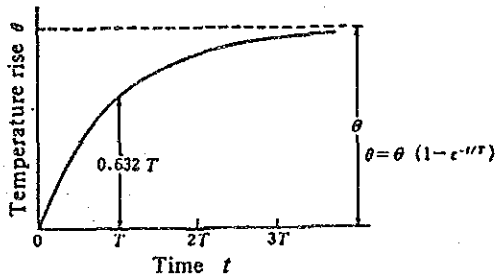


Figure 14–10 Temperature Rise Curve of Motor

Table 14–9 Example of Thermal Time Constant

Type	Thermal time constant (minute)
Open type	20 ~ 40
Totally enclosed fan cooling type	50 ~ 150
Totally enclosed self cooling type	90 ~ 180

In separately-ventilated motors, the thermal time constant when stopped is the same as when operating because the amount of cooling air does not change even while stopped, but in self-ventilated motors it will be about three times that during operation.

B) Short-time rating

There are 5, 10, 15, 30, 60, 120 minutes, etc. as a standard time in the short-time rating, among which the nearest one to the actual load condition should be selected.

C) Periodic rating

Periodic load means that load and rest period are periodically repeated, which is represented by a crane. For motors with crane, rated motors with % ED display are used (See Table 14-10).

40% ED indicates a condition for use in which the motor is used at a rated capacity for four minutes in ten minutes.

Table 14–10 Frame Number Application Table

Frame number \ Load time factor / Output	15%ED kW	25%ED kW	40%ED kW	60%ED kW	100%ED kW	Number of pole
132 M	3	2.5	2.2	1.8	1.5	6
	5	4	3.7	3	2.8	6
160 M	7.5	6.3	5.5	4.5	4	6
	10	8.5	7.5	6.3	5.5	6
160 L	15	13	11	9	7.5	6
180 L	20	17	15	13	11	6
200 L	30	25	22	18.5	15	6
225 M	40	33	30	25	22	6
250 M	50	40	37	30	25	6
	63	50	45	37	33	6
280 M	75	63	55	45	37	8
315 M	100	85	75	63	50	8
	125	100	90	75	63	8
355 L	150	125	110	90	75	10
	185	150	132	110	90	10
400 L	220	185	160	132	110	10
	280	220	220	160	132	10

D) Calculation of output by the root mean square method

Rated output of a motor is selected from the timely characteristics of the load, but when the load varies irregularly, it is rather difficult to determine the motor output.

However, when the load varies continuously and periodially, the root mean square method is often used as a simple output calculation method.

When the terminal voltage is constant in induction and DC shunt motors, the output is approximately in proportion to the load current. There are copper and iron losses as an exothermic source for motors and the copper loss is far greater than the iron loss. Also, since the copper loss is in proportion to the square of the load current, the loss in motor is almost in proportion to the square of the output.

Assuming the load current as I (t), and the output at this point as P(t),

$$I(t)^2 R = k\ P(t)^2$$

Assuming that it takes time of t_1, t_2, ... t_n for load of P_1, P_2, ... P_n during one period T, the equivalent load as Pa

$$k\ P_1^2 t_1 + P_2^2 t_2 + \ldots + P_n{}^2 t_n = kP_a{}^2 \cdot T$$

Where, $T = t_1 + t_2 + \ldots + t_n$

$$\text{Hence, } P_a = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + \ldots\ldots + P_n{}^2 t_n}{T}} \qquad \ldots\ldots (6)$$

This P_a is an equivalent continous load which gives out the same loss of load P which fluctuates periodically. In the case of an intermittent load, it is necessary to determine the equivalent load, taking into consideration generated heat and cooling during starting and stopping, since starting occurs very frequently.

For example, the equivalent load when a motor with a continuous rating is used for intermittent load as shown in Fig. 14-11 is determined in the following way:

$$P_a = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + P_3 t_3}{t_1 \alpha_1 + A_2 \alpha_2 + t_3 \alpha_3 + t_4 \alpha_4}} \qquad \ldots\ldots (7)$$

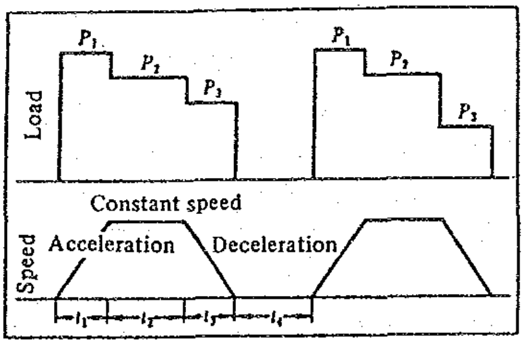


Figure 14–11 Example of Periodic Load

Table 14–11 Example of Cooling Coefficient Values

Type of motor	During stop	During acceleration	During operation	During deceleration
Open type AC motor	0.2	0.5	1	0.5
Enclosed type AC motor	0.3	0.6	1	0.6
Totally enclosed fan cooling type AC motor	0.5	0.75	1	0.75
Separately-cooling AC motor	1	1	1	1

However, α is heat extraction coefficient and its value is as shown in Table 14-11. Also,

$$T = t_1 \alpha_1 + t_2 \alpha_2 + t_3 \alpha_3 + t_4 \alpha_4$$

T shown in the above equation is an equivalent period, taking the heat extraction coefficient into consideration.

E) Determination of motor capacity

When the rated output of motors are to be decided, it is oftenly determined by the maximum load. However, it should be determined by calculating the equivalent load as described in the preceding item.

For example, in continuous operation as shown in Fig. 14-12,

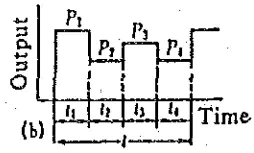


Figure 14–12

P_1 = 100 kW t_1 = 10 minutes

P_2 = 5 kW t_2 = 15 minutes

P_3 = 80 kW t_3 = 10 minutes

P_4 = 50 kW t_4 = 20 minutes

From equation (6), the required motor output P is

$$P = \sqrt{\frac{100^2 \times 10 + 50^2 \times 15 + 80^2 \times 10 + 50^2 \times 20}{10 + 15 + 10 + 20}} = 67.6 \text{ kW} \fallingdotseq 70 \text{ kW}$$

Accordingly, 75 kW should be selected for the motor. In this case, at the maximum load, 100/75 = 1.33 Namely, it will be 133% overload, but there will be no problem because the maximum torque of the motor is more than 200%. If the motor is selected at the maximum output of 100 kW, it will be a significant adverse factor for energy conservation.

When a motor for crane is periodically used as shown in Fig. 14-13.

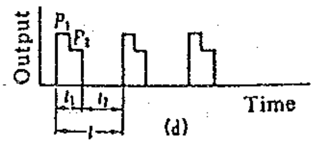


Figure 14–13

P_1 = 50 kW 1.5 minutes

P_2 = 30 kW 1.5 minutes

t_1 = 1.5 +1.5 = 3 minutes t_2 = 7 minutes,

the root mean square load in operation is

$$P = \sqrt{\frac{50^2 \times 1.5 + 30^2 \times 1.5}{3}} = 39.3 \text{ kW} \fallingdotseq 40 \text{ kW}$$

Accordingly, a motor corresponding to 40% ED 45 kW may be selected from Table 14.11.

(6) Class, efficiency and power factor of motors

Let us compare the typical DC, induction and synchronous motors with induction motors mostly used in respect to efficiency and power factors.

A) DC and induction machines

Fig. 14-14 shows the comparison in efficiency between DC and induction motors. As can be seen from the figure, the efficiency of the DC motor is 5 to 8% lower than the induction motor for small capacity machines 100 kW or less and 2 to 3% lower for 300 to 100 kW. This DC motor, being of the separately-ventilated type, must be essentially evaluated including loss of the blower for cooling. Since, however, this value is omitted, the efficiency actually tends to lower further.

The DC motor is capable of operating in accordance with the load characteristic and also in easily controlling the speed or torque because it can be easily provided with various characteristics by means of excitation systems. On the other hand, the DC motor has the following defects; the efficiency is lower than AC mtors such as induction and synchronous motors, etc.; it has difficulties in maintenance and in environment-proof because of a current collecting mechanism.

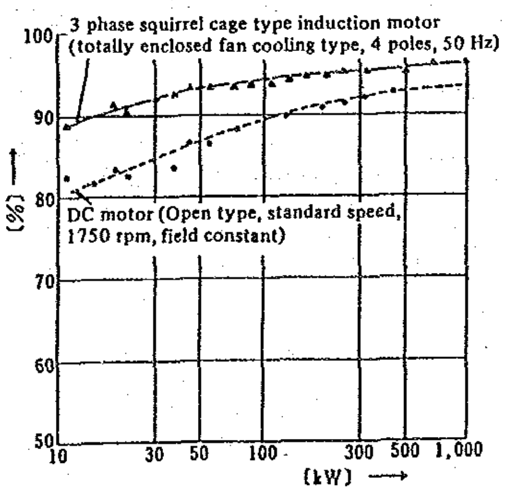


Figure 14–14 Comparative Example of Efficiency for Induction and DC Motor

B) Synchronous and induction motors

Fig. 14-15 shows the comparison in efficiency between synchronous and induction motors.

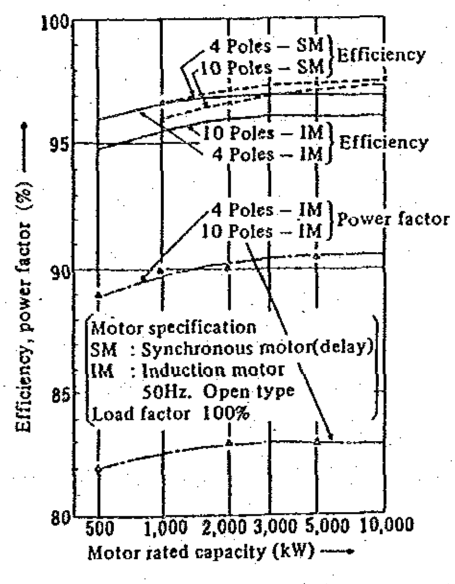


Figure 14–15 Comparative Example of Efficiency and Power Factor between Synchronous and Induction Motors

The efficiency of synchronous motors is generally higher than that of induction motors and the tendency is remarkable in low-speed motors with larger numbers of poles. For example, in the case of 10 MW class, the efficiency of 4 pole synchronous motors is about 0.5% higher than induction motors, while 10 pole synchronous motors have an efficiency of about 1 to 1.5% higher.

Also, the greatest special feature of the synchronous motors is to freely select the power factor, enabling power factor 1.0 or advancing power factor and, at this point, they are quite different from the induction motors. Moreover, it is possible to control the system at a constant power factor by means of the field control, or to restrain voltage fluctuation of the system by performing constant control of the power factor or terminal voltage. Since the power factor considerably lower with low-speed large capacity induction motors as can be seen from the figure, they are disadvantageous as compared to the synchronous motors in this respect also. Since, however, the synchronous motors including excitation power source equipment for the field system are expensive, generally selection should be studied, with the following points:

a. For 10 MW or more, study adoption of synchronous motors in respect to efficiency.

b. For low-speed motors with larger numbers of poles even 10 MW or less, study adoption of synchronous motors.

c. When power factor and voltage of the system must be controlled, study adoption of synchronous motors. However, the motor is limited to sufficient enough large capacity to supply the system reactive power (Var).

d. Generally, for MW or less, induction motors are superior in simple starting and power source composition.

C) Induction motor and its number of poles

Fig. 14-16 shows the relationship between number of poles and efficiency, power factor of a totally enclosed fan cooled type three phase squirrel cage induction motor with the output capacity as a parameter. In the figure, the efficiency does not vary much with the number of poles, because it is designed so that the efficiency does not vary much with the number of poles for each output capacity.

However, the power factor remarkably lowers with increased numbers of poles because the exciting current is in proportion to the number of poles. This tendency is remarkable with the smaller capacity motors with higher exciting current component as compared to load current components. Number of poles of a motor is selected according to rotating speed of the opposite machine. Generally, for motors with the same output, the larger the number of poles is, the larger the volume and weight become.

Since the weight is intimately related to the amount of materials used and material manufacturing expenses, it may represent a tendency of cost. Accordingly, since the larger numbers of poles generally raise the cost, it is better not to make the number of poles unnecessarily larger, otherwise, the initial investment will be larger and uneconomical.

Motors are rarely directly coupled to the opposite load machine and usually, a reducer lies between them. When a four-pole motor is selected with reference to the reducer, there will be no problem in respect of cost and power factor. But when a motor with larger numbers of poles is selected, it should be determined by taking into consideration the equilibrium between the efficiency merits of the drive system including the reducer and the increased investment amount for the motor.

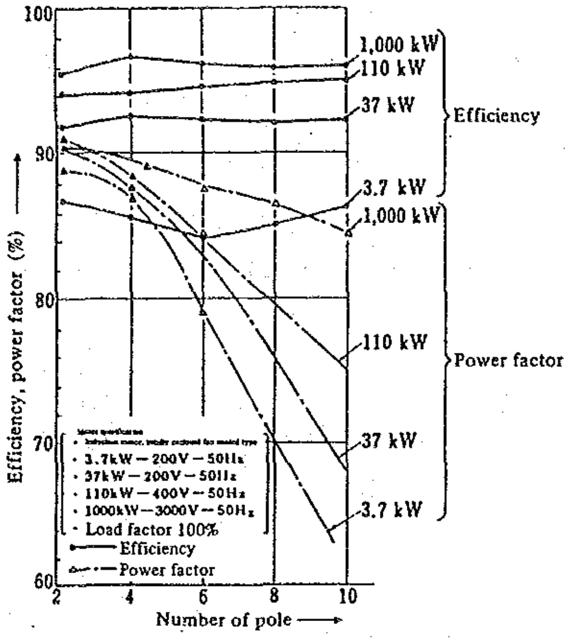


Figure 14–16 Relation between Number of Pole, Efficiency and Power Factor of Induction Motors

(7) Selection of motor voltage

Determination of the distribution voltage is an important factor for energy conservation because the motor voltage is deeply related to efficiency and cost. It is not desirable to select an especially high rated voltage for a small capacity motor, or to select on the contrary, a low voltage for a large capacity motor.

Fig. 14-17 shows the range of motor capacity for each voltage taking into consideration the technical problems and economical efficiency. The range shown with a white frame in this figure is a comparatively economical range containing few problems in manufacturing technique, and the shaded portion is the range which it is possible to manufacture technically if the economical efficiency is ignored to a certain degree.

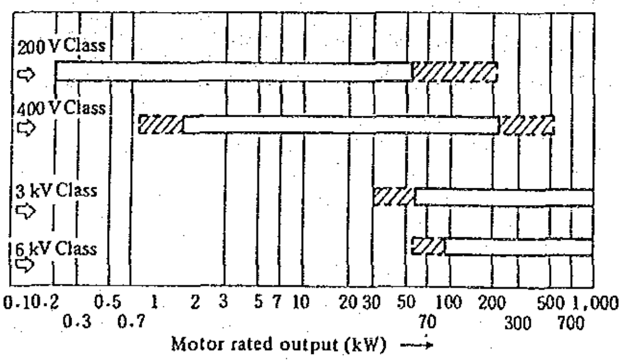


Figure 14–17 Optimum Output Range of Motor

(8) Adoption of high-efficiency motors

In recent years, high-efficiency motors with iron and copper losses reduced by 20 to 30% have been sold on the market.

They have been developed by improving the low-voltage squirrel cage type induction motors through adoption of high-class steel plate and optimization of design with leaving the frame number and external dimensions as the present standard. Although the initial investment will be somewhat higher, they will deserve studying for adoption for long-time operating motors. Fig. 14-18 and Fig. 14-19 show comparison in efficiency between high-efficiency motors and standard type motors which are being manufactured at present. It should be noted in Fig. 14-19 that the high-efficiency motors are remarkable in the improvement of efficiency at light-load.

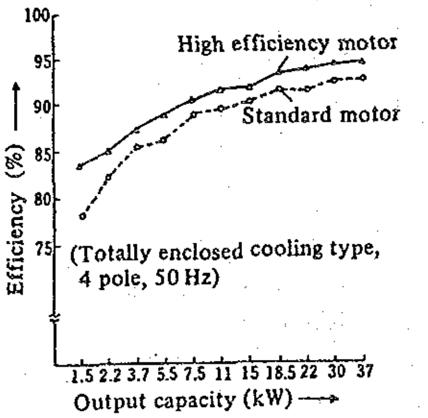


Figure 14–18

Efficiency Comparison of 3 Phase Squirrel Cage Type Induction Motor

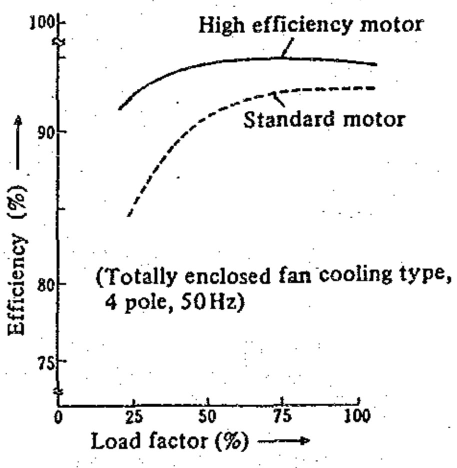


Figure 14–19

Efficiency Comparison of 3 Phase Squirrel Cage Type Induction Motor

14.3.2 Energy Conservation by Remodelling the Existing Equipment in a Small Scale

(1) Induction motors and voltage control

Although induction motors are generally used because they are low-cost and simple to handle, it should be noted that supply voltage has the greatest impact on these motors. Fig. 14–20 shows one example of loss of a three phase induction motor with a comparatively small capacity. As can be seen from this figure, a greater part of the loss is copper and iron losses which account for 86%. Accordingly, the impact of supply voltage fluctuation on the induction motor will be clarified by investing these two.

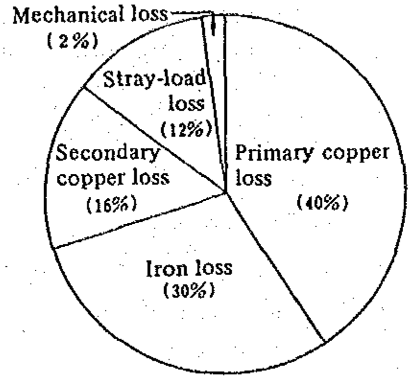


Figure 14–20 Loss Analysis Example of Standard 3 Phase Induction Motor

The copper loss is a resistance loss which occurs by current flowing through the induction motor stator winding (primary winding) and rotor (secondary winding) and it is in proportion to the square of the load current. Therefore, it is a loss component much dependent on the load factor.

$$W_c = 3\,(\gamma_1 + \gamma_2')\,I_2'^2 \;\; (W) \qquad (8)$$

Where W_c: Copper loss

γ_1: Resistance of primary winding each phase (Ω)

γ_2: Resistance of secondary winding each phase (primary side converted value) (Ω)

I_2': Load current (A)

Secondary current, when the motor runs at a rated speed close to the synchronous speed, is as follow from the basic formula of the induction motor.

$$I_2' = \frac{\omega_0 T}{3V_1} \;\; (A) \qquad (9)$$

Where ω_0: Synchronous angular velocity

V_1: Supply voltage

T: Load torque

From equation (8) and equation (9), the relation between the supply voltage and copper loss is

$$W_c = (\gamma_1 + \gamma_2')\,\frac{\omega_0{}^2 T^2}{3V_1{}^2} \;\; (W) \qquad (10)$$

That is, when the load torque does not change before and after the supply voltage fluctuation, the copper loss will be in inverse proportion to the square of the voltage.

On the other hand, iron loss W_i occurs when the magnetic flux in the iron core changes by means of the revolging magnetic field and consists of eddy current loss W_e and hysteresis loss W_h. The eddy current loss is in proportion to the square of the thickness of the iron plate of the core and the square of the magnetic flux density B, while the hysteresis loss is said to be in proportion to the frequency f and the magnetic flux density to the 1.6th power according to Steinmetz's research. Since, however, silicon steel plate has recently been used for iron plate, considerably high magnetic flux density can be obtained. Therefore, the hysteresis loss is also considered to be practically in proportion to the square of the magnetic flux density.

Since B • f are in proportion to the voltage, the iron loss W_i is:

$$W_i = W_e + W_h = k_1\ (dfB)^2 + k_2 fB^2 = V_1^2\ (k_1' + \frac{k_2'}{f})\ (W) \dots\dots (11)$$

Where k_1, k_1' : Constant representing the eddy current loss

k_2, k_2' : Constant representing the hysteresis loss

Since a greater part of the motor loss is iron and copper loss, supposing that total loss is a sum of the iron loss W_i and copper loss W_c, the total loss W comes to the following equation from equation (10) and equation (11).

$$W = (k_1' + \frac{k_2'}{f})\ V_1^2 + (\gamma_1 + \gamma_2')\ \frac{\omega_0^2 T^2}{3V_1^2}\ (W) \dots\dots (12)$$

Supply voltage V at which the total loss W is minimized is determined by using a condition of dW/dV = 0 into the following equation:

$$V = \sqrt[4]{\frac{(\gamma_1 + \gamma_2')\omega_0^2}{3\ (k_1' + \frac{k_2'}{f})}} \cdot \sqrt{T}\ (V) \dots\dots (13)$$

Since the supply voltage at which the loss is minimized is in proportion to $\sqrt{T}$ from the above equation, it lowers as the load factor lowers.

Fig. 14–21 shows a conceptual diagram of the characteristics of copper and iron losses against the supply voltage. The torque may be regarded as the load factor because it is balanced with load torque Tl. Accordingly, copper loss curve W_e rises with the load factor and the iron loss value has nothing to do with the load factor. Since the minimal loss point is the point of intersection of iron loss curve W_i and copper loss curve W_c, it will swift to the right when the load factor is high, and it will swift to the left when the load factor is low.

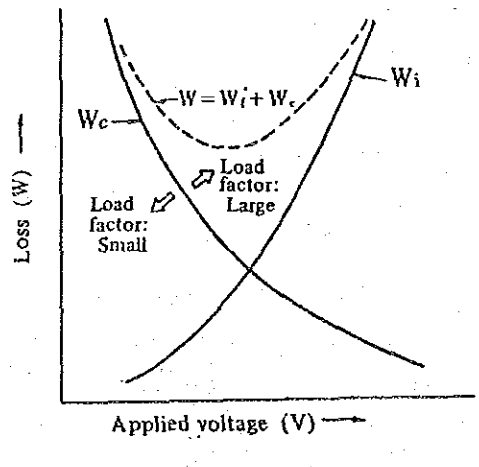


Figure 14–21 Tendency of Loss Against Applied Voltage

Fig. 14–22 shows one example of the efficiency curve when the survey voltage is actually changed with a motor. As shown in the figure, the efficiency during voltage fluctuation exhibits varied tendencies according to the load factor. When the load factor is high, the highest efficiency is shown at the rated voltage, while, when the load factor is low, the efficiency lowers as the voltage increases.

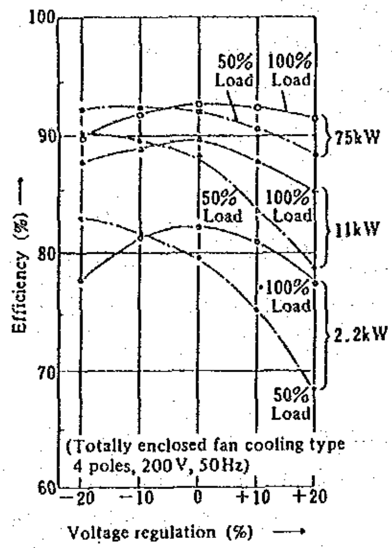


Figure 14–22
Example of Efficiency during Voltage Fluctuation of Induction Motor

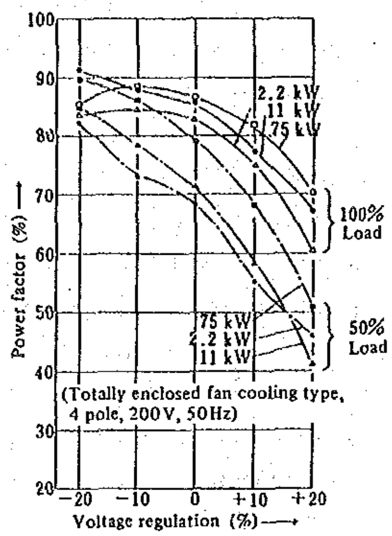


Figure 14–23
Example of Power Factor during Voltage Fluctuation of Induction Motor

Fig. 14–23 shows the change in the power factor of induction motors when the supply voltage fluctuates. The power factor increases as the voltage drops, because the exciting current of induction motors is in proportion to the supply voltage. What has been described until now is summarized in Table 14–12. Efficiency and power factor during supply voltage fluctuation have been described in the foregoing. When the above are actually applied to motors in operation within the field, the following items should be studied together.

Table 14–12 Effect of Voltage Fluctuation on Induction Machine

	Voltage fluctuation		
	90% Voltage	Proportional relation	110% Voltage
Starting torque Stalling torque	–19%	V^2	+21%
Synchronous speed	Remain unchanged	Constant	Remain unchanged
% slip	+23%	$1/V^2$	–17%
Full-load speed	–1.5%	–	+1%
Efficiency Full load	–2%	–	Slightly increased
Efficiency ¾ Load	Actually no change	–	Actually no change
Efficiency ½ Load	+1 ~ 2%	–	–1 ~ 2%
Power factor Full load	+1%	–	–3%
Power factor ¾ Load	+2 ~ 3%	–	–4%
Power factor ½ Load	+4 ~ 5%	–	–5 ~ 6%
Full-load current	11%	–	–7%
Starting current	–10 ~ 12%	V	+10 ~ 12%
Full-load temperature rise	+6 ~ 7°C	–	–1 ~ 2°C
Magnetic noise	Slightly decrease	–	Slightly increase

a. Study when the supply voltage is lowered

When wanted to operate with the supply voltage lowered below the rated voltage, it is necessary to check accelerating torque during starting and the value of the peak load because the starting torque and maximum torque decrease at a rate of the square of the voltage as shown in Table 14–12.

Since the load current increases in inverse proportion to the voltage even if the total loss decreases, the motor copper loss increases, thus increasing the winding temperature and the line loss of distribution line, etc. Care should be taken. Therefore, the lower limit of the supply voltage should be determined within a range not to exceed the motor rated current.

b. Study when the supply voltage is raised

When operated with the supply voltage raised above the rated voltage, saturation of the magnetic flux increases the exciting current remarkably, causing lowered power factor, unusual magnetic noise and an unusually heated iron core due to increased iron loss, etc. Also, since the motor output torque increases at a rate of the square of the voltage, it is necessary to check whether the machine is ruined by excessive torque.

c. Study of entire equipment

Many motors are usually connected to the same distribution system and operated, but the individual motors are rarely operated under the same load conditions. Some of them are operated at close to the rated load and the rest may be operated at a load 50% or below. Since it is not possible to determine the supply voltage uniformly under such a condition, it is necessary to study the entire equipment.

1) When motors operated at light-load hold an overwhelming majority, lower the distribution voltage and replace a few heavy-loaded motors with one rank higher capacity. In this case, if there are any unused motors available, study whether they are utilized or whether they are exchanged between respective equipment.

2) When motors operated at heavy-load hold an overwhelming majority, maintain the distribution voltage at the motor rated voltage value and lower the output capacity of a few light-loaded motors by one rank. Also in this case, study utilization of any unused motors and exchange between respective equipments.

3) When large-capacity motors are operated at heavy load and other small-capacity motors at light load, separate the distribution system for only large-capacity motors from others and lower the supply voltage for the light-loaded motor group.

Besides the above, various combinations are considered and, as such, study on a case-by-case basis. In any case, when replacement and installation of new motors are involved, it should be determined by taking into consideration the equilibrium between the investment amount and conservation energy charge due to improvement of the efficiency.

Another problem with voltage control is the unbalanced voltage. When unbalanced voltage is applied to a three phase. AC motor, unbalanced current of zero-phase-sequence, positive-phase-sequence and negative-phase-sequence component current flows. Of these, the zero-phase-sequence component current, its resultant magnetomotive force being zero, induces no voltage in the secondary winding and, as such, no torque is generated.

However, the magnetic field due to the negative-phase-sequence component rotates at synchronous speed in the opposite direction to the magnetic field due to the positive-phase-sequence component current, thus inducing a voltage having a frequency of ω_0 (2-S) in the secondary winding – then current flows and torque is generated. This torque is called "Negative-phase-sequence component torque".

This negative-phase-sequence component torque increases the copper loss remarkably, because the torque is going to rotate the motor in the reverse direction. As a result, the motor efficiency lowers.

Therefore, it is necessary to minimize the unbalance factor of supply voltage as much as possible and it should be controlled within 1 to 2%. When a single phase load is applied to a three phase AC power source, the current during each phase becomes unbalanced and voltage drops as each phase differs, causing unbalanced voltage. Therefore, it is important to electrically arrange a single phase load properly so that each phase is balanced.

(2) Prevention of idle running and reduced starting loss

Since a motor is sure to be connected to the opposite machine, electric power consumed at no-load running will be about two to three times that of the motor itself. Accordingly, it is important for electric power conservation to stop the motor when unnecessary. Also, in this case, it is desirable to stop the motor cooling fan and field system for the DC motor. At this time, the precautions are as follows:

a. Deterioration and output drop of motors due to multi-frequency starting should be restricted within a range so that they can be used as usual. In the case of large-capacity motors 100kW or more and motors with high GD^2 as a load such as blower, etc., it is recommended to consult with the motor manufacturer.

b. Electric energy during starting should not exceed the electric energy during idle running.

Generally, to re-start a motor, care should be taken, because certain starting methods cause a considerable amount of loss. Starting loss of induction motors and its countermeasures are described as follows:

1) Starting loss of three phase induction motors

Internal loss W_l of a motor when accelerated from a state of slip S_1 to a state of S_2 is generally expressed by the following equation:

$$W_l = \frac{1}{2} \cdot \frac{GD^2}{4} \omega_0^2 (S_1^2 - S_2^2)(1 + \frac{\gamma_1}{\gamma_2'}) \frac{T_m}{T_m - T_l} \quad \cdots\cdots (14)$$

The loss from state of stop to synchronous speed is calculated as

$S_1 = 1, S_2 = 0,$

$$W_l = \frac{1}{2} \cdot \frac{GD^2}{4} \omega_0^2 (1 + \frac{\gamma_1}{\gamma_2'}) \frac{T_m}{T_m - T_l} \quad \cdots\cdots (15)$$

Where γ_1 : Primary resistance of induction motor (Ω)

γ_2' : Secondary resistance of induction motor (Primary side converted value) (Ω)

T_m : Accelerating torque of induction motor (Mean value) (N-m)

T_l: Mean torque of load in acceleration (N-m)

ω_0 : Synchronous angular velocity

2) Reducing method of starting loss

Equation (15) shows that the following will reduce the starting loss.

- Start with a higher motor generated torque.
- From the standpoint of operation efficiency, it is desirable to start with the motor torque as high as possible. Starting with reduced voltage or with reduced current to restrain the starting current lowers the motor torque thus increasing the loss. Therefore, it is desirable to directly start as far as the power source circumstances permit.
- Increase the secondary resistance when starting. When a wound-rotor type induction motor is used, inserting a high external resistance when starting will not only greatly reduce the entire motor loss including the external resistance, but also restrain rotor heat and starting current.
- Change the synchronous angular velocity ω_0.

Changing the synchronous angular velocity of induction motor together with a rise in the motor speed greatly reduces the loss during starting.

To change this ω_0, there are two methods; one is to switch the synchronous angular velocity to step-wise using a pole change motor, and the other is to continuously change the power source frequency together with the speed.

Taking the case of two-step pole change induction motors, we will explain. First, starting with the low-speed side winding, accelerate to the synchronous angular velocity ω_{OL} of the low-speed winding (Number of poles: P_L), and switching to the high-speed winding side, accelerate to the synchronous angular speed ω_{OH} of the high-speed winding (Number of poles: P_H). Total loss of the motor during this period $W^2{}_l$ will be determined as follows. For simplification, it is assumed in equation (14) that $\gamma_1 = 0$, $Tl = 0$.

$$W_{2l} = \frac{1}{2} \cdot \frac{GD^2}{4} \omega_{OL}^2 (1^2 - 0^2) + \frac{1}{2} \cdot \frac{GD^2}{4} \omega_{OH}^2 \left(\frac{\omega_{OH} - \omega_{OL}}{\omega_{OH}}\right)^2 - 0^2 \text{ (J)} \quad \ldots (16)$$

Assuming pole ratio $n = \frac{P_L}{P_H} = \frac{\omega_{OH}}{\omega_{OL}}$

$$W_{2l} = \frac{1}{2} \cdot \frac{GD^2}{4} \cdot \omega_{OH}^2 \left(1 + \frac{2}{n^2} - \frac{2}{n}\right) \text{ (J)} \quad \ldots (17)$$

Assuming the reduction factor for the loss when started with only the high-speed winding from the beginning as K_a, K_a is expressed by the following equation:

$$K_a = \frac{\text{Loss during starting with pole change}}{\text{Loss during starting with only high-speed winding}} = 1 + \frac{2}{n^2} - \frac{2}{n} \quad \ldots (18)$$

The pole ratio at which the loss is minimized in the above equation is determined by a condition of $dk_a/dn = 0$ and the loss will be 1/2 when n = 2. Moreover, increasing numbers of poles changing steps will reduce the loss further.

The following measures are effective in preventing idle running.

- Installation of an idle running alarm device
- Automization of the process and equipment
- Reduction of the waiting time for handling the treated matter by improving the equipment layout and jigs and tools

3) Control of induction motor rotating speed

Control of induction motor rotating speed is widely used for energy conservation of pump, fan, blower and motor for crane. Induction motor rotating speed is generally expressed by the following equation:

$$N = \frac{120f}{P}(1 - S) \quad \cdots\cdots (19)$$

As can be seen from the above equation, the induction motor rotating speed is controlled by any changing of the number of poles P, changing slip S or changing power source frequency f. Rotating speed control systems classified by these control factors are as below:

(3) Control of induction motor rotating speed

Control of induction motor rotating speed is widely used for energy conservation of pump, fan, blower and motor for crane. Induction motor rotating speed is generally expressed by the following equation:

$$N = \frac{120f}{P}(1 - S) \quad \cdots\cdots (19)$$

As can be seen from the above equation, the induction motor rotating speed is controlled by any changing of the number of poles P, changing slip S or changing power source frequency f. Rotating speed control systems classified by these control factors are as below:

- Control of induction motor rotating speed
  - Change of number of poles — Pole change system
  - Control of slip
    - Secondary resistance control system
    - Primary voltage control system
    - Kuramer system
    - Static Scherbius system
  - Primary frequency control
    - Opened-control type frequency conversion system
    - Closed-control type frequency conversion system

Of these, the primary frequency control system (VVVF) can be materialized from the standpoint of remodelling the existing equipment and as such it will be described.

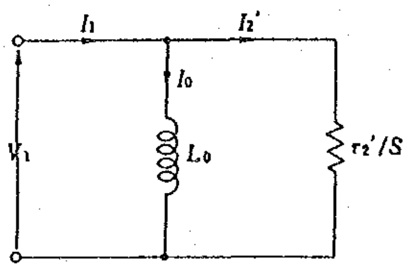
The primary frequency control system controls the primary voltage and frequency of the motor at the same time, by means of a frequency converter, to change the synchronous speed. This control system is mainly divided into opened-control and closed-control types. Of these, the opened-control type is open-loop control in which the converter frequency is determined based on frequency instructions from a setting apparatus irrespective of changes in state such as the motor rotating speed, torque, etc. On the other hand, the closed-control type is closed-loop control in which the converter frequency is controlled according to changes in state of the motor. The opened-control type has V/f constant control in which the ratio of the motor primary voltage V to frequency of (V/f) is constant. The closed-control type has slip frequency control and vector control.

For a characteristic equation during primary frequency control of induction motor, approximations and simple equivalent circuits can be obtained if attention is given to the following points.

Exciting circuit is represented by exciting inductance L_0. Since operated at close to the synchronous speed with this system, the characteristic equation is approximated by a condition of $S \fallingdotseq 0$.

The simple equivalent circuit prepared under this condition is shown in Fig. 14-24.

Therefore, approximation of the characteristic equation can be expressed by the following equations:



Equivalent circuit during operation near synchronous speed.

Figure 14–24 Simple Equivalent Circuit of Induction Motor at Slip = O

$$I_1 = I_0 + I_2' \ [A] \quad \cdots\cdots (20)$$

$$I_0 = \frac{V_1}{\omega_0 L} [A] \quad \cdots\cdots (21)$$

$$I_2' = \frac{SV_1}{\gamma_2'} = \frac{S\omega_0}{\gamma_2'} \frac{V_1}{\omega_0} [A] \quad \cdots\cdots (22)$$

$$T = \frac{3SV_1^2}{\omega_0 \gamma_2'} = 3 \frac{S\omega_0}{\gamma_2'} \left(\frac{V_1}{\omega_0}\right)^2 [N \cdot m/rad] \quad \cdots\cdots (23)$$

On the other hand, assuming the voltage factor as K_ν, the magnetic flux ϕ is

$$\phi = \frac{V_1}{K_\nu \omega_0} = K_1 I_0 \ [W_b] \quad \cdots\cdots (24)$$

Where, $K_1 = \frac{L_0}{K_\nu}$

When control (V/f constant control) is performed so that the ratio of voltage V_1 to frequency ω_0 in the above characteristic equation is constant, the motor torque, current I_0, I_2 and magnetic flux become constant at constant slip frequency $S\omega_0$. Fig. 14-25 shows torque-speed characteristic curve at this point and the maximum torque

Tmax becomes constant against speed ω_0.

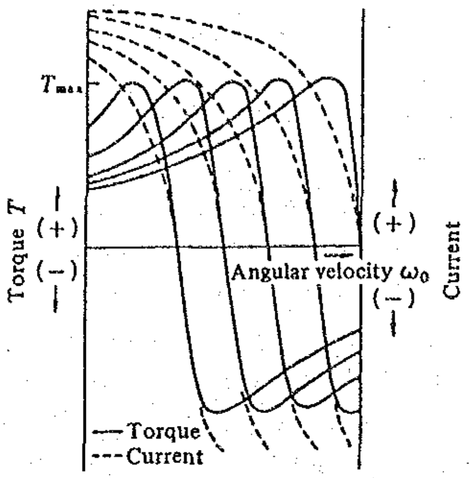


Figure 14–25 Torque-Speed Characteristic of V/f Constant Control

When this VVVF system is used for motor for crane, this has basically the following merits as compared to the rheostatic control system of conventional would-rotor type motors:

a. *Energy conservation effect is great because there will be no heat loss of secondary resistance.*

b. Maintenance is easier because there will be no slip ring and brush.

c. Adding a speed control device enables high precision control.

d. It is very convenient to operate, especially for inching operation at low speed, etc.

(4) Other countermeasures

Diagnose the present equipment capacity. When the equipment capacity is too large as compared to the production scale, it is important for energy conservation to reduce the rotating machine and equipment output. For example, with motors being used as-is, the power to drive the load can be reduced by changing the power transmission mechanism (diameter of a pulley, or reduction ratio of gear etc.). Also, when there are stand-by motors, the energy can be saved by replacing them with smaller motors or lower rotating speed motors.

14.4 Compressors

Energy conservation countermeasures for pneumatic systems are mainly divided into for air compressor, piping and air-operated apparatus.

Power used for compressors is generally given by the following equation:

$$L = \frac{(a+1)K}{K-1} \cdot \frac{P_s Q_s}{6120} \cdot \left[\left(\frac{P_d}{P_s}\right)^{\frac{K-1}{K(a+1)}} - 1\right] \cdot \frac{\phi}{\eta_e \eta_t} \quad \cdots\cdots (1)$$

L: Required power (unit kW)

P_3: Absolute pressure of intake air (unit; kg per square m)

P_d: Absolute pressure of discharge air (unit; kg per square m)

Q_s: *Amount of air per unit time converted to a state of intake (unit; cubic m per minute)* a: Number of intercoolers

K: Adiabatic coefficient of air

η_c: Overall adiabatic efficiency of compressor

η_t: Transfer efficiency

Values η_c and η_t shall be given by the manufacturer.

Accordingly, to reduce service power for compressors,

(1) Lower temperature of intake air. Also, improve the cooling effect in the intercooler.

(2) Lower the discharge pressure. Also, reduce the amount of air used.

(3) Select compressors and systems with good efficiency.

(4) Prevent air leakage from the compressor proper and piping, etc.

(5) Intensify management for the entire system for compressed air.

The above items are important. Respective items will be described below.

14.4.1 Intake Air and Intercooler

When intake temperature rises, air density generally becomes smaller and the actual volume of air sucked with the same power reduces. Since this relation is in inverse proportion to the absolute temperature of intake air, for example, changing intake side temperature from 35°C to 25°C reduces power cost by 3.3%.

Therefore, the air intake opening should be located at a cool place where it is not exposed to the direct rays of the sun. Insusficient cooling in the intercooler brings air compression close to adiabatic compression and increases the compression power on the second stage and after. Since lowered efficiency of the intercooler is caused possibly by lowered heat transfer efficiency due to adherence of scale or slime, or insufficient amount of cooling water, it is necessary to clean the inter-cooler and work out other appropriate countermeasures.

14.4.2 Discharge Pressure and Amount Used

In equation (1), lowering discharge pressure of the compressor reduces the axial power greatly. Table 14-13 shows an experimental example of a compressor actually in use and the required power could be reduced by about 4% by lowering the service pressure 1 kg/ cm².

Table 14--13 Actual Measurement Example of Compressor Performance

(1) Discharge pressure and motor input (kW)

Pressure (kg/cm² G) / Load (%)	7	6	5	4	3
100	226	216	205	190	166
50	156	150	144	134	120

(2) Load (flow rate) and motor input

Load (%)	0	50	100
Discharge amount (m³/min)	0	20	40
Input (kW)	44	132	220

(3) Compressor specification

Discharge pressure (kg/cm°C)	7
Discharge amount (m³/min)	40
Capacity adjustment (%)	0, 50, 100 3 stage
Motor	3.3 kV 220 kW

Fig. 14-26 shows an example of characteristics of 37 kW air compressor.

Generally, when the same operation is performed, many machines and tools having the same capacity differ in the pressure of air required by them. Therefore, if possible, study thoroughly and standardize service pressure of machines and tools in the whole factory to the lower one, to reduce the required electric power.

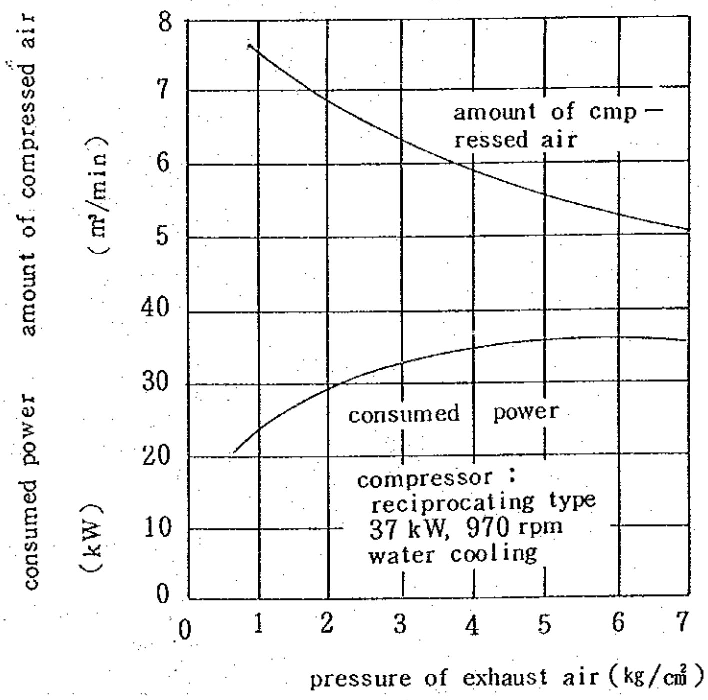


Figure 14–26 Characteristics of 37 kW Air Compressor

When there is equipment requiring high compressed air such as pressing machines in the factory, it is economical to install a booster for exclusive use.

Also, since reduction in the amount of air used is almost in proportion to reduction in the power cost, it is better not to use compressed air for cooling, cleaning, etc., if possible, and it is also better to control the condition for use thoroughly by re-checking the nozzle diameter, etc.

14.4.3 Selection of Kinds of Machines and Operation Systems

The air compressors have the following tendencies from the standpoints of efficiency and it is important to take into consideration when selecting the kinds of machines:

(1) The larger the compressor capacity is, the higher the efficiency will be.

(2) The more the number of compression stages is, the higher the efficiency will be.

(3) When operated with the load factor nearer to 100%, the efficiency will be higher.

Therefore, in a factory where small-scale operation is performed during holidays, operating a large-capacity compressor causes a great power loss and, therefore, it is advisable to separately install a small-capacity compressor which is capable of operating at a load close to 100% on holidays.

Also, when two or more compressors are operated in parallel, it is important to control the number of the compressors in order to make the compressor load factor as high as possible. When the load fluctuates, operate the rotary type compressor at base load and operate the reciprocating type compressor to correspond to the fluctuating load. This serves for energy conservation in the respect of efficiency of both types. Table 14-14 shows classification of air compressors by pressure range.

Table 14–14 Classification of Air Compressor

Type	Class	Main pressure range (kg/cm^2)		Applications
Reciprocating compressor	General purpose compressor	7~8.5		2 stage compressor for 100 kW or more Standard type for 1,000 kW or less
	Intermediate pressure compressor	10~100		For petroleum refining, petro-chemical and general chemical industry processes
	High pressure compressor	150~1,000		For synthetic chemistry such as ammonia, methanol and hydrogenation. Mostly large scale such as several thousand kW.
	Superhigh pressure compressor	1,500~3,500		Mainly, ethylene compressor for synthesis of polyethylene and ethylene.
	Oilless compressor	7~8.5		Oxygen gas, air for food processing industry and instrumentation, etc.
Rotary compressor	Movable profile compressor Screw compressor	1 Stage 2 Stage 1 Stage 2 Stage	3 8.5 7 7~8.5	Air capacity 2~60 m^3/min.

14.4.4 Air Leakage from Clearance, Hole, etc.

(1) Air leakage

Flow rate when air flows out from a vessel with a pressure of P inside into a space at pressure of P_2 is, from Bernoulli's equation

$$Q = S\sqrt{\frac{2g(P_1 - P_2)}{\gamma}}\ [m^3/s] \quad \cdots\cdots \quad (2)$$

Where g: Acceleration of gravity 9.8 (m/S^2)

γ: Specific weight of air (kg/m^3)

s: Effective cross section (m^2)

P_1, P_2: Absolute pressure inside and outside vessel (kg/m^2 abs)

Actually, compressibility and adiabatic expansion become problems and as a practical equation,

$$Q = CS\sqrt{\frac{2g(P_1 - P_2)}{\gamma}}\ [m^3/S] \quad \cdots\cdots \quad (3)$$

Where C: Discharge coefficient

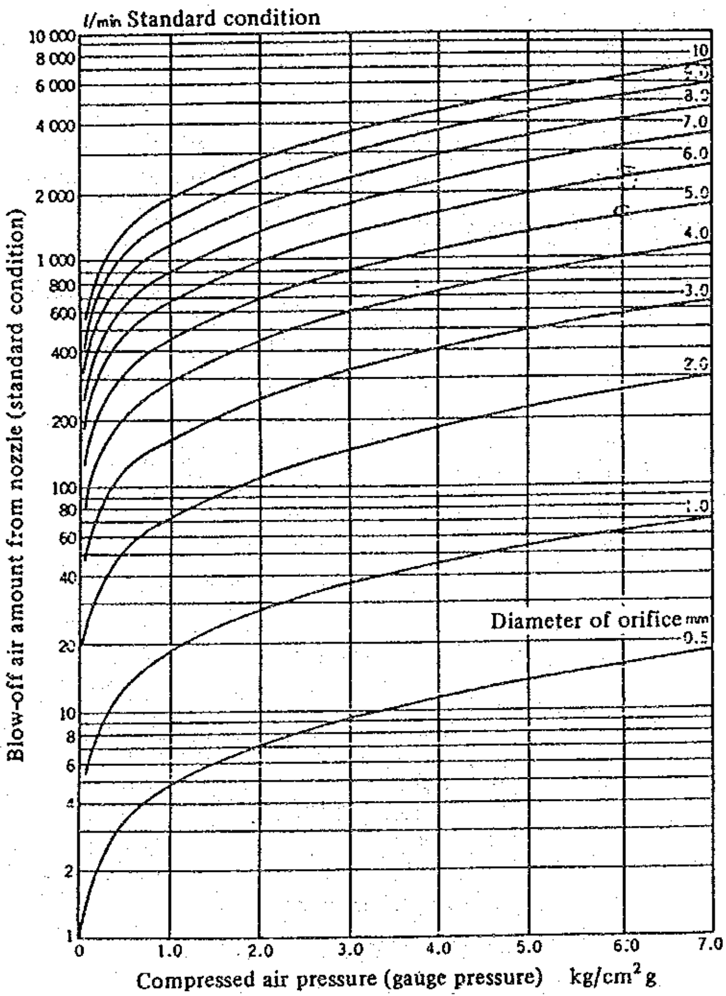


Figure 14–27 Compressed Air Pressure and Blow-Off Air Amount from Nozzle

Since the loss due to this air leakage is very great, it is necessary to check the piping, etc. for leakage and, if any, to repair and correct immeciately. The leakage is in proportion to $\sqrt{P_1 - P_2}$ in equation (3) and, as such, reducing the service pressure surely reduces the leakage. Fig. 14-27 shows the blow-off air amount from a small diameter orifice. Fig. 14-27 is used to determine the blow-off air amount whehn there is a sufficient large capacity receiver tank and piping as compared with the size of the blow-off nozzle. It is assumed that pressure in the tank and piping remains unchanged during blow-off at normal temperatures. The blow-off air amount is converted to a standard condition (20°C, 1 atmospheric pressure).

To apply practically, use selectively a value multiplid by 0.97 to 0.65 because values in Fig. 14-28 are based when discharge coefficient c = 1.

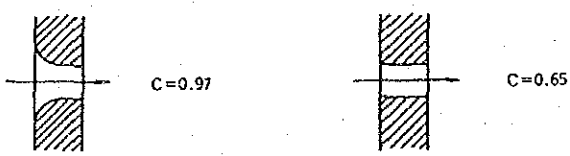
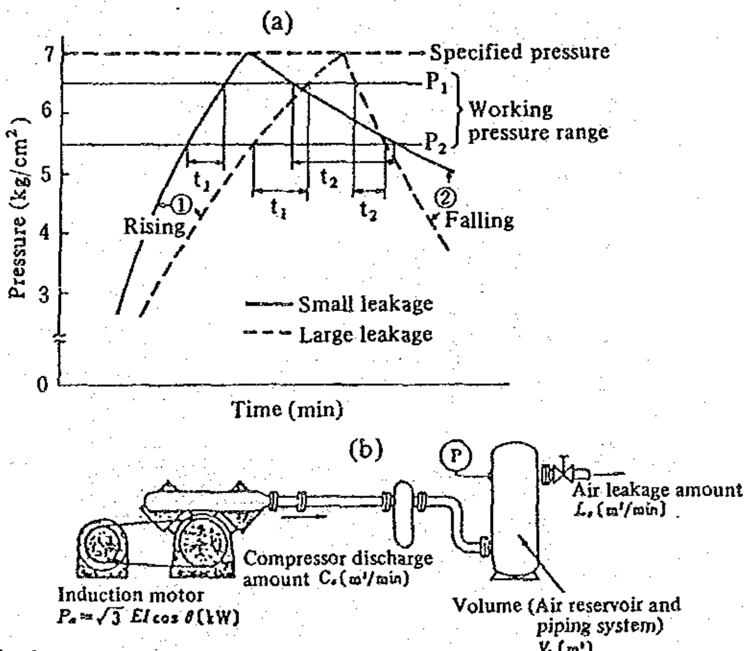


Figure 14–28 Shape of Orifice and Value of Discharge Coefficient

(2) Measurement of air leakage

It is possible to measure air leakage in the following way: first, operate a compressor with the end closed and the pressure gradually rises as shown by (1) in Fig. 14-29(a). Stop the compressor at the specified pressure and let stand as-is, then the pressure will lower of the air leakage as shown by (2). In the case of (a), it shows that the solid line has less leakage than the dotted line.



Ca : Compressor discharge amount

L_y : Air leakage amount

t_1 : Time required for pressurizing

t_2 : Time required for lowering

Figure 14–29 Pressure – Time Curve

Assuming that pressure range (P_1 to P_2) is treated as a pressure to be practically used, and t_1, t_2 are treated as shown in the figure, the following equation is formed.

Assuming volume of compressor equipment, piping system, etc. as V_t,

$V_t = t_1 (C_a - L_y) = L_y t_2$ (m^3)

When air leakage L_y is determined from the above equation,

$$L_y = \frac{C_a t_1}{t_1 + t_2} (m^3/min)$$

Air leakage factor L_p (%) is

$$L_p = \frac{L_y}{C_a} \times 100 = \frac{t_1}{t_1 + t_2} \times 100 (\%)$$

Air leakage is measured by measuring compressor equipment (compressor proper, intercooler, air tank, etc.), piping system, pneumatic machine, control circuit, etc. in the group unit using the sound and the sprinkled soapy water.

14.4.5 Management of Compressed Air Equipment

Precautions for management of compressed air system are as follows:

(1) Management of compressor

To operate compressors in a stable condition at all times, items to be daily checked are:

a. Is cooling water for compressors, aftercoolers, etc. well supplied?
b. Is not generated heat of compressors unusually high?
c. Is the pressure switch for unloader normally operating? Also, is the set value for the pressure switch proper?
d. Does not the compressor give unusual noises?
Also, is the vibration within a normal range?
e. Is the amount of the lubricating oil normal?
Is normal lubricating oil used?
f. Is not the intake side filter clogged?
g. Does the safety valve normally operate?
Is the set value for the safety valve normal?
h. Is the indicated pressure on the pressure gauge normal?
Also, is not the pressure gauge out of order?
i. Is the air tank drain ejector operating normally?
j. Is the intercooler operating normally?

(2) Control of pressure

To control pressure, it is necessary to know the following points:

a. What is the minimum pressure of the line required?
: the minimum pressure to get stable control.
b. What is the maximum pressure of the line?
: the maximum pressure to get stable control.
c. What is the proof pressure of the line?
: the pressure which the control equipment will be damaged.

Set the pressure switch, safety valve and relief valve after knowing the above matters. Items to check in this case are as follows.

a. Are the set values for the pressure switch, safety valve and relief valve in the air tank and piping proper?
Are they operating normally?

b. Is the check valve to prevent back flow of air operating normally?

c. Is the regular operating normally?

d. Is the pressure gauge used in the line normal?
Is not the indication out of order?

(3) Control of drain

For the drain valve installed where drain collects, always discharge drain at least once a day (preferably in the morning when the equipment is operated).

Check Items:

a. Discharge drain by means of the drain valves installed in the air tank, piping down portion, end of the piping and air filter.

b. Is the automatic drain apparatus operating normally?

c. For the air filter and automatic drain apparatus, etc., clean the internal elements periodically.

(4) Control of pipe

Since air leakage causes energy loss and lowered pressure, take care to prevent leakage as much as possible.

Check Items:

a. Does not air leak due to looseness of joints?

b. Does not air leak due to breakage of pipe, hose or tubes?

c. Can the stop valve, etc. be securely closed?

14.5 Blowers (Fan and Blower)

14.5.1 Characteristics of Blowers

Although blowers and compressors have the same principles, below 1 mAq, 1 mAq to below 10 mAq (1 kg/cm^2) and 10 mAq, or the above in discharge pressure are usually called "Fan", "Blower" and "Compressor" respectively.

For classification, they are mainly divided into turbo types and displacement types according to the operating principle, and the turbo type is further classified into an axial-flow system and centrifugal system.

Table 14-15 and Fig. 14-30 sow characteristics of blowers and the characteristic curves respectively.

Table 14–15 Characteristic Comparison of Blowers

Item \ System	Axial flow system	Turbo system	Multivane system	Radial system
Range of use	Air capacity 1~10,000 m³/min Static pressure 1 mmAq~1 kg/cm²	Air capacity 1~10,000 m³/min Static pressure 1 mmAq~1 kg/cm²	Air capacity 1~10,000 m³/min Static pressure 1 mmAq~1 kg/cm²	Air capacity 1~10,000 m³/min Static pressure 1 mmAq~1 kg/cm²
Efficiency (%)	80~92	70~85	50~60	60~70
Efficiency curve	When varied from the planned air capacity, rapidly decreases.	Shows no rapid decrease.	Comparatively smooth	Shows no rapid decrease.
Starting	Fully open damper.	Fully close damper.	Fully close damper.	Fully close damper.
Noise (dB)	39~55	32~44	22~41	28~42
Limit surging air capacity (%) (against air capacity at maximum efficiency point)	70~80	30~60	60~80	50~70
Applications example	For ventilation fan (buildings, architecture, tunnel), for boiler forced draft, for induced exhaust, for mine blower	For various blowers for steel mills, for dust collecting tunnel ventilation, for boiler forced draft, for induced exhaust, for cement kiln exhaust	For various blow and exhaust for steel mills, for boiler forced draft, for building and tunnel ventilation,	For various blow and dust collection for steel mills, for boiler induced draft, exhaust for gas re-circulation, for cement kiln exhaust

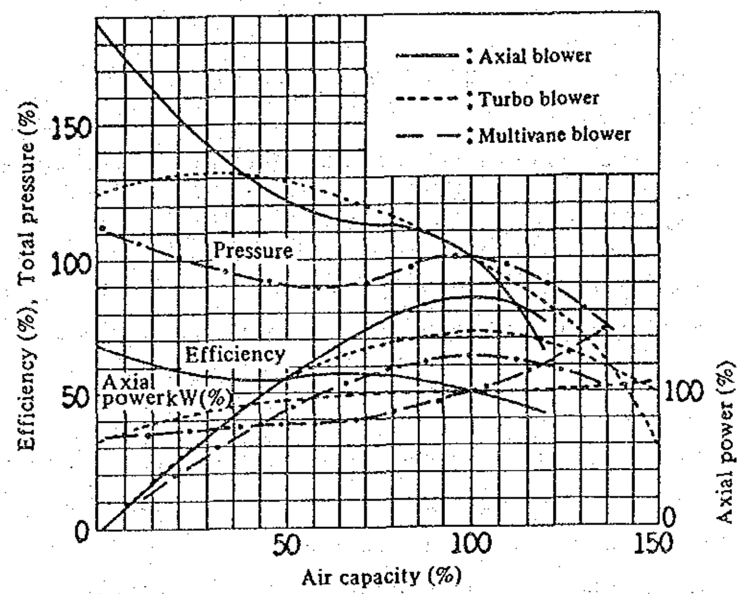


Figure 14–30 Characteristic Curve for Various Blowers

(1) Turbo types

The turbo types have two systems: centrifugal system, and axial-flow system. In the former, centrifugal force is involved in rotation of impellers housed in the casing which provides the gas with speed energy, while in the latter, pressure and speed energy are provided while the gas is being flowed un the direction of rotation by rotating impeller blades with the blade section in the straight pipe. "Turbo type blowers" is a general term for these types.

(2) Displacement types

In the displacement types, the gas is sucked in a chamber with a specified volume, the inlet port is closed and the gas is pressed out to the discharge opening separately provided while the chamber is being pushed, lessened and compressed. This operation is repeated. The gas is pushed out by means of piston reciprocating operation or rotary operation of cocoon type (roots type) rotor.

14.5.2 Required Power of Blowers

(1) Air power (L_r)

Air power means effective energy given to air by a blower in unit time.

$$L_r = \frac{K}{K-1} \cdot \frac{P_{t1} \cdot Q}{6,120} \left(\frac{P_{t2}}{P_{t1}}\right)^{\frac{K-1}{K}} - 1 \;\; [kW] \quad \cdots\cdots (1)$$

Where

P_{t1} : Absolute pressure on suction side (kg/m² abs)

P_{t2} : Absolute pressure on discharge side (kg/m² abs)

Q: Air flow (m³/min)

K: Specific heat ratio (1.4 for air)

When the pressure ratio is 1.03 or below, it may be claculated by the following equation:

$$L_r = \frac{QP_r}{6,120} \; [kW] \quad \cdots\cdots (2)$$

Where P_r: Total pressure of blower (mmAq)

(2) Axial power (L)

Axial power is obtained by dividing the air power by the blower efficiency (η_F).

$$L = \frac{L_r}{\eta_F} (kW) \quad \cdots\cdots (3)$$

The efficiency varies with the air flow as shown in Fig. 14-30, but is generally displayed by that during rated air flow. Its approximate figures are shown in Table 14-15.

(3) Motor output

Induction motors with simple construction and low-cost are generally used for blowers. Squirrel cage type induction motors are used for comparatively small-capacity blowers. In this case, since the inertia (GD^2) of the blower impeller is great, it is necessary to select after due consideration. The motor output (L_M) is determined by the following equation:

$$L_M = L \times \phi \frac{1}{\eta_t} (kW) \quad \cdots\cdots (4)$$

Where ϕ: Allowance rate

η_t: Transfer efficiency

Values of ϕ and η_t are from Table 14-16 and Table 14-17.

Table 14–16 Value of ηt

1 stage parallel shaft type gear reducer with transfer power of 55 KW or less	1 stage parallel shaft type gear reducer with transfer power of 55 KW or more	Constant speed type fluid coupling with transfer power of 100 KW or less	Constant speed type fluid coupling with transfer power of 100 KW or more
0.95	0.96	0.94	0.95

V-belt	Flat belt	Direct-coupled
0.95	0.90	1.00

Table 14–17 Values of ϕ

Propeller fan	Disk fan	Multivane fan	Turbo fan	Plate fan	Profile type fan
1.30	1.50	1.30	1.15	1.25	1.15

14.5.3 Electric Power Conservation for Blowers

Factors for blower electric power conservation are shown in Fig. 14-31 Namely, the fundamental conception of the electric power conservation is:

- Reduce the operating time.
- Adopt high-efficient equipment.
- Reduce air power.

These will be described as follows:

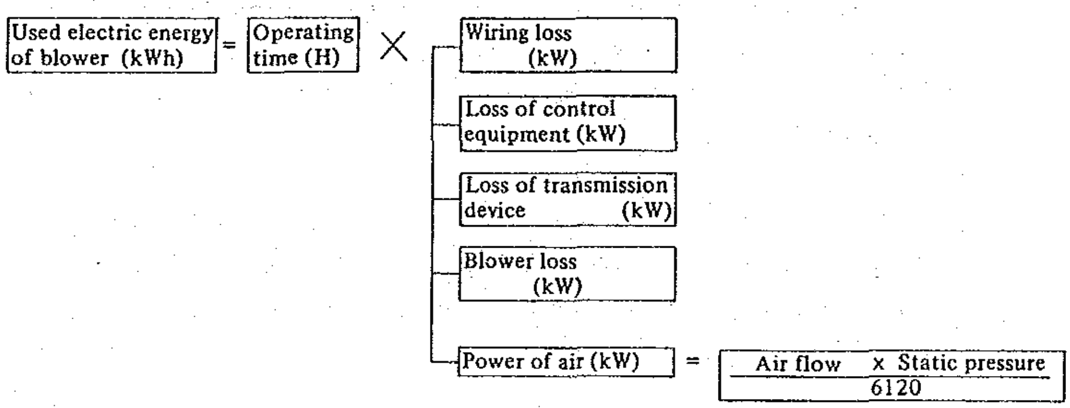


Figure 14–31 Factors for Blower Electric Power Conservation

(1) Reduce the operating time.

Too early start of blowers before the factory operation starts, or very late stop of blowers after close of the factory is often seen in factories which haven't much interest in energy conservation. Also, blowers in operation, although the entire factory is at a stop because of some troubles, are often seen in general factories. Since such useless operation of blowers is a significant adverse factor for energy conservation, it is necessary for the factory manager to give special attention.

The most direct method to eliminate this useless operation of blower is many times ON-OFF operation of blowers. Countermeasures and precuations for prevention of general idle operation for motors were described in the section for Motors. However, blowers generally have great GD^2 and special precautions for ON-OFF operation are as follows:

A) Check the motor for mechanical and electric life

When new equipment is established, the daily number of times for start-up as the conditions is indicated to the manufacture and the equipment fit for the condition is ordered. Therefore, there will be no problem. However, when the blower being almost continuously operated at present is going to be changed to operate to this system, it is necessary to carefully study problems concerning mechanical strength and heat, etc. of the motor caused by frequent start-up.

B) Voltage drop of power source

Since the blower has been started while other loads are at a stop, voltage drop the to the starting current has not become a problem. However, when ON and OFF is repeated while other loads are in operation, troubles by voltage drop of power source may be occured.

Electric machinery and apparatus are generally designed to perform their functions even at a voltage drop of about 10% and they are likely to cause trouble at a voltage drop of more than that. Therefore, in this case, appropriate counter-measures such as reactor starting or adoption of VVVF will be required.

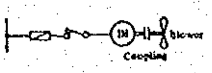
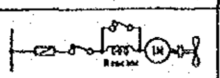
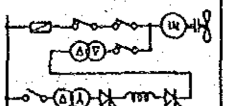
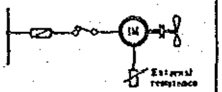
C) Life of starting equipment

Reactors for start-up and starting compensator are generally of a shrot-time rating and when they are changed to very frequent use, the temperature of winding in these equipment will increase, possibly resulting in insulation deterioration and a burning accident. Therefore, for very frequent use, it is necessary to carefully study the temperature rise beforehand.

D) Others

Precautions other than the foregoing are for generated heat for power source cable and life of switches, etc. Table 14-18 and Table 14-19 show comparison of various starting systems when an induction motor is used for a blower, and general life of switches respectively.

Table 14–18 Comparison of Various Starting Systems

Starting system	Composition diagram	Starting current	Starting torque	Voltage when starting	Electromagnetic force	Armature heating capacity	Problems when starting at multi-frequency
Direct starting		100 (6 to 7 times full-load current)	100 (About 150% on rated torque)	100	100 (In proportion to square of current)	$100\left(\frac{GD^2 \cdot N_s^2}{730}[J]\right)$	Power voltage drop, Motor life, Breaker life
Reactor starting		50, 65, 80	25, 42, 64	50, 65, 80 (Standard tap)	25, 42, 64	100	Reactor heating capacity, motor life, breaker life
Closed circuit transition autotransformer starting		25, 42, 64	25, 42, 64	50, 65, 80 (Standard tap)	25, 42, 64	100	*Starting compensator* heating capacity, motor life, breaker life
VVVF Starting		17 or less (Any value below rated current)	70 or less (Any value below rated torque)	0~100 (In proportion to speed)	2~3 (Large when there is inrush current)	Hardly any	Transient torque (when switched from VVVF to main power source), inrush current (when switched from VVVF to main power source), effects from higher harmonic (motor temperature rise, occurrence of shaft voltage, resonance of pulsating torque and shaft torsion, surging voltage when commutating
Secondary side resistor starting (limitted to wound-rotor type)		18~40 (Optional)	80~200 (Optional)	100	3~16	Hardly any (Consumed by external resistance)	External resistance heating capacity, breaker life, slip ring heating capacity, mechanical life of brush lifting mechanism, life of motor for brush lifting

(Note) (1) Value at direct starting is regarded as 100%. (2) Starting torque is generated torque of motor and shall be (Starting torque + Stalling torque)/2.

Table 14–19 Life of Switch (When not Repaired)

	Mechanical life	Electrical life (rated current opening and closing)
Oil breaker	10,000 times	2,000~5,000 times
Vacuum breaker	10,000 times (Possible also for 50,000 times)	10,000 times
Gas (SF.) breaker	10,000 times (Possible also for 50,000 times)	10,000 times
High voltage electro-magnetic contactor	5 million times (Class 1)	500 thousand times (Class 1)

(2) *Adopt high-efficiency equipment*

In this case, the points to which attention should be given are:

a. Efficient of blowers

b. Efficiency of power transmission equipment

c. Efficiency of motors.

Especially for blowers, it is necessary to select the optimum type after having a correct understanding of the fluctuation range for air flow, pressure and temperature. Recently, new products with higher efficiency by improving shape of blade, even of the same type, have been developed.

(3) Reduce air power.

As described in the section for compressors, lowering the air flow, pressure and intake temperature reduces the required power. In the case of a blower, it is generally used with an excessive air flow. For example, when dust collecting effect is sufficient even if the air flow of the dust collector is reduced, it is operated at full capacity because the proper air flow is not known. Also, when a blower for cooling has no problems, even if this air flow is reduced according to the season, it is operated at full capacity. These examples are often seen.

That is, to reduce the air flow, it is necessary to study the following:

a. What is the proper air flow?

b. To acquire this proper air flow, what is the most efficient method?

c. Does not air leak from piping and at the place for use?

There are two methods to reduce the air flow; stationary (fixed) type, and variable tyep.

A) Stationary types

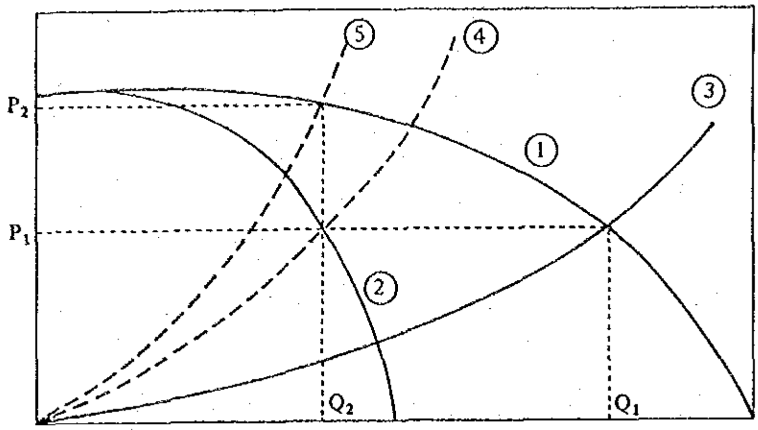
Table 14-20 shows a table for stationary types. The main items of these will be described.

Table 14–20 Method to Reduce Blow Air Capacity (Fixed System)

Main classification	Sub-classification
Reduction in blowing capacity	When blowers are operated, reduce the number. Replace blower. Blower impellers (replace or cut)
Damper, vane opening adjustment	Reducing damper opening Reducing vane opening
Change in rotaing speed	Replace motor. Repalce belt-driven pulley. Insert or replace reducer.

a. Reduction in units

In case two blowers with the same specifications are operated in parallel, when the required air flow is changed from Q_1 to 1/2 of Q_1 as shown in Fig. 14-32, it is necessary to change the resistance curve of the piping system including damper from (3) to (5). The required power at this point is in proportion to $P_2 \times Q_2$. On the other hand, when the operated blowers are reduced to one unit and the resistance curve is changed to (4) the required power at this point is in proportion to $P_1 \times Q_2$. That is, the difference in blowing power between two units and one unit operation is in proportion to $P_2 \times Q_2 - P_1 Q_2 = Q_2 \times (P_2 - P_1)$ and it gives a great energy conservation effect. Since, in fact, the difference in efficiency is added to this, this effect will be greater.



(1) Static pressure curve when two units are operating

(2) Static pressure curve when one unit is operating

(3) Resistance curve to obtain required air capacity, Q_1 (When two units are operating)

(4) Resistance curve to obtain required air capacity, Q_2 (When one unit is operating)

(5) Resistance curve to obtain required air capacity, Q_2 (When two units are operating)

Figure 14–32 Performance Curve during Parallel Operation

b. Replacement ofimpellers

When the blower output becomes too high and the damper is exceedingly narrowed down after the amount of air used is reduced, or when the gas specific weight becomes higher, the wind pressure is too high and the motor is overloaded, it is desirable to replace the impellers.

Assuming the diameter of impeller as D_1, the air flow as Q_1, the pressure as P_1 and the axial power as L, the following relations generally exist.

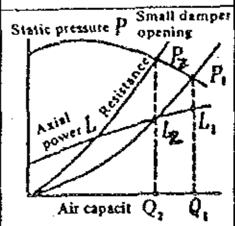
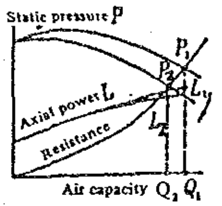
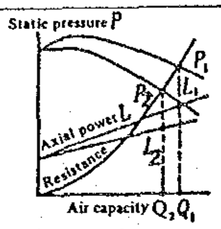
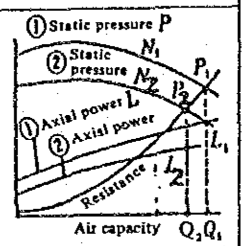
$$Q \propto D^1$$
$$P \propto D^2 \qquad \cdots\cdots (5)$$
$$L \propto D^4$$

Accordingly, diminishing the diameter of the impeller as required will bring very great energy conservation. In this case, it is of course necessary after working to adjust the balance. If there is a large amount of working in the case of multi-stage block, the blade in the 1st stage or 2nd stage may be removed. Adjustment of blowing capacity by this method is limited to about 20%.

c. Damper, vane opening adjustment

The damper is installed vertically to the air duct shaft direction to change the opening and when installed on the outlet side, the opening changes the resistance curve and, when installed on the inlet side, the opening changes the static pressure curve. The vane means a movable blade which is installed at the inlet of the blower and provides the gas entering the blower impeller with swirl in the direction of rotation. Accordingly, adjusting the vane changes the wind pressure-air flow curve. special features of this method are shown in Table 14-21, in which the rotating speed control method is specified for comparison.

Table 14–21 Damper, Vane Opening Adjustment

Method	Discharge damper opening adjustment	Intake damper opening adjustment (discharge side piping)	Intake vane control	Changing the rotating speed
Principle	Change blower resistance curve by intentionally increasing resistance of the piping system.	Since damper resistance is provided on intake side, it serves as a negative pressure and pressure curve slightly changes. Axial power curve also changes slightly.	Reduce the impeller work done by intentionally changing gas flowing angle against blower impellers, thus changing the pressure and power curves at the same time.	Air capacity is in proportion to the rotating speed, the pressure to square of the rotating speed, and the axial power to cube of the rotating speed.
Diagram of principle	 When damper is closed, resistance increases and operating point changes from (P_1, L_1, Q_1) to (P_2, L_2, Q_2). Note; Operating point is a point of intersection of pressure and resistance curves.	 When damper is closed, pressure curve falls and operating point changes from (P_1, L_1, Q_1) to (P_2, L_2, Q_2).	 Reducing vane lowers pressure and axial power curves. Operating point changes from (P_1, L_1, Q_1) to (P_2, L_2, Q_2). Reduction in axial power is far larger than damper opening adjustment.	 Changing the rotating speed from N_1 to N_2 shifts the pressure and axial power curves from (1) to (2), and the operating point from (P_1, L_1, Q_1) to (P_2, L_2, Q_2).
Special features	1) Surging area is wide and effective air capacity control cannot be performed. 2) Axial power does not lower much even in low air capacity area.	1) Surging area is narrower than for discharge damper. 2) Axial power lowers almost in proportion to air capacity.	1) Same as at left. 2) Axial power lowers almost in proportion to air capacity and tends to lower much more than the intake damper.	Axial power lowers most and this is the best method for electric power conservation.

d. Change in rotating speed (change of motor or diameter of pulley)

Assuming the rotating speed of blower as N,

$$Q \propto N$$
$$P \propto N^2 \qquad (6)$$
$$L \propto N^3$$

Since there is the above relation, when it is possible to replace with a motor with lower rotating speed, energy can be greatly saved. However, in this case, once it is changed, it cannot be easily returned to the oroginal position unlike the damper adjustment. Therefore, carefully investigate the resistance curve of load, etc. and be careful so that the air flow is not insufficient after replacement. Also, in the case of belt-drive, it is an effective method to lower the rotating speed by changing the diameter of the pulley.

e. Variable types

In variable control systems of air flow, there are various systems as shown in Table 14-22, of which we will describe the eddy current joint control and Scherbius control.

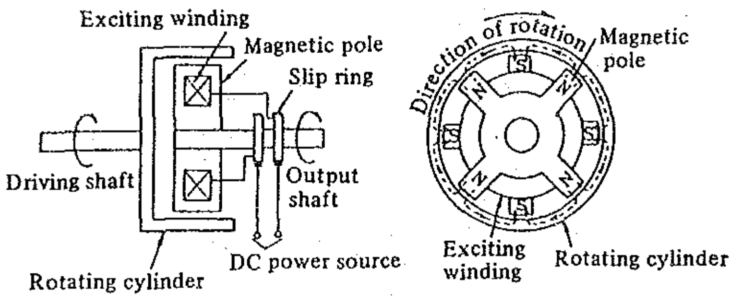
Table 14–22 Method to Control Air Flow (Variable System)

Discharge damper control (Variable)	Intake damper control(Variable)
Intake vane control (Variable)	Change in number of poles
Eddy current coupling control	Secondary resistance control
VVVF control	Scherbius control
	Others

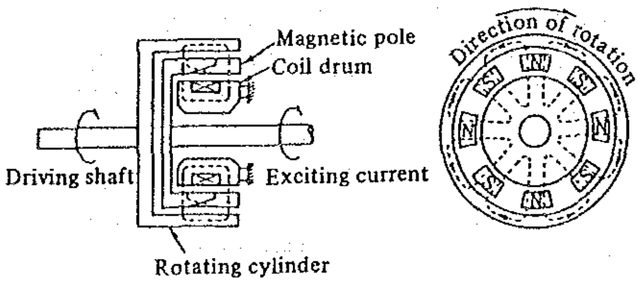
f. Eddy current joint control

This eddy current joint control is a method to change the rotating speed in the following method: while a prime mover (motor) is running at a specified rotating speed, an eddy current joint is direct-coupled to the prime mover output shaft and the slip of the rotating speeds of the input and output shafts is altered to change the rotating speed. Fig. 14-33 (a) shows a principle diagram of the eddy current joint. The salient magnetic pole equipped with the exciting winding inside is direct-coupled to the output shaft, outside of whuch the rotating cylinder is provided across a small clearance. This rotating cylinder is direct-coupled to the output shaft of the prime mover and while the cylinder is rotating at a specified rotating speed, the magnetic flux generated by the exciting winding is cut and, as such, eddy current flows. Electromagnetic force working between this eddy current and magnetic flux generates transfer torque and the magnetic pole direct-coupled to the load rotates in the same direction as the rotating cylinder.

The exciting current is supplied through the slip ring because the magnetic pole is a rotor. However, the slip ring can be eliminated by equipping the stator side with the exciting winding and providing the salient magnetic pole across the small clearance as shown in (b).



(a) With slip ring



(b) Slip ring-less

Figure 14–33 Principle of Eddy Current Joint

Since the amount of the generated torque varies with the amount of the exciting current, changing the exciting current changes the output torque or the speed optionally. The outside rotor has high-slip characteristics as shown in Fig. 14-34.

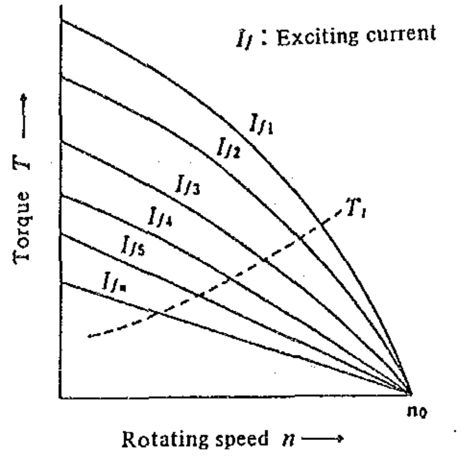


Figure 14–34 Torque Characteristic of Eddy Current Joint

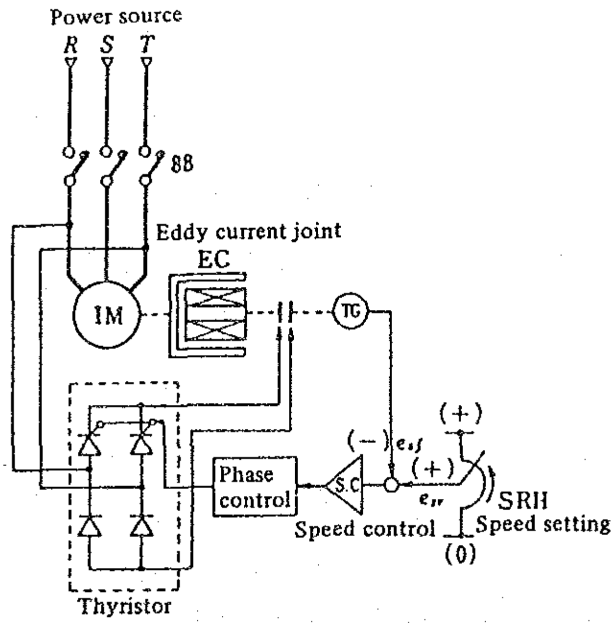


Figure 14–35 Distribution Diagram of Rotating Speed Control by Means of Eddy Current Joint

Fig. 14-35 shows a distribution diagram of rotating speed control when an induction motor is used for the prime mover. For this control, first turn on switch 88 and operate the induction motor before operating the load. If the desired speed is set with the automatic control operated by means of the presetter SRH, the speed standard signal e_{sr} and speed feedback signal e_{sf} are compared and amplified by the speed control circuit and the control angle α of thyristor conversion is controlled through the phase control circuit. The rotating speed can be controlled by controlling the exciting current of the eddy current joint. For the eddy current joint, assuming the slip between the input and output shaft as S, and efficiency of the prime mover as η_m, the system efficiency η_s

will be quite the same as the secondary rheostatic control of the induction motor, and the efficiency in the low-speed area remarkably lowers.

$$\eta_s = (1 - S)\eta_m \times 100\,(\%) \quad \cdots\cdots (7)$$

Since the slip generates heat as eddy curretn loss within the rotating cylinder, the water cooled tyepe is generally adopted for of more than 55 kW.

g. Scherbius control

Assuming the induced electromotive force on the secondary as E_2, the secondary winding resistance per phase as γ_2 and reactance when slip s = 1 as x_2, the secondary current of the wound-rotor type induction motor I_2 (A) is

$$I_2 = \sqrt{\frac{sE_2}{\gamma_2{}^2 + (s_{x2})^2}} \quad \cdots\cdots (8)$$

If electromotive force Ec with the same phase and frequency is supplied to the secondary winding from the outside,

$$I_2 = \sqrt{\frac{sE_2 + E_c}{\gamma_2{}^2 + (s_{x2})^2}} \quad \cdots\cdots (9)$$

Here, E_2 is constant and if the load is constant, I_2 will be constant. Accordingly, changing E_c will change the slip s speed. This is the principle of Scherbius control. Fig. 14-36 shows a principle diagram. In the diagram, electric power corresponding to the secondary copper loss is taken out through the slip ring and returned to the power source by means of a DC-AC converter through a transformer. Adjusting the return power changes the speed.

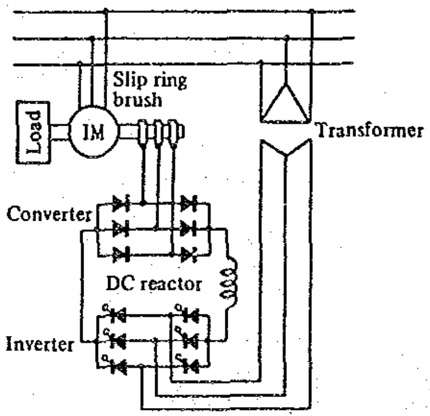


Figure 14–36 Principle of Scheribius Control

The secondary rheostatic control system is of control with low efficiency because electric power corresponding to the secondary copper loss is consumed at the external resistance. This Scherbius control system recovers that electric power and, therefore, becomes a variable control system with very high efficiency. Fig. 14-37 shows motor input (%) of various variable air flow control methods specified in Table 14-23.

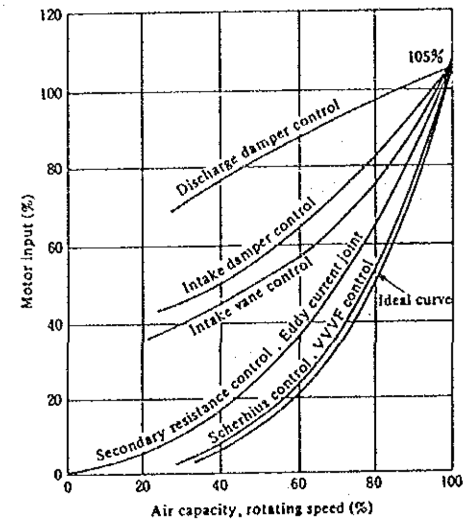


Figure 14–37 Comparison of Blower Motor's Input

Table 14–23 Illumination Standard

Illumination [lx]	Place	Operation
3,000 – 2,000 – 1,500	o Instrument panel and control panel in control room, etc.	Exceedingly fine visual operation in manufacture of precision machines and electronic parts, printing factory, etc., such as o assembly a, o inspection a, o test a, o selection a, o design, o drawing.
1,500 – 1,000 – 750	Design and drawing rooms	Fine visual operation in selection and inspection in textile mills, typesetting and proofreading in printing factory, analysis, etc. in chemical industry, such as o assembly b, o insepction b, o test b, o selection b.
750 – 500 – 300	Control room	Ordinary visual operation in general manufacturing processes, etc., such as o assembly c, o inspection c, o test c, o selection c, o packing a, o desk work in warehouses.
300 – 200 – 150	Electricity room and air conditioning machine room	Rough visual operation such as o packing a, o wrapping b, o restricted operation
150 – 100 – 75	Entrance/exit, corridor, passage, warehouses involving operation, staircases, lavatories	Very rough visual operation such as o wrapping c, o packing b, o restricted operation
75 – 50 – 30	Indoor emergency staircases, warehouses, outdoor power equipment	Operation such as o loading, unloading, load transfer, etc.
30 – 20 – 10	Outdoor (for passage and safety guard within compound)	—

(Remarks)

1. Similar operation are divided into the following three according to the object to view and nature of the operation:
   (1) a in the above table indicates fine, dark colored, weak-contrasted, specially expensive, hygiene-related ones and when high precision is required or when long working hours are required, etc.
   (2) b in the above table indicates an intermediate between (1) and (3).
   (3) c in the above table indicates coarse, light-colored, strong-contrasted, robust, not so expensive ones.
2. For dangerous operation, double above shall be required.
3. For places for operation marked o, this illumination may be obtained by local lighting. It is desirable that illumination for general lighting in this case is more than 1/10 of illumination by local lighting.

14.6 Lighting

14.6.1 Factory Lighting

(1) Purpose of factory lighting

Good lighting facilitates various visual operations and has the following effects:

A) Improved operation efficiency

Proper illuminance diminishes nerve strain, reduces defective products and improves the operation efficiency.

B) Improved operation safety

Since things can be clearly seen and the visual range is widened, employees are careful for their operation and any disasters due to mistakes, etc. can be prevented.

C) Thorough shop management

It becomes easier to point out any defects in the operation and shop, morale for proper arrangement and environmental hygiene is enhanced, and management for the operation and equipment, etc. can be thoroughly achieved.

D) Improved operator's morale

A shop with a well-ordered working environment including lighting enhances the employees' pride and responsibility for their appointed tasks, and excites their desire to work.

(2) Good factory lighting

Good factory lighting has the following factors:

- Proper illuminance and illuminating distribution
- Free from flickering and glare
- Color rendering properties of light source should not be exceedingly improper.
- Good economical efficiency

For proper illuminance, the necessary value is determined by content of the operation, size of the object and color, etc. Values specified in Table 14-24 are recommended as illuminance standard values in Japan. For the aged, these standard values should be somewhat increased.

Also, flickering and glare cause eye fatigue, hindering the operation and lowering the efficiency. Color rendering properties may also hinder some operations.

14.6.2 Energy Conservation for Lighting

As an equation for general lighting in a factory and office, the following equation is well-known.

$$E = \frac{N \times F \times U \times M}{A} \text{ (lx)} \qquad \cdots\cdots (1)$$

Where E : Illuminance (lx)

A : Area of room (m^2)

N : Number of lamps

F : Luminous flux emitted from one lamp (*l*m)

U : Utilization factor (See Note 1)

M : Maintenance factor (See Note 2)

Note 1: Utilization factor U is the ratio of luminous flux applied to the working plane against the full luminous flux from the lamp, and varies with luminous intensity of the luminaire, installed position, room condition, etc.

Note 2: Maintenance factor is the predicted lowering rate (figure) of initial illuminance with lapse of the working time. This varies with how well the equipment will be maintained, which is determined at the design stage.

Determining the energy required for lighting by transforming equation (1),

$$W \cdot H = \frac{N \times F}{\eta} \times t = \frac{A \times E \times t}{U \times M \times \eta} \text{ [Wh]} \quad \cdots\cdots (2)$$

Where W·H: Watt-Hour

η : Lamp efficiency

t : Lighting time (hour)

Since the actual electric power consumed for lighting contains the distribution line loss for lighting added to this equation (2), the following can be considered for energy conservation for lighting:

- Reduce the lighting time.
- Reduce the distribution line loss.
- Keep the illuminance proper.
- Use high-efficient luminaires.
- Improve the utilization factor.
- Improve the maintenance factor.

14.6.3 Concrete Measure for Energy Conservation

(1) Reduce the lighting time

Concrete measures are:

a. Lights-out while unnecessary, including noon recess

b. Individual lights-out near windows

c. Provide many switches for individual lights-out.

d. Lights-out in quiet areas

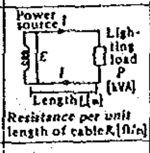
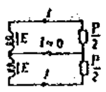
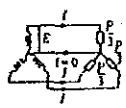
e. Adopt automatic switches or timer switches for outdoor lamps, etc.

In any case, these countermeasures much depend upon the employees' consciousness and therefore, it is necessary to endeavour to enhance it.

(2) Reduce the distribution line loss

Since the distribution line loss greatly varies with the distribution system (See Table 14-24), it is desirable to compare and study well for determination when establishing new equipment. Besides, to increase voltage in the distribution line and to improve of power factor, etc. must be studies.

Table 14–24 Comparison of Loss by Wiring System

Wiring system	Connection	Loss calculation	Loss ratio
Single phase two wire system		$P = EI \times 10^{-3}$ [kVA] Loss $W = I^2 \times 2LR_1 = \left(\frac{P}{E} \times 10^3\right)^2 \times 2LR_1 = \frac{2P^2LR_1}{E^2} \times 10^6$ [W]	100%
Single phase three wire system		$\frac{P}{2} = EI \times 10^{-3}$ [kVA] $W = 2I^2LR_1 = \left(\frac{P}{2E} \times 10^3\right)^2 \times 2LR_1 = \frac{P^2LR_1}{2E^2} \times 10^6$ [W]	25%
Three phase three wire system		$\frac{P}{3} = E \times \frac{I}{\sqrt{3}} \times 10^{-3}$ [kVA]. $W = 3I^2LR_1 = \left(\frac{P \times 10^3}{\sqrt{3}E}\right)^2 \times 3LR_1 = \frac{P^2LR_1}{E^2} \times 10^6$ [W]	50%
Three phase four wire system		$\frac{P}{3} = EI \times 10^{-3}$ [kVA] $W = 3I^2LR_1 = 3\left(\frac{P \times 10^3}{3E}\right)^2 LR_1 = \frac{PLR_1}{3E^2} \times 10^6$ [W]	16.7%

NOTE: Each cable size is same

(3) Keep the illuminance proper

Although it is of course important to secure illuminance required for the operation, it is important for energy conservation to reexamine the lighting level and provide with local lighting for passages, places where persons do not much enter and outdoor lighting, etc.

Also, when establishing a new factory, adoption of natural daylight should be positively considered.

(4) Use high-efficient luminaires

Luminaires here mean stabilizers, lamps and light reflectors. Table 14-25 shows one example of stabilizers' characteristics. To diminish the distribution line size, the current when starting should be smaller, and to reduce the distribution line loss, the power factor should be higher. However, the weight and cost increase in inverse proportion to these and, therefore, it is necessary for selection of kinds of luminaires to study the economical efficiency.

Table 14-26 and Table 14-27 show features and general applications of various lamps.

Table 14–25 Example of Stabilizer Characteristic (For 400W Mercury Lamp)

		Non-dimming type			Dimming type			
		Low power factor type	High power factor type	Constant power type	Constant power type		General type	
Input voltage (V)		200	200	200	200		200	
Voltage tap (V)		200, 220	200, 220	200	200		200, 220	
					Normal	Dimmed	Normal	Dimmed
Input current (A)	When starting	5.7	4.0	2.3	2.3	–	3.8	–
	When stabilized	3.3	2.3	2.3	2.3	1.3	2.4	1.3
Input power (W)		425	425	435	435	255	432	255
Power factor (%)		64	90	95	95	95	90	95
Weight (kg)		4.6	5.2	10.0	13.5		7.0	
Volume ratio (%)		100	160	270	340		220	
Price ratio (%)		100	150	240	310		260	

Table 14–26 Special Features and Applications of Various Lamps

Class of lamps	Special features	Scope of size (W)	Main performance of standard quality: Efficiency (lm/w)	Color temperature (K)	Color rendering index (Ra)	Life	Applications
Incandescent lamp	• Stable light color • Possible to light as-is. • Instantaneous lighting high luminance	Several W ~ Several kW	100W				Residence, store, office
			15	2,850	100	1,000	
Tungsten halogen lamp	Small-size, high efficiency and long life lamp	Several 10W~ Several kW	For general use 500W				For floodlamp, for automobiles, for projection, for photography, for copying machine, studio
			21	3,000	100	2,000	
Fluorescent lamp	• High efficiency and long life • A wide variety of light colors • Little glare	4~ 220W	White 40W				Residence, office, store
			82	4,500	69	10,000	
Mercury lamp	High efficiency, long life, high luminance lamp	40~ 2kW	400W				For floodlamp (baseball ground, golf course)
			51	5,800	23	12,000	
Fluorescent mercury lamp	Mercury lamp with luster improved	40~ 1kW	400W				Roads, factory, street lighting, arcade lighting
			56	4,100	44	12,000	
Choreless mercury lamp	Mercury lamp requiring no stabilizer	160,250 500W	500W				For works, stores
			27	3,000	42	6,000	
Halide lamp	Higher efficiency and lustrous lamp than mercury lamp	250~ 1kW	400W				Gymnasium, factory, shopping street, open space, park
			80	4,500	65	9,000	
High lustrous halide lamp	High lustrous, high luminous lamp	250~ 400W	400W				Cymnasium, lobby, hall
			50	5,000	92	6,000	
Low pressure sodium lamp	Highest efficiency, yellow, luminous lamp	35~ 180W	180W				Tunnel, high-way, switch-yard
			175	–	–	9,000	
High pressure sodium lamp	Highest efficiency, luminous lamp for general lighting	150~ 1,000W					Gymnasium, high-ceiling factory, warehouse, roads, open space
			120	2,100	29	12,000	

Note: Efficiency of fluorescent and mercury lamps is of 100 hrs value.

Table 14–27 Selection of Lamps from Standpoint of Typical Applications

Class of lamps		Incandescent lamp			Fluorescent lamp			Mercury lamp				Halide lamp		Sodium lamp		Xenon lamp
		General lamp	Reflector lamp	Halogen lamp	General fluorescent lamp	High color rendering properties	High output type	Transparent mercury lamp	Fluorescent mercury lamp	Reflector mercury lamp	Stabilizer built-in type	General type	High lustrous type	High pressure	Low pressure	
Residence		◎	○	△	◎	○	×	×	×	×	×	×	×	×	×	×
Office	General office	△	△	△	◎	△	○	×	×	×	×	△	△	×	×	×
	High-ceiling office, lobby	○	○	○	○	△	○	×	○	○	△	◎	○	×	×	△
	Single room, drawing room	○	○	△	◎	○	×	×	△	×	×	△	△	×	×	×
Store	General stores	◎	◎	○	◎	◎	○	×	○	△	△	△	△	×	×	×
	High-ceiling stores	○	○	○	○	○	◎	×	○	○	○	◎	○	△	×	△
	Exhibits, showcase	◎	◎	◎	◎	◎	○	×	△	△	○	○	○	×	×	△
Factory	Low-ceiling factory	△	△	○	◎	○	○	×	△	△	△	△	△	△	×	×
	High-ceiling factory	△	△	○	△	△	◎	×	◎	○	○	◎	○	○	×	△
	Warehouse	○	△	○	◎	△	○	△	◎	○	○	○	△	○	×	×
School	Class room	△	△	△	◎	○	△	×	△	×	×	△	△	×	×	×
Hospital	Operating room	○	○	△	◎	◎	△	×	×	×	×	×	×	×	×	×
Theater, hall	Spectator's seats	◎	◎	◎	◎	○	△	×	△	△	△	○	○	×	×	△
	Stage	◎	◎	◎	◎	○	○	×	△	△	△	△	△	×	×	△
Art museum, museum	General	◎	◎	○	○	◎	△	×	△	△	△	○	○	×	×	△
	Exhibits	◎	◎	○	○	◎	△	×	×	×	×	○	○	×	×	△
Roads	Automobiles exclusive roads	×	×	×	△	×	×	△	◎	×	×	△	×	○	○	△
	Automobiles exclusive tunnel	×	×	×	△	×	×	△	○	×	×	△	×	○	◎	×
	Streets	△	×	×	○	×	×	△	◎	△	△	△	△	○	△	×
	Shopping streets	○	×	○	○	△	◎	×	◎	△	△	◎	△	○	×	×
	Roads in resident area	○	×	×	○	×	×	△	◎	△	×	△	×	○	×	×
Parking zone	Indoor	△	△	△	◎	×	○	×	○	△	△	△	△	○	×	×
	Outdoor	△	△	△	○	×	×	△	◎	○	△	△	△	○	△	△
Open space, park, garden		○	△	△	○	△	×	△	◎	△	△	○	△	○	×	△
Floodlight lighting	Structure	○	○	○	×	×	×	△	◎	◎	○	○	○	○	△	○
	Advertisement, signboards	○	◎	◎	○	○	○	△	◎	◎	△	○	○	△	×	○
Sports	Indoor	○	○	◎	○	○	○	△	◎	○	△	◎	○	△	×	△
	Outdoor	○	○	○	×	×	×	△	◎	○	△	◎	○	◎	×	○

(5) Improving utilization factor

Table 14-28 shows an example of the utilization factor table. Room index RI in this table is calculated in the following equation:

Table 14–28 Example of Coefficient of Utilization Table

Ceiling	80 %									50 %								
Wall	60 %			30 %			10 %			60 %			30 %			10 %		
Floor surface	40 %	20 %	10 %	40 %	20 %	10 %	40 %	20 %	10 %	40 %	20 %	10 %	40 %	20 %	10 %	40 %	20 %	10 %
Room index	Coefficient of utilization																	
0.60	.45	.42	.40	.31	.30	.30	.26	.25	.25	.41	.39	.38	.30	.29	.29	.25	.25	.25
0.80	.56	.51	.49	.41	.39	.38	.35	.34	.33	.51	.48	.47	.39	.38	.37	.34	.33	.33
1.00	.63	.57	.55	.47	.45	.44	.41	.40	.39	.57	.53	.52	.45	.44	.43	.40	.39	.38
1.25	.71	.63	.60	.55	.52	.50	.48	.46	.45	.64	.59	.57	.52	.50	.49	.46	.45	.44
1.50	.76	.68	.64	.61	.56	.54	.54	.51	.50	.68	.63	.61	.57	.54	.53	.52	.50	.49
2.00	.85	.75	.70	.71	.65	.62	.64	.59	.57	.76	.70	.67	.66	.62	.60	.60	.58	.56
2.50	.91	.79	.74	.78	.70	.66	.71	.65	.62	.80	.73	.70	.71	.67	.65	.66	.63	.61
3.00	.95	.82	.76	.83	.74	.70	.77	.69	.66	.84	.76	.73	.76	.70	.68	.71	.67	.65
4.00	1.01	.86	.80	.91	.79	.75	.85	.76	.71	.88	.80	.77	.28	.75	.72	.78	.72	.70
5.00	1.09	.88	.82	.96	3.8	.77	.91	.79	.78	.91	.82	.79	.88	.78	.78	.82	.76	.73
10.00	1.13	.93	.86	1.08	.90	.84	1.05	.89	.82	.97	.87	.83	.94	.85	.81	.92	.84	.80

Light output ratio: 83% Light source: FL 40 SW 3,400 lm Fluorescent lamp reflector used

$$RI = \frac{W \times L}{H(W + L)} \quad \cdots\cdots (3)$$

Where w: Width of room (m)

L : Depth of room (m)

H : Height of light source from the working plane (m)

The room index has a higher value when it is a square room. And the utilization factor will be higher with the higher reflectivity of the inner wall and floor and the higher room index.

(6) Improving maintenance factor

To improve the maintenance factor, first adopt luminaires with less lowering of luminous flux with lapse of the working time and secondly periodically clean the luminaires and replace the lamps. However, under the actual circumstances of the factory with much expenditures in labor cost, it will be unavoidable to replace the lamps and clean the luminaires when the lamps are burnt out. Therefore, the first countermeasure is to use luminaires with less lowering rate.

Fig. 14-38 and Fig. 14-39 show the lowering tendency of the luminous flux of lamp itself and the lowered luminous flux when dirt accumulates on luminaires respectively.

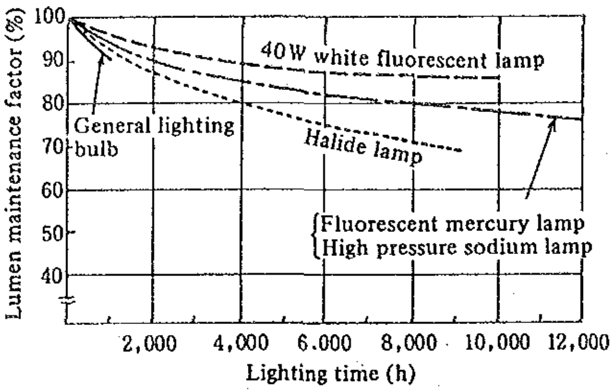


Figure 14–38
Lumen Maintenance Characteristic of Various Light Source

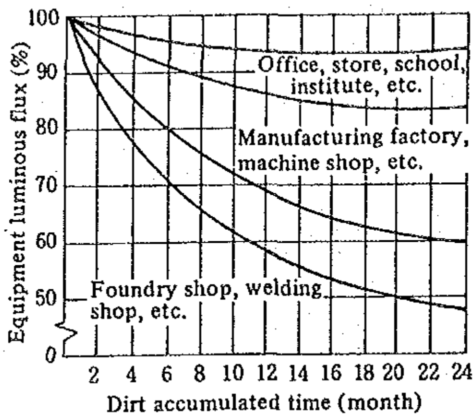


Figure 14–39
Lowered Lumen when Dirt Accumulated on Lamp and Lighting Equipment

(7) Others

Other precautions for lighting are not to fluctuate the supply voltage. Although motors, etc. are capable of operating smoothly even at ±10% fluctuation, lamps are manufactured to perform their best functions and ensure the longest lives at the rated voltage. Therefore, it is desirable to separate illuminating circuits from motor circuits and also to restrict the voltage fluctuation with ±5%.

Also for ambient temperatures, it is important not to deviate from the manufacturer's specified value.

14-7 Electric Heating Systems

14.7.1 Types of Electric Heating Systems

The electric heating systems are classified as shown in Table 14-29. Their common features are as stated below.

a. High temperature

It is possible to heat to the high temperature of 2,000°C or more by arc heating and direct or by directly making a current flow through a heating unit.

b. High heating efficiency

The heating efficiency is high because an object generates heat and there is no exhaust gas loss. However, it is necessary to make a general judgement of the power generation process including heat loss and input conversion efficiency.

c. Quick heating

It is possible to change the direct electric power to heat in an object heated and conduct quick heating by raising the electric power density.

d. Easy temperature control

As automatic control and remote control can be made easily, it is possible to control the temperature precisely.

e. Easy atmospheric control

Atmospheric control can be made easily because no combustion is involved.

Table 14–29 Type and Main Applications of Electric Heating Systems

Heating method	System for converting electric energy to heat		Main applications and examples of units
	Conversion system	Heating system	
Utilization of Joule heat and arc heat	Resistance heating	Indirect resistance heating (50/50Hz)	Various types of heat treatment furnaces using resistance heating means, sintering furnace, diffusion furnace, brazing furnace, salt bath furnace, and fluid bed heating
		Direct resistance heating (50/60Hz) (DC)	Direct energizing heating of metal, graphitizing furnace, glass melting furnace, and ESR furnace
	Infrared ray heating	Proximate infrared ray heating (0.76 – 2.5μm)	Baking of painted surface, drying, and molding and processing of plastics
		Remote infrared ray heating (2.5 – 25μm)	Heating at 650°C or less, drying of painting, braking, resin hardening and processing, bread braking, heating, plant rearing
	Arc heating	Arc heating (50/60Hz)	Steel making, dissolution of fire resisting materials, and dissolution of vacuum arc
		Plasma arc heating (DC)	Dissolution of heat resisting steel, Ni alloy steel, high melting point metal and alloy, dissolution of high melting point compound, production of single crystal, and high temperature thermochemical processing of other materials
Utilization of electromagnetic induction	Surface leather heating	High frequency induction heating (50/60Hz – 450 kHz)	Dissolution of metal and alloy, heating for thermal processing, heat treatment of metal, welding, and brazing
		Low frequency induction heating	Dissolution of cast steel and heating of large-sized steel
	Transverse flux heating		Heating of sheets such as non-ferrous metal and stainless steel
	Short-circuit heating	For metal dissolution	Groove-shaped blast furnace and temperature rise of molten bath
		For metal heating	Interference of metal parts
Utilization of high frequency electric field	Induction heating (3 – 40MHz)		Drying of lumber, drying and heat treatment of food, leather, textile, chemicals and synthetic resin, bonding of lumber, and welding of synthetic resin
Heat developed by the impact of electronic and ion flow	Electron beam heating		Evaporation of metal, dissolution of high melting point metal, and fine processing of metal
	Ion and ion beam heating and processing		Ion carburizing, heat treatment such as nitriding, surface coat treatment, etching of semi-conductor, implantation, and other surface treatment
	Glow discharge heating		Surface heat treatment of metal and metal heating
Utilization of electromagnetic wave	Laser heating and processing (1 – 11μm)		Drilling processing of process-resistant material, welding, heat treatment and cutting of metal material, welding and processing of electronic parts, etc.
	Microwave heating (915, 2,450MHz)		Preparation (electronic oven), drying and thawing of food, heating and vulacanization of rubber, and sterilization of food and chemicals
Utilization of electric mechanical power	Heat pump system	For household use	Air conditioning, hot water supply, and building air conditioning
		For industrial use	Drying of food, lumber and leather, effective utilization of exhaust heat, and others

14.7.2 Special Features of Far Infrared Rays

(1) Infrared rays

Infrared rays are electromagnetic waves ranging from 0.75 μm to 1,000 μm, namely having a wavelength longer than visible light and shorter than microwaves. Infrared rays are further divided into near infrared rays for 0.75 μm to 4 μm and far infrared rays for 4 μm to 1,000 μm.

(2) Principles of infrared heating

A substance is heated by other heat sources in three ways; convection, conduction and radiation. As the infrared rays are electromagnetic waves, the transfer of heat is by radiation. That is, infrared rays emitted from a heat source are directly absorbed by an object to transfer heat.

Various molecules of which a substance is composed have respective peculiar vibrations and rotary frequencies by difference in kinds of its atoms and binding power in the molecules. When the frequency of incident infrared rays coincides with these vibrations or rotary inherent frequencies, the molecule absorbs energy from the infrared rays, and these vibration or rotation gets harder, generating heat. This phenomenon is known as resonance absorption.

When the incident infrared wavelength is not within the absorption wave range, the infrared rays pass through molecules and no heat is generated. Fig. 14-40 shows infrared absorption spectrum of vinyl chloride resin and there is a strong absorption wave range mostly in far infrared areas though there is also a portion of absorption wave range which is in the 3.5 μm medium infrared areas.

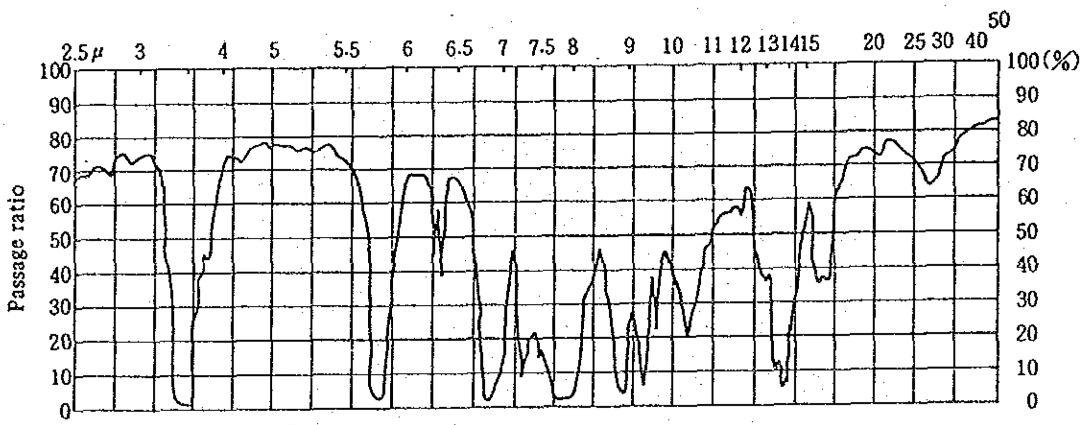


Figure 14–40 Vinyl Chloride Infrared Absorption Spectrum

For organic matters of macromolecular and a portion of inorganic matters, a greater part of the absorption wave range is in medium and far infrared areas and there is almost no absorption wave range in near infrared areas in most cases.

Far infrared heating is effective for high-molecular compounds, enable to heat for a short time, and energy can be saved as compared to the use of an infrared ray lamp having an energy peak near infrared areas.

Fig. 14-41 shows one example of spectral radiation characteristics of infrared ray lamps and far infrared heaters, from which superior emission characteristics of the far infrared heaters in long wave areas are well understandable.

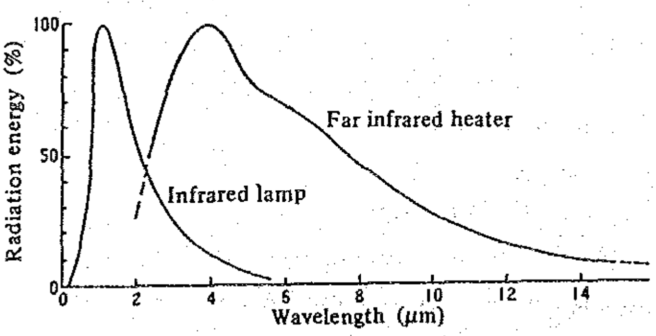


Figure 14–41 Special Radiation Characteristic of Infrared Lamp and Far Infrared Heater (Example)

(3) Features of far infrared heating

Points, in which infrared heating is considered to be more advantageous than other methods such as hot air heating, high frequency heating, etc. are as follows:

a. It is simple to operate.

b. No medium is required to transfer heat, and the object can be directly heated: therefore, response is quick and energy can be saved.

c. It is easy to heat and control.

d. Much space is not required, and it is comparatively easy to move.

e. Equipment cost is low.

f. The object to be heated is easy to monitor.

Also, points the which far infrared heating is considered to be superior to conventional infrared heating are as follows:

A) Drying finish is good.

Since the far infrared heater uniformly heats up the inside of a substance by long wavelength, it is not necessary to heat the substance surface more than required, and the dried substance obtains superior physical properties. Accordingly, in the case of paint drying, no foaming is caused and internal hardening of the coat is also good.

B) Heating unevenness does not occur due to difference in color.

C) Heat-treating time is shortened and energy can be saved.

D) Life is long.

Since the far infrared heater heating unit is sealed and contact with air is shut off, the performance is not lowered much.

Even if it is located at a place exposed to waterdrops or with severe vibration, it is not likely to be damaged and can hold a life of more than several years.

(4) Precautions for application of the far infrared heating

Precautions for application of the far infrared heater are as follows:

A) Selection of effective object

The object to be processed must be of suitable material for the far infrared absorption characteristics and it is important to get an accurate absorption characteristics by literature or experiments beforehand.

B) Construction of equipment

It is necessary, as much as possible not to project a shadow on the object. To do this, it is advisable to avoid an object with a complicated construction. However, somewhat of the shadow can be supplemented by arrangement of the heater or arranging a reflector on the inner wall surface of oven.

C) Ventilation in the ovens

Generally, natural ventilation is enough. When, however, steam or carbon dioxide gas is produced in large quantities, forced ventilation is required. When forced ventilation is performed, it is necessary not to lower the heater temperature.

D) Temperature measurement

It should be noted that the temperature of the object may often exceed the atmosphere temperature in the furnace.

E) Light reflectors

Dirty or damaged light reflectors remarkably lower the reflection efficiency. When dirty, clean by spraying air, etc. so that they are not damaged.

F) Re-examination of irradiation conditions

Heating efficiency lowers due to long-term use or change in the reflection efficiency, etc. even if the object remains unchanged. When any change is recognized in disposal conditions, it is important to investigate the causes and adjust the irradiation conditions such as irradiation distance, heater voltage, conveyor speed, etc.

14.7.3 Application of far infrared Equipment to Industry

As already described, in far infrared heating, the heater itself is an energy-saving heat source, unlike convection and conduction heating, and research and development are expected to advance increasingly and its applicable fields are considered to be enlarged in the future. Table 14-30 shows applicable examples in industrial fields considered at present and Table 14-31 shows examples of practical use in various industries. This indicates how great the energy conservation effect of the far infrared rays is.

Table 14–30 Applicable Industrial Fields of Far Infrared Rays Heating

Type of industry	Examples of applications
Manufacture of machinery and appliances	Automobile body paint drying, Motorcycle marking drying, Automobile frame primer drying, Casting paint drying, Home electrical appliances paint drying, Transformer case paint drying, Injection molding heating, Furnitures paint baking, Dental cream tube and beer can print drying, Condenser paint drying, Pulverulent body paint drying
Chemical industry	Printed circuit board drying, Vinyl chloride resin gelatinization, Chemicals drying, Acrylic sheet softening, Printing ink drying
Lumber, wooden product, building material, paper pulp	Furniture and batt plywood drying, Plywood adhesive drying and hardening, Lacquer ware drying, Half-split chopsticks drying, Plywood paint drying, Gypsum board drying, Slate roofing primer and finish coat drying, Mirror surface letters baking, Fire board resin processing, Laminated paper baking and drying, Wall paper processing and drying
Textile industry	Sizing and drying, Printing and drying, False twister
Food manufacture and processing	Boiled fish paste, a kind of fish paste baking and drying equipment, Rice cake baking, Ripening SAKE, Frozen food thawing, Meets drying, Smoked fish drying.
Agricultural and marine products	Heating for pig breeding, Brooder, incubation, Plant forcing culture, Raising (Laying eggs acceleration, frys breeding, baits multiplication)

Table 14–31 Example of Practical Use of Far Infrared Rays Heating

Classification	Name of process	a. Conventional heat source	Outline of processing	b. Effect of application of far infrared rays (b/a)				Scale of practical use
				Consumed energy (%)	Fuel cost (%)	Processing time (%)	Others	
Textiles-related	Narrow fabrics manufacture	LPG direct flame	Sizing, finishing and drying of narrow fabrics containing rubber in use for training ware, trousers and underwares.	46	73	100	Improved quality, Omission of water washing process	16.8 kW × 14 unit
	Resin treatment of textile products	Schwung burner for LPG	Heat and set vinyl chloride on gloves, socks, entrance mats, car seat, etc. and provide non-slip processing	43	85	67	Improvement of operating circumstance, homogenizing and quality improvement of products	154 kW
	Yarn-dyeing woven textile	Infrared lamp	Sizing and drying fabric yarn (nylon) for umbrellas	71	71	100	Preventing damage to bulbs, etc. Improvement of equipment and operation safety	8 kW × 2 unit
	Sewing and dyeing	Quartz pipe heater	Athletic shirts print drying	32	32	67	Improvement of operational circumstances	1.5 kW × 3 unit
	Crepe dyeing	Schwung burner for LPG	Crepe 80% dyeing (brushing) drying	71	68	100	Improvement of operational circumstances	6 kW
	Manufacture of printing screen	Kerosene warm air	Drying after coating high class printing screen with developing solution	16	27	20	Quality improvement	12 kW
	Manufacture of insect screening	Fuel oil steam warm air	Heat set of vinyl chloride, polypropylene insect screening	60	56	100	Improvement of operational circumstances	16 kW
	Sizing, woven textile	Infrared lamp	Beaming process, sizing and drying of woven textile warp (polyester)	24	24	33	Improvement of operational circumstances	2 kW
Electric and construction machinery, home appliances, others	Manufacture of construction machine parts	Fuel oil steam warm air	Cast iron products paint drying	50	80	33	Reduced equipment area 1/4	26 kW
	Water heater, hot water feeding machine manufacture	Schwung burner for LPG	Armored portion paint drying	20	28	25	Reduced equipment area 1/3 Quality improvement	25.2 kW
	Manufacture of large-sized crests and nameplates	Fuel oil steam or natural	Drying ground of hard porcelain and large-sized crests before calcination	• Natural drying 30 to 40 days, steam drying 20 days → Far infrared 3 to 4 days • Fuel cost for drying process unknown			Yield 30 → 100% Improvement of operational circumstances	1.5 kW × 3 unit
	Manufacture of aluminum home appliances	Electrial heat	Heating in glazing process of aluminum pans and kettles, etc.	14	23	38	Furnace efficiency 30 → 78% Equipment capacity 37% Improvement of operational circumstances	16.5 kW × 3 unit
	Sale of herb	Natural	Drying to keep harb from getting moldy during storing herb	—	—	(3 ~ 5 minutes)	Quality improvement Preventing occurrence of mold and insects	12 kW

14.8 Air Conditioning

14.8.1 What is Air Conditioning?

Air conditioning means to control so that the air conditions in a room are kept at an optimum, according to the use application or purpose of the room or factory.

Air conditions in a room to be controlled have the following four factors:

(1) Temperature

Control the dry-bulb temperature to the specified value by cooling or heating air in the room.

(2) Humidity

Control air in the room to the specified comfortable relative humidity.

(3) Cleaness

Remove dust in the air and, at the same time, maintain so that the concentrations for smoke, carbon dioxide gas, odor, poisonous gas, etc. do not exceeded the limit.

(4) Distribution

Prepare moderate air flow so that conditioned air is distributed in the room and make temperature and humidity conditions at each point in the room constant.

The purpose of air conditioning is mainly divided into two; one is A) health air conditioning, and the other is B) process air conditioning.

A) Health air conditioning

This is to hold air in the room at air conditions fit for persons in the room or operators in the room, and the two main factors to control optimum air conditions are temperature and humidity. Fig. 14-42 shows the comfort zone in summer and winter.

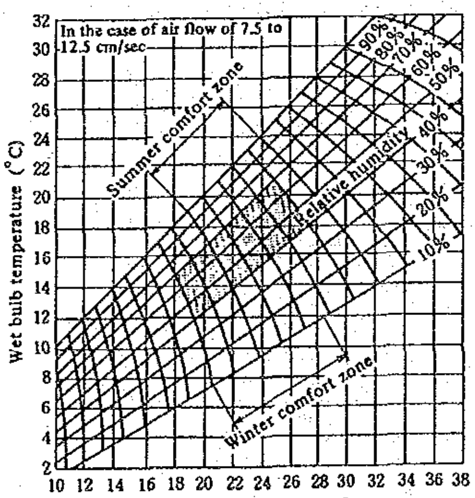


Figure 14–42 Comfort Zone

Separately from this diagram, to eliminate shock from air-conditioning, it is said to be preferable to keep temperature difference between indoors and outdoors small, and humidity low. The temperature difference between outdoors and indoors is said to be proper at 5 to 7°C.

B) Process air conditioning

Many of various industrial production processes require individually peculiar conditions for temperature and humidity of ambient air and cleanness in each process from raw material to completion of the products.

Table 14-32 shows typical design air conditioning conditions for each industrial process. However, values on this table are only for the standard and, therefore, it is necessary to investigate well for determination when individually designing.

Table 14–32 Example of Process Air Conditioning

Classification	Process	Temperature (°C)	Relative humidity (%)
Color printing	Bronze plating room	24~27	45~50
	Plate preparation	24	"
	Printing room	24~27	"
Printing	Book binding	21~24	45
	Form	24~27	45~50
	Printing room	"	"
	Web press	"	50~55
	Paper storage	20~23	50~60
	Photographic printing	21~23	40~50
Optics	Melting room	24	45
	Abrading room	27	80
Plywood	Manufacture	–	55~60
	Gluing	–	"
Rubber	Storage	14~24	40~50
	Cementing	27	25~30
	Dipping	24~27	"
	Manufacture	32	–
	Sulfurization	26~28	25~30
Laboratory	Animal laboratory	24~27	40
	General analysis room	23	50
Photograph	Manufacture of ordinary film	23~24	24~40
	Printing	"	65~70
	Finished product storage	16~27	45~50
	Developing	21~24	60
Bakery	Base mixing	24~27	45~55
	Base fermentation	27	70~80
	Bread cooling	21	"
	Bread wrapping	18~24	50~65
	Powder storage	21~27	50~60
	Cake freezing	"	45~50
Precision machinery	Gear cutting	24~27	45~55
	Precision parts	24	"
	Precision assembly	20~24	40~50
	Precision test room	24	45~50
Pharmacy	Capsuling	24~27	35~40
	Colloid	21	30~50
	Deliquescene salt	27~32	15~40
	Gelatin capsule	26	40~50
	Powder product	24~27	5~35
	Tablet forming	21~27	35~40
	Tablet finish coating	24~27	"
	Serum	23~26	45~50
	Powder material drying	54~71	20
	General pharmacy room	21~27	10~50
Electricity	Manufacture of thermostat	24	50~55
	Manufacture of insulating material	24	65~70
	Assembly of electron tubes	20	40
	Cable insulation	40	5
	Transformer coil winding	16~24	15~35
Food	Manufacture of butter	16	60
	Coffee substitute	24~27	40~45
	Milling	–	60
	Macaroni	21~27	38
	Mayonnaise	24	40~50
	Mushroom growing room	14~27	75
Brewing	Storage of grains	16	35~40
	General manufacture	16~24	45~65
	Aging room	18~22	50~60
	Beer fermentation room	3~ 4	50~70
	Beer malthouse	10~15	80~85
Confectionery	Chewing gum — Cooling	22	50
	Drying	49~60	50
	Wrapping and storage	21~24	45~60
	Candy — Manufacture	18~27	35~50
	Cooling	24~27	40~45
	Product storage	16~24	45~55
	Dry fruits storage	10~13	50
	Chocolate — Bar manufacture	18	45~50
	Center cream manufacture	24~29	50
	Nougats	18	50
	Starch room	24~29	50
	Wrapping	18	50
	Product storage	16~24	40~50
Tobacco	Cigarette — Raw material storage	27	75~78
	Cutting	24~27	80
	Cut tobacco storage	27~29	60~65
	Manufacturing room	21~27	55~65
	Wrapping room	27~29	50
	Truck removing room	27	70~75
	Sweating	49	80
Cotton spinning	Roving	21~24	50~55
	Spinning	"	55~65
	Drawing	"	55
	Picker	"	45~50
	Roving	"	50~60
	Warp spinning	24~27	50~65
	Weft spinning	"	"
	Cotton reel	"	60~70
	Twister	21~24	65
	Woven textile	24~27	70~85
	Fabric storage	24~27	65~75
Jute spinning	Fabric conditioning room	24~27	90~95
	Spinning	24~27	60
	Woven textile	26~27	80
	Preparation	18~20	80
	Roving and spinning	24~27	60
Match	Manufacture	22~27	45~50
	Storage	15	50

14.8.2 Setup of Air Conditioning System

Air conditioning is generally performed by blowing air at a suitable temperature with moderate humidity and cleanness from diffusers into a room. Accordingly, to accomplish this, there are various methods considered. Fig. 14-43 shows a setup example of a comparatively large-scale air conditioning system, on the basis of which we will describe with an eye to cooling.

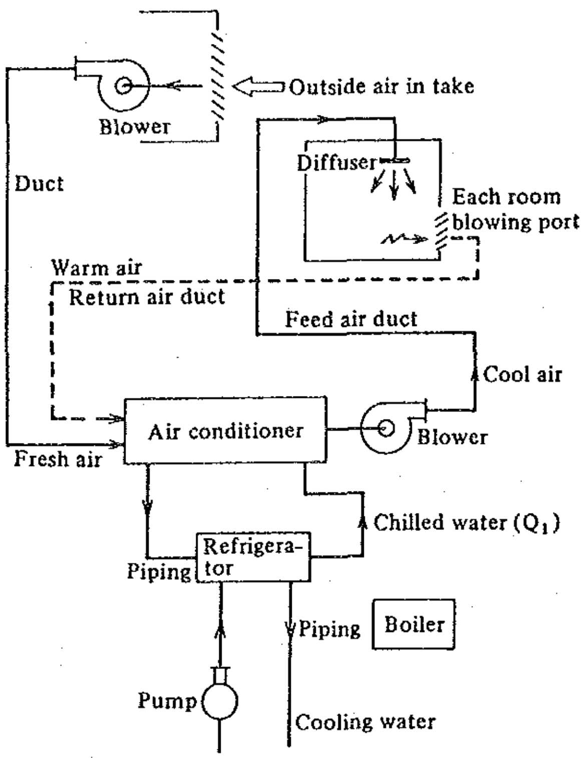


Figure 14–43 **Composition Example of Large Scale Air Conditioning System (During Cooling)**

(1) Heat source equipment (Refrigerator)

This feeds hot water (heating medium) or cold water (refrigerant) to an air conditioner. A boiler, heat storage tank, heat pump, etc. prepares the heating medium and a refrigerator feeds the refrigerant. In addition, there are heat exchanger and pumps, blowers, pipings, etc. for the auxiliary equipment.

(2) Air conditioners

Air conditioners are used to make the feed air to the room suitable temperature, humidity and cleanness.

Accordingly, air conditioners contain various apparatus to achieve functions such as air cleaning, cooling, dehumidification, heating, humidification, blast, etc.

(3) Transport equipment

Transport equipment is used to transport liquid and gas and consists of blower and fan, pump, duct, piping equipment, etc. For example, feed air conditioned by an air conditioner is fed through a duct into the room for cooling by a blower. Also, warmed air in the room is sucked by negative pressure in the blower and enters the air conditioner.

(4) Air distributors

Air distributors consists of diffuser, intake port, muffler, damper, etc. and are installed at outlets and inlets of the transport equipment.

(5) Switchboard, control panel, monitor panel

These are electric equipments to operate, control and monitor an air conditioning system.

The above equipments are not always separately installed. According to the scale of an air conditioning system, 1 unit may be composed of several equipments and also 1 unit may be composed of each equipment, like package type air conditioners.

Capacity of each apparatus in Fig. 14-43 is as follows:

A) Capacity of intake air blower (Q)

Assuming sensible heat load in a room as q_s (kcal/h),

$$Q = \frac{q_s}{\text{Air specific weight (kg/m}^3) \times \text{Air specific heat (kcal/kg}\cdot{}^\circ\text{C)} \times (t_1 - t_2)}$$

$$= \frac{q_s}{1.2 \times 0.24\,(t_1 - t_2)}$$

$$= 3.47 \frac{q_s}{t_1 - t_2} \; [\text{m}^3/\text{hr}] \quad \cdots\cdots (1)$$

Where t_1 (°C): Indoor dry-bulb temperature (preset temperature)

t_2 (°C): Diffuser dry-bulb temperature

B) Cooling capacity of air conditioner (q)

$$q = \text{Air specific weight} \times Q \times (i_1 - i_2)$$

$$= 1.2\,Q\,(i_1 - i_2)\;(\text{kcal/hr}) \quad \cdots\cdots (2)$$

Where i_1 (kcal/hr): Air enthalpy-at air conditioner inlet

i_2 (kcal/hr): Air enthalpy at air conditioner outlet

C) Capacity of refrigerators

Amount of cooling water Q_1 fed from the refrigerator to the air conditioner to achieve the above cooling capacity q is, assuming thermal efficiency of the air conditioner as η_1,

$$Q_1 = \frac{q \times 10^{-3}}{\eta_1\,(tw_1 - tw_2)} \; [\text{m}^3/\text{hr}] \quad \cdots\cdots (3)$$

Where tw_1, tw_2 : Temperature of cooling water at inlet and outlet of the air conditioner (°C)

Also, power of the compressor P is, assuming the compressor efficiency as η_2, and coefficient of performance of the refrigerator as ϵ,

$$P = \frac{q}{860\,\eta_2 \cdot \epsilon} \; [\text{kW}] \quad \cdots\cdots (4)$$

14.8.3 Energy Conservation for Air Conditioning

To install an air conditioner, the planner determine the load to be air conditioned and select a suitable air conditioner and system for this load. Accordingly, for energy conservation for an air conditioning, it is important to reduce the cooling load as the first step, and to select or improve to an energy-saving air conditioner or system for the cooling load as the second step.

(1) Class of cooling loads

Table 14–33 shows load for cooling. Total cooling load is a sum of these loads. Fig. 14–44 shows an example of cooling load for a factory office. Their building construction is shown in Fig. 14–45. This indicates that the load due to heat conduction is the highest, followed by outside air, lighting, solar radiation and the human body in sequence.

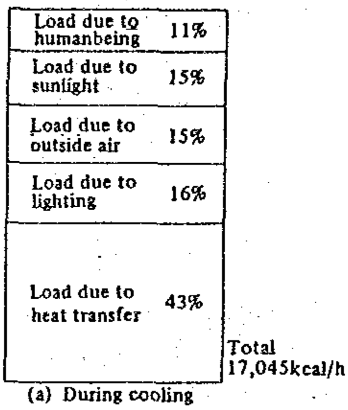


Figure 14–44
Example of Air Conditioning Load in Factory Office

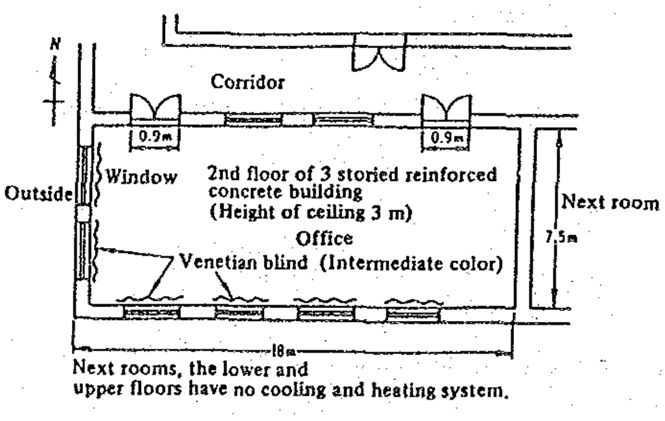


Figure 14–45 Example of Office

Table 14–33 Class of Cooling Load

<table>
<tr><th>Main classification</th><th>Sub-classification</th><th>Outline</th></tr>
<tr><td rowspan="5">Indoor acquisition heat capacity</td><td>Heat capacity from wall by heat transfer qW (kcal/h)</td><td>This is infiltration heat capacity from wall by heat transfer and varies according to thickness of the wall, the material, inner wall, outer wall, etc.
$qw = Aw \cdot K \cdot \Delta t$
Where Aw : Area of wall (m^2), K : Heat once-through factor (kcal/$m^2 \cdot h \cdot {}^\circ C$),
Δt : Equivalent temperature difference (°C)
Note (1) Difference between wall surface temperature and indoor side temperature is called "Equivalent temperature difference".
(2) Heat once-through factor varies according to material of wall (Ceiling, floor, side wall, window, etc.), combination and thickness.</td></tr>
<tr><td>Infiltration heat capacity from window glass qg (kcal/h)</td><td>(1) qgr : Radiation heat capacity = Radiation amount passing through glass (kcal/$m^2 \cdot h$) x Shielding coefficient x Area of window (m^2) x Radiation decrease ratio for double glass
(2) qgc : Heat capacity infiltrating from inner surface of glass by convection (including heat transfer) = Convection heat capacity coefficient (kcal/$m^2 \cdot h$) x Area of glass window (m^2)
qg = qgr + Qgc</td></tr>
<tr><td>Load due to draught (Infiltrating outside air), qi (kcal/h)</td><td>This has sensible load (qis) and latent load (qil).
qis = 0.29 x Amount of draught (m^3/h) x Difference between inside and outside temperature (°C) = 0.29 x nV x Difference between inside and outside temperature (°C)
Where n : Number of times for ventilation hourly
V : Volume of room (m^3)
qil = 720 x Amount of draught (m^3/h) xDifference between inside and outside absolute humidity (kg/kg)</td></tr>
<tr><td>Heat capacity from human body qh (kcal/h)</td><td>This varies according to his or her age, distinction of sex, operating conditions, indoor temperature and humidity, etc. Heating capacity of a Japanese adult male during rest at normal temperature is 45 in sensible heat and 35 in latent heat, totaling 80 kcal/h, and in the case of a clerk in an office, 50 in sensible heat and 45 in latent heat, totaling about 95 kcal/h. For female and the aged or little one, their heat capacity are assumed as 80 to 90%, and 50 to 80% respectively. Total heat capacity is obtained by multiplying by the number.</td></tr>
<tr><td>Heating capacity from indoor appliances, qe (kcal/h)</td><td>This is heat capacity from various appliances such as lighting appliances, electric heater, appliances for motor, production equipment and appliances for cooking, etc.
Heat capacity from lighting appliances = kW number of All lighting (Stabilizer input base) x 860 x Use ratio of lighting appliances x Net heat release ratio[*1] of lighting appliances (kcal/h)
Heat capacity from motor = Motor rated output (kW) x Load factor x Following coefficient[*2]
*1 This is used when a portion of heat capacity has been arranged not to discharge inside the room (for example, it is purged from the ceiling).
*2
<table>
<tr><th>Place of Motor</th><th>Place of Machine</th><th>Coefficient</th></tr>
<tr><td>Inside air-cooled room</td><td>Inside air-cooled room</td><td>1/motor efficiency</td></tr>
<tr><td>Outside "</td><td>" "</td><td>1</td></tr>
<tr><td>Inside "</td><td>Outside "</td><td>(1−motor efficiency)/motor efficiency</td></tr>
</table></td></tr>
<tr><td>Fresh air load</td><td>Acquisition heat capacity from intake outside air (forced intake), qo (kcal/h)</td><td>Sensible heat load qos = 0.29 x Amount of intake outside air (m^3/h) x (Outside temperature − Indoor temperature) (°C) (kcal/h)
Latent heat qol = 720 x Amount of intake outside air (m^3/h) x (Outside absolute humidity − Indoor absolute humidity (kg/kg) (kcal/h)
In general air conditioning, this load is not necessary when the required fresh air is sufficiently supplemented by draught.
Amount of intake outside air = Number of times for ventilation hourly x Volume of room (m^3) (m^3/h)</td></tr>
<tr><td>Miscellaneous heat</td><td></td><td>This means once-through heat load receiving from the outside when feed and return ducts are passing through the place where are not cooled, and exothermic heat from fan and compressor, etc. are included, and it shall be 3 to 7% of the indoor acquisition heat capacity.</td></tr>
<tr><td>Others</td><td></td><td>When some allowance is considered for cooling capacity, it shall be 8 to 20% of the total load.</td></tr>
</table>

(2) Methods for energy conservation

A) Reduction of outside air load and intensification of heat insulation

Outside air load has two loads: load due to draught q_i and fresh air load q_o. Load due to draught q_i is due to natural ventilation when the outside air at higher temperatures enters through the window and door clearance and by the opening and shutting and is expressed generally by the following equation.

$$q_i = \text{Sensible heat load} + \text{Latent heat load (kcal/hr)}$$

$$= 0.29\,NV\,(t_1 - t_2) + 720\,NV \times (x_1 - x_2) \quad \cdots\cdots (5)$$

Where N (times/hr): Number of times for natural ventilation (See Table 14–34)

V(m^3): Volume of a room

t_1, t_2 (°C): Outdoor, indoor temperature

x_1, x_2 (kg/kg): Outdoor, indoor absolute humidity

Table 14–34 Number of Times for Natural Ventilation (N)

Class of room	n
1 wall surface facing outside air and having window or door	1
2 walls surface facing outside air and having window or door	1.5
3 walls surface facing outside air and having window or door	2
4 walls surface facing outside air and having window or door	2
Room without window facing the outside air or door	½ ~ ¾

For air-tight window, ½ of this table shall be used. However, n shall be more than ½ in any case.

To reduce the draught load, it is advisable to shut the doors tighly and reduce the number of times for opening and shutting by adopting automatic doors as much as possible. When, however, outdoor temperature lowers more than the room temperature at night, $t_1 - t_2$ becomes negative, which means reduced cooling load. In this case, induce outdoor air by opening the window and door, of course resulting in a better cooling effect. As fresh air load q_o is due to forced ventilation, assuming the amount of intake fresh airs as Q (m^3/hr), q_o is determined by replacing NV with Q in equation (5). Amount of ventilation Q is provided for mainly from human safety and hygiene and the required amount of fresh air per person in room will be about 30 m^3/hr assuming an allowable carbon dioxide gas concentration of 0.1%.

To reduce the outdoor air load in any case, it is important to reduce the number of times for ventilation as much as possible to the extent that the carbon dioxide gas concentration as 0.1% is not exceeded.

When there is a return air system as shown in Fig. 14–46, it is better to circulate air as much as possible to reduce the intake of outdoor air. To be more specific, make the damper opening of the return air system larger to increase the amount of return air and at the same time, make the damper opening of the outdoor air intake system smaller to reduce the amount of outdoor air intake.

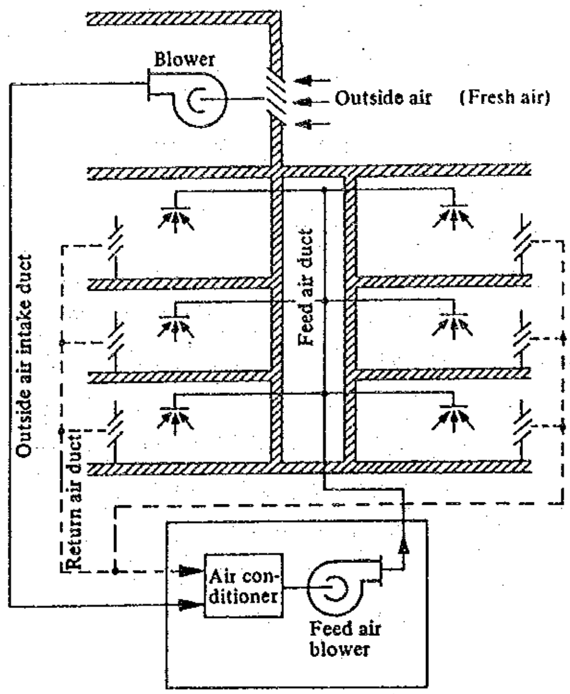


Figure 14–46 Air Conditioning System when Return Air is Available

For a precaution at this case, when the amount of return air is too much, the pressure in the room becomes negative against the outdoors, and dust is liable to enter the room. Therefore, it is desirable to keep the pressure in the room 0.1 mmAq to 1 mmAq higher than the outdoor.

For reducing load by heat conduction such as solar heat, it is of course important to intensity the heat insulation of the building.

Heat insulation for piping and duct for cooling is particularly important. In the case of heat insulation, condensation does not occur since the temperature of the fluid in the piping is higher than the dew point temperature of ambient air. However, in the case of cold insulation, condensation occurs when the surface temperature of the insulator is lower than the dew point temperature of ambient air, since the temperature of the fluid in the piping is low. Once condensation occurs, the cold insulator absorbs moisture and the heat conductivity increase more and more, expediting condensation. Care should be taken.

B) Relief of indoor preset temperature

Raising the preset temperature during cooling greatly reduces the cooling load because heat conduction from wall surfaces is in proportion to the temperature difference between indoors and outdoors. In the example shown in Fig. 14–44, raising the preset temperature from 26°C to 27°C causes the cooling load by about 100 kcal/hr.

In equation (1), q_s decreases and t_1 increases and if t_2 is assumed constant, the amount of feed air can be reduced and, therefore, the blower axial power can be reduced. Thus, it is also possible to reduce the compressor output and temperature of cooling water.

C) Reduction of heating value of indoor appliances

Except when circumstances comple it, it is desirable not to place any heat-generating appliances in air conditioned rooms. Fig. 14–44 shows that lighting load accounts for 15% of the total load. As the countermeasure for it, it is desirable to save electric power by adopting efficient lighting, and to ventilate the heat portion of the luminaires collectively by a separate duct.

D) Re-examination of humidity

In an air conditioner with dehumidifying capacity, releasing the humidity condition effectively saves electric energy. In a trial calculation example, changes in air conditioning load when temperature and humidity is changed respectively are shown in Fig. 14–47.

According to this diagram, when humidity is released from 40% RH to 60% RH at a temperature of 23°C, the load is reduced by about 4.2 kcal/hr. Also, when the temperature is released from 21°C to 25°C at 50% relative humidity, the load is reduced by only about 0.7 kcal/hr and humidity releasing is about six times advantageous in energy conservation. However, it should be noted that excessively high humidity gives human beings discomfort and affects the product quality.

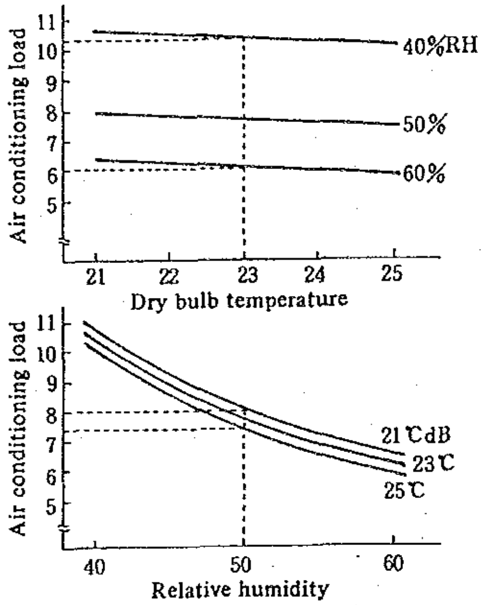


Figure 14–47 Energies Required for Temperature and Humidity Changes (Trial Calculation on a Certain Conditions)

E) Improved control methods

As shown in equation (1) and equation (3), heat load carried by refrigerant is in proportion to the flow rate and temperature difference. For controlling heat load there are two methods; one is to change the flow rate, and the other is to change the refrigerant temperature under constant flow rate. The former is greater in reduction in amount of air flow and pump power and more energy can be saved. As for fluid control methods, there are damper control, vane control and various variable speed controls as described already and each consumed power is in the following order: Discharge damper control> Inlet vane control> Variable speed control. Therefore, the system with the best efficiency should be selected within the allowable conditions. Especially, the variable speed control by means of VVVF can be easily installed on the existing motor equipment and is very effective when large flow change is often occurred. So it is advisable to study this first when modifying the existing equipment. See the items "Motor" and "Blower" for details.

F) Periodic maintenance and control

a. Cooling water piping

Adherence of scale and sludge to the piping system causes increased resistance, thus increasing the pump output to feed the same flow rate. If the water quality is improper, naturally scale and sludge adhere heavily. Accordingly, it is necessary to control water quality. Reference values for water control standards are shown in Table 14–35.

b. Heat exchangers

In evaporators and condensers, scale, sludge and germs occur from cooling water, adhere and accumulate, lowering the heat exchange efficiency and increasing the consumed power per refrigerating ton. Therefore, it is necessary to clean periodically.

c. Air ducts

When a filter is used for air purification, periodic cleaning is necessary. Needless to say, filter clogging increases the pressure loss, reducing the air flow and lowering the cooling capacity. Since air conditioners in improper environmental conditions are quickly contaminated, it is desirable to clean once a week.

Table 14–35 Quality Standard of Cooling Water

(Japan Refrigeration and Air Conditioning Industrial Association Standard)

	Item		Standard value for makeup water	Standard value for cooling water*1	Tendency*3	
					Corrosion	Scale
Standard item	PH (25°C)		6.0~8.0	60~8.0	O	O
	Conductivity	(μv/m)	200 or less	500 or less (1,000 or less)	O	
	Chlorine ion Cl	(ppm)	50 or less	200 or less	O	
	Sulfuric acid iron SO_4^{2-}	(ppm)	50 or less	200 or less	O	
	Total iron Fe	(ppm)	0.3 or less	1.0 or less*2	O	O
	M Alkalinity $CaCO_3$	(ppm)	50 or less	100 or less		O
	Total hardness $CaCO_3$	(ppm)	50 or less	200 or less		O
Reference item	Sulfur ion S_1	(ppm)	Not be detected	Not be detected	O	
	Ammonium iron NH_4	(ppm)	Not be detected	Not be detected	O	
	Silicon oxide SiO_2	(ppm)		50 or less		O

*1. Cooling water means water passing through condenser for both transient and circulation systems.
*2. Standard value for plastic piping shall be 0.5 ppm or below.
*3 Mark O in "Tendency" column indicates a factor concerning either corrosion or scale tendency.

G) Others

On each season, it is desirable to re-examine the air conditioning zone by studying whether there is any unbalance due to supercooling and overheating in each room and whether the air conditioning level is proper in each corridor, etc., in order to reduce the air conditioning load as much as possible.

When establishing a new air conditioning system, it is necessary to carefully study the advisability of installation of a heat storage tank, of waste heat utilization, and selection of the most effective air conditioning duct system, etc., with an eye to reducing operation cost.