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NR TYPE, TOTALLY ENCLOSED FAN-COOLED THREE PHASE INDUCTION MOTOR

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I. PREFACE

Totally enclosed fan-cooled induction motors have been used for many years, mainly because of their very wide service range. Recently, demand for these motors of large unit capacity has been rapidly increasing at iron and steel plants, coal mines, oil refineries and chemical plants; consequently there is a ready market for large capacity and outdoor type totally enclosed motors. Furthermore, extensive application of automatic controls and perfected power supply equipment have spurred the development of a totally enclosed cage type motor of high reliability and large unit capacity.

Our company has had experience with the totally enclosed motor: more than forty years of rib and fan-cooled types and water-cooled types. Fuji Denki pioneered in the manufacture of the totally enclosed fan-cooled motor with tube-cooler in 1951. Next came direct water-cooled types (circulating water for stator frame and in hollow shaft) in 1959; thus much research data has been accumulating up to the present time.

In the self-ventilated totally enclosed motor, rib and fan-cooled construction is applied for medium capacity and the tube-cooled construction for the large capacity. In the rib and fan-cooled type, heat loss generated within is dissipated by cooling air passing over the surface of the stator frame. With a large capacity, it is no longer feasible to keep a proportionate ratio between cooling surface and heat loss, for it would mean construction of an uneconomical motor size. For this reason, output range of rib-cooling type is limited under 3 kV, 300 kW, 1500 rpm. For the output exceeding the above mentioned range, tube-cooled type is employed: heat is dissipated effectively by cooling air passing through tubes distributed along the stator frame. Two fans supply the air: an external fan on the outside of the motor and an internal fan fitted in the enclosed stator frame, effective also for wound-rotor type. This company's standards for this type: At 3 kV and 1500 rpm, the cage type up to 1100 kW and wound rotor type up to 900 kW. The following outline describes the standard tube-cooled, totally enclosed fan-cooled motor for your reference.

II. CONSTRUCTION OF TUBE-COOLED INDUCTION MOTOR

1. Inner Air Circulation and Cooling of Core

Fig. 1 is a sectional drawing of a tube-cooled cage motor. Thick arrow lines show the circulating path of outer air and fine arrow lines show that of the inner air. Inner air circulation is carried on by air ducts distributed parallel in the core axially as can be seen in the drawing. Features of this circulating method are as follows.

1) Air circulation in the core follows a parallel path

Inner air passed through the cooling tubes circulates parallel to the outer part of stator core, the air duct in the stator core, the gap and the air duct in the rotor slot and rotor core. In this way, rotor heat loss does not directly effect stator winding. (Particularly effective for cage motors which allow a high temperature rise in the rotor. Consequently motor output can be increased, this being an advantage over the wound rotor type.)

2) Heat conduction path in the core is short and temperature gradient is small

Because the inner air circulates near the heat source, the passage of conducted heat is quite short,

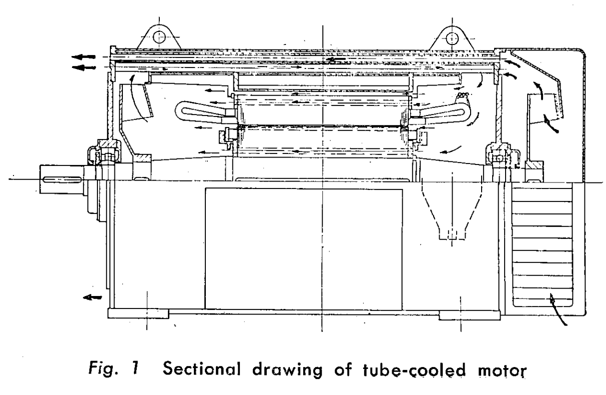


Fig. 1 Sectional drawing of tube-cooled motor

thus heat resistance in the core is small. Further, as thermal conductivity at radial direction is far better than that of axial direction, the radial heat transfer in the core is effective in diminishing the heat resistance.

3) The shape of the air duct in the core is conductive to good heat transfer;

By selecting proper number and dimensions of air ducts, placed in the stator and rotor core, the air velocity needed for heat transfer of inner air can be obtained. The shape, as shown in *Fig. 2,* further increases the heat radiation surface of air ducts receiving the effective magnetic path of yoke. In order to obtain good heat radiation from an air gap, it is sometimes necessary to provide an air path in the opening of stator slots, as shown in *Fig. 2. Fig. 3* shows the stator winding and its frame.

These characteristics show that this cooling system improves heat conduction in the core and heat transfer between the core and the inner air.

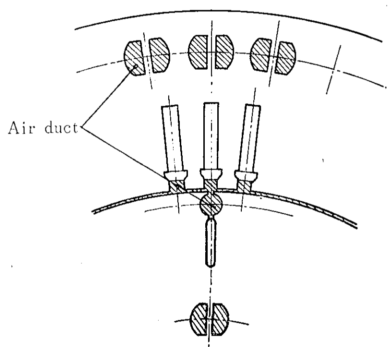


Fig. 2 Air duct arrangement in core

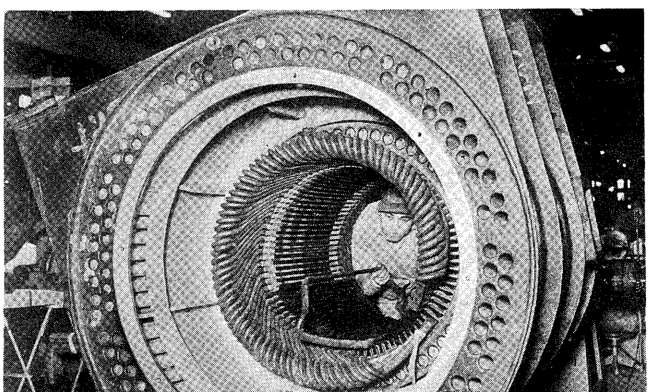


Fig. 3 Stator winding and frame

2. Internal and External Fans

Because heat in the tube-cooled type is dissipated by the heat exchange between the inner air and the outer air passing through the cooling tubes, besides the arrangement of tubes and the selection of tube size, the dimensions of both the internal and external fan have an important influence upon the heat exchange characteristics. Dimensions used for the fan have been properly selected in respect to the air volume required and loss of head. As the internal fan loss occurs within the stator frame, it causes the inner air temperature rise and increases the tubes' load for heat exchange. For this, special care is given in the designing of the fans. In high speed motors with over 1000 rpm of large capacity, turbo fans are used in an effort to decrease the internal fan loss.

3. Insulation of Winding

Tube-cooled type motor, used for output exceeding 300 kW, 1500 rpm. requires high tension (3 kV, 6 kV class) winding. Our company uses the formed coil, asphalted and impregnated in vacuum, as insulation of standard high tension winding. The motor used in a high humidity or in a tropical zone, has increased moisture proof characteristics found in epoxy resin coils. Further, concerning 6 kV class, besides increasing the thickness of slot insulation and the corona resist treatment, conductors with special insulators are used to increase the layer dielectric strength.

4. Rotor Construction

Regarding cage rotor, the skewed deep slot construction is our standard. To withstand the vibration of rotor conductor and temperature rise caused by the frequent starting and the heavy load starting, consideration is given to suitable sizes for slot and conductor. Further, the support ring for short-circuit ring is fitted so that the short-circuit ring slides smoothly in axial direction. To increase thermal capacity, a high resistance conductor is sometime used for starting high inertia loads. Generally speaking, load is mainly the blower, which has a small starting torque and a high moment of inertia. Motor to be used for such a service does not need to have a larger starting torque; rather the value of load GD^2 becomes an important factor, this service condition taken into consideration when it is designed. In the case of a load with a low moment of inertia but a high starting torque, double squirrel cage construction is adopted. For 2-pole high speed and 4-pole large output machines, short-circuit rings are mechanically strengthened by using a non-magnetic ring. *Fig. 4* shows an example of a cage rotor. In the wound rotor type, the insulated formed conductor is inserted into the semi-enclosed slot which has an air duct at the upper part, so that it can withstand dielectric strength and mechanical stress.

5. Bearing

Ball-and-roller bearing is used for the standard

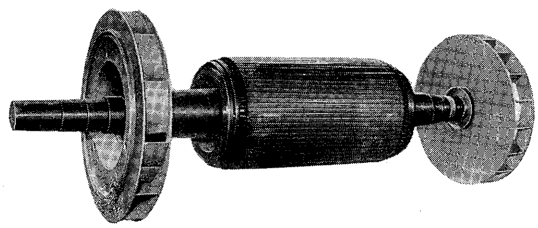


Fig. 4 Cage rotor of tube-cooled motor

motor (except large 2-pole). Our company, having over 30 years' experience since adopting the ball-and-roller bearing for motors, has much confidence in the use of this type of bearing for large output motors. *Fig. 5* is a sectional drawing for the bearing construction. Its maintenance is quite easy: the grease can be replaced during operation. Greasing specifications are indicated on the name plate.

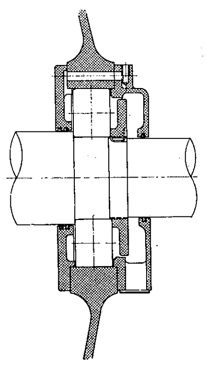


Fig. 5 Bearing construction

6. Terminal Box

The terminal box in which the motor lead is connected to external wiring is dust-proof and roomy enough for adequate insulation. An explosion-proof box has been manufactured upon request.

7. Silencer

The sound absorbers are attached inside, on the external fan cover, to diminish the noise.

8. Slipring and Brush

For wound motor, types with or without the brush lifting device are standard, and the short-circuit device for slipring and the interlock switch at start are provided in the type with brush lifting device. This lifting device is also supplied in the hand operated or the motor-drive type. Brush for the type with the brush lifting device is a metallic graphite with low resistance, so cannot be used for continuous running. Slipring brush without brush lifting device is used in the case of speed control or frequent starting. In this case, because the brush contacts the slipring continuously, we selected a sparkless and low wear brush.

9. Outdoor Type

The standard outdoor type is well protected against hot sun and wet weather, and also constructed for easy maintenance and inspection. All parts of outside and the bearing are corrosion-proof and the winding is treated with moisture-proof insulation.

III. COOLING METHOD FOR TUBE-COOLED MOTORS

In the interior cooling method, the tube-cooled type since the air inside circulates through the paths that are parallel in axial direction, the thermal conductive resistance in the core and stator is decreased and not influenced by the rotor loss. This method has the advantage of getting good heat conduction between the core and the inner air. Heat flow circuit of this type can be easily expressed by replacing the temperature difference with the voltage and the loss with the current[1]. *Fig. 6* is the heat equivalent circuit of a wound rotor type motor, and *Fig. 7*

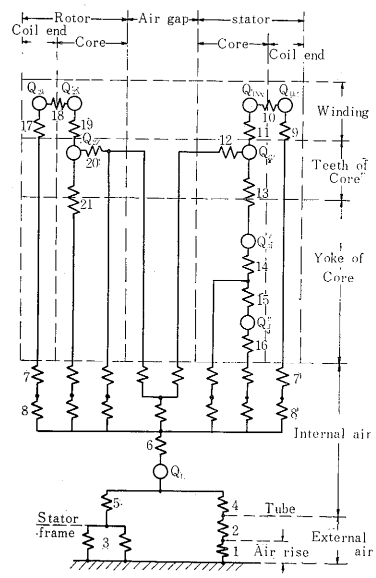
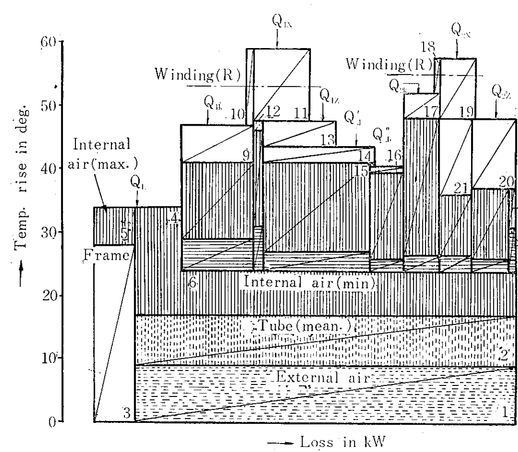


Fig. 6 Heat equivalent circuit of a wound rotor type motor with tube-cooler



Q_{1N}: Stator coil loss inside slot	Q_{2N}: Rotor coil loss inside slot
Q_{1K}: Stator coil end loss	Q_{2K}: Rotor coil end loss
Q_{1Z}: Teeth loss of stator core	Q_{2Z}: Teeth loss of rotor core
Q'_J, Q''_J: Yoke loss of stator core	Q_L: Internal fan loss

Winding (*R*): Temperature rise of winding by resistance method

Fig. 7 Loss-temperature diagram of a wound rotor type motor with tube-cooler

indicates the loss-temperature diagram of a wound rotor type motor, results obtained from a test in which thermo-couples were inserted in each part of a motor.

Concerning this temperature rise, as shown in *Fig. 7,* the temperature rise of outer air is 9°C; temperature difference between the inner air and the outer air is 24.5°C; the temperature rise of stator winding is 53°C by resistance method; rotor winding is 55°C. Thus each loss distribution and temperature difference for the construction having the parallel ventilation can be obtained by replacing with the relatively simple heat circuit, so the temperature rise of each part must be considered with the variation of load in mind. To acknowledge the heat resistance at each parallel circuit of inner air: the characteristic curves of air pressure for internal fan, external fan and each parallel circuit are to be calculated in a construction design; finally these values are confirmed by measuring the inner and outer air quantities at factory test. *Fig. 8* shows the fan and system characteristics of a wound rotor type motor explained in *Fig. 6* and *7.*

Effectiveness of the heat exchange of tubes of tube-cooled type is an important factor for determining machine size. δ m (°C), the mean temperature difference between the internal and the external air, is given by the following formula:

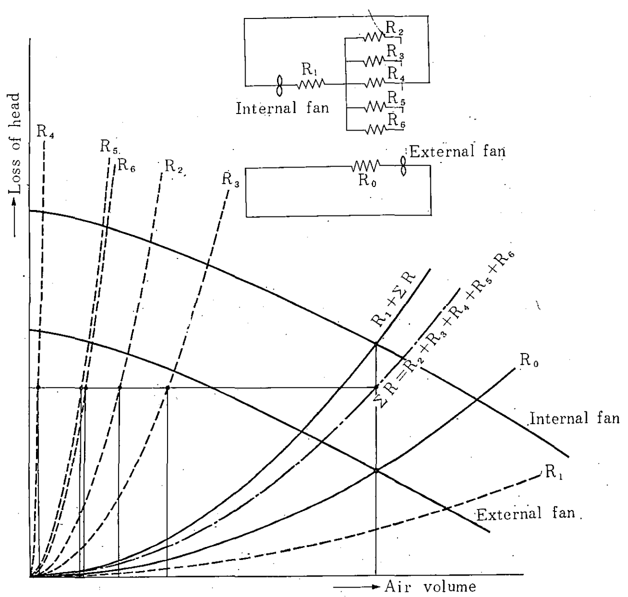
$$\delta\,\mathrm{m}=\frac{V\times 860}{k\cdot L}\,(^\circ\mathrm{C})$$

where k = coefficient of overall heat transmission per meter of tube (k cal/m. hr. °C)

L = total length of tube (m)

V = heat loss to be cooled by tube (kW)

$k\cdot L$ must be increased to have the small δ m in proportion to the amount that the internal fan is enlarged and the number of tubes is increased, as the air velocity in the tube and the cooling surface is increased. As the fan loss increases corresponding to the size of internal fan, we adopted a turbo-fan for the large high speed machines of more than 1000 rpm, increasing its fan efficiency nearly twice as much as the ordinary plate fan, thus decreasing fan loss. Size of internal fan of tube-cooled type does not influence the amount of noise, because sound is absorbed by the stator frame. The external fan, having little loss of head, needs only a relatively small diameter.



R_1: Tube cooler (internal)
R_2: Circumference of stator core
R_3: Air duct of stator core
R_0: Tube cooler (external)
R_4: Air gap
R_5: Air duct of rotor slot
R_6: Air duct of rotor core

Fig. 8 Fan and system characteristics

IV. OUTLINE DIMENSIONS AND CHARACTERISTICS

There are two ways of ventilating the core in the tube-cooled type. One is the parallel ventilating method, a standard type shown in *Fig. 1,* and the other is the radial ventilating method having the air duct in the core, as can be seen in open-type construction.

Our standard method has not only the cooling merits as described above, but also the characteristics which allow relatively small diameter of stator frame, due to the fact that a rotor spider is unnecessary and because good cooling at the center of core is obtained when the core length becomes long. Thus our tube-cooled type motor, in spite of its being totally enclosed, has a center height near to that of the open type motors shown in *Fig. 9,* and stands in an extension line of rib-cooled type motor. Because the tube-cooled type has good heat radiation for the rotor side, we limit the application range of rib-cooled type to the wound rotor type motor and apply the tube-cooled type, for the output of more than 150 kW, 1500 rpm.

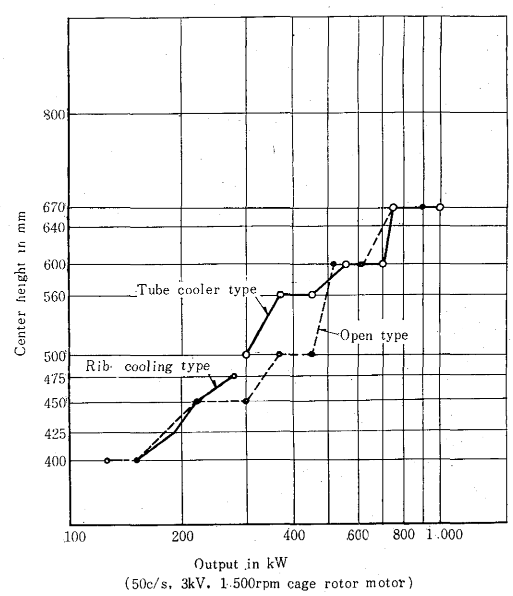


Fig. 9 Center height in relation to output

***Table 1* Specification of Fuji totally enclosed fan-cooled type induction motor with tube-cooler**

(1) Output table (3 kV, A class insulation)

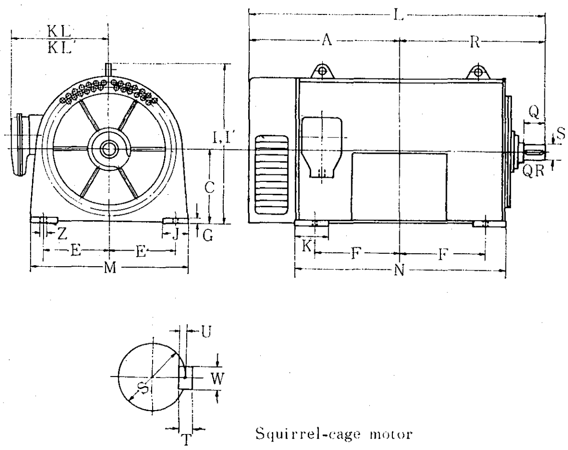
Squirrel-cage rotor type (kW)

Model \ Poles \ Freq.	50 c/s					60 c/s				
	2	4	6	8	10	2	4	6	8	10
NRK 2262	300	300				350	350			
2661	350	370	280			420	420	320		
2662	420	450	370	220	150	500	500	420	260	170
2861		550	450	300	200		650	500	350	220
2862		700	600	370	280		800	700	420	320
3061		750	650	450	320		850	750	500	370
3062		1,000	800	550	400		1,100	900	650	450

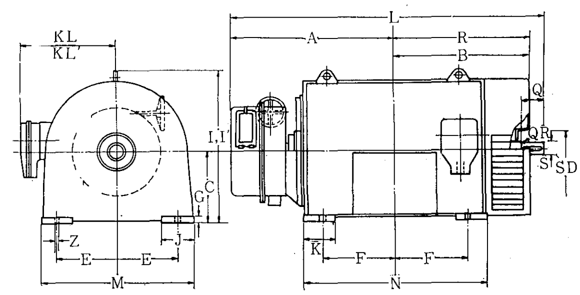
Wound rotor type (kW)

Model \ Poles \ Freq.	50 c/s					60 c/s				
	2	4	6	8	10	2	4	6	8	10
NRW 2261		180	110				200	125		
2262		260	160	100			300	180	110	
2661		320	220	160	100		370	260	180	110
2662		400	320	200	125		450	370	220	150
2861		480	420	260	180		550	480	300	200
2862		600	550	320	250		700	650	370	280
3061		700	620	420	290		800	700	480	320
3062		900	700	500	370		1,000	800	550	420

(2) Outline dimension



Squirrel-cage motor



Wound motor

(3) Dimension table

Squirrel-cage rotor type

(mm)

NRK ONRK	Poles	A	C	E	F	G	I	J	K	KL	L	M	N	R	Z	I′	KL′	Q	QR	S	T	U	W
2262	4~10	1,055	500	485	645	24	1,080	160	180	670	2,015	1,130	1,510	960	36	1,110	720	160	2	100	18	9	28
2661	4~10	1,070	560	500	570	40	1,190	200	250	750	2,080	1,200	1,450	1,010	43	1,220	800	180	2.5	110	18	9	28
2662	4~10	1,150	560	500	650	40	1,190	200	250	750	2,240	1,200	1,610	1,090	43	1,220	800	180	2.5	110	18	9	28
2861	4	1,175	600	550	640	40	1,320	200	300	800	2,325	1,300	1,600	1,150	43	1,350	850	200	2.5	130	22	11	35
2861	6~10	1,175	600	550	640	40	1,320	200	300	800	2,285	1,300	1,600	1,100	43	1,350	850	200	2.5	130	22	11	35
2862	4	1,255	600	550	720	40	1,320	200	300	800	2,485	1,300	1,760	1,230	43	1,350	850	200	2.5	130	22	11	35
2862	6~10	1,255	600	550	720	40	1,320	200	300	800	2,445	1,300	1,760	1,190	43	1,350	850	200	2.5	130	22	11	35
3061	4	1,215	670	600	660	40	1,470	200	300	850	2,405	1,400	1,640	1,190	50	1,500	900	220	2.5	140	22	11	35
3061	6~10	1,215	670	600	660	40	1,470	200	300	850	2,365	1,400	1,640	1,150	50	1,500	900	220	2.5	140	22	11	35
3062	4	1,295	670	600	740	40	1,470	200	300	850	2,565	1,400	1,800	1,270	50	1,500	900	220	2.5	140	22	11	35
3062	6~10	1,295	670	600	740	40	1,470	200	300	850	2,525	1,400	1,800	1,230	50	1,500	900	220	2.5	140	22	11	35

Wound rotor type

(mm)

NRW ONRW	Poles	A	B	C	E	F	G	I	J	K	KL	L	M	N	SD	I′	KL′	R	Z	Q	QR	S	T	U	W
2261	4~10	1,130	925	500	485	565	24	1,080	160	180	670	2,180	1,130	1,350	250	1,110	720	1,050	36	160	2	100	18	9	28
2262	4~10	1,210	1,005	500	485	645	24	1,080	160	180	670	2,340	1,130	1,510	250	1,110	720	1,130	36	160	2	100	18	9	28
2661	4~10	1,275	1,070	560	500	570	40	1,190	200	250	750	2,450	1,200	1,450	250	1,220	800	1,175	43	180	2.5	110	18	9	28
2662	4~10	1,355	1,150	560	500	650	40	1,190	200	250	750	2,610	1,200	1,610	250	1,220	800	1,255	43	180	2.5	110	18	9	28
2861	4	1,460	1,175	600	550	640	40	1,320	200	300	800	2,740	1,300	1,600	300	1,350	850	1,280	43	200	2.5	130	22	11	35
2861	6~10	1,460	1,175	600	550	640	40	1,320	200	300	800	2,740	1,300	1,600	300	1,350	850	1,280	43	200	2.5	130	22	11	35
2862	4	1,540	1,255	600	550	720	40	1,320	200	300	800	2,900	1,300	1,760	300	1,350	850	1,360	43	200	2.5	130	22	11	35
2862	6~10	1,540	1,255	600	550	720	40	1,320	200	300	800	2,900	1,300	1,760	300	1,350	850	1,360	43	200	2.5	130	22	11	35
3061	4	1,580	1,220	670	600	660	40	1,470	200	300	850	2,900	1,400	1,640	300	1,500	900	1,320	50	220	2.5	140	22	11	35
3061	6~10	1,580	1,220	670	600	660	40	1,470	200	300	850	2,900	1,400	1,640	300	1,500	900	1,320	50	220	2.5	140	22	11	35
3062	4	1,660	1,300	670	600	740	40	1,470	200	300	850	3,060	1,400	1,800	300	1,500	900	1,400	50	220	2.5	140	22	11	35
3062	6~10	1,660	1,300	670	600	740	40	1,470	200	300	850	3,060	1,400	1,800	300	1,500	900	1,400	50	220	2.5	140	22	11	35

Note: Dimensions of I′, KL′ to apply outdoor type (ONRK, ONRW) motor.

The high tension frame-proof type motor uses tube-cooled type as the standard type.

Fig. 10 shows the outer view of a 480 kW, 6000 V, 990 rpm, outdoor-use increased safety explosion-proof wound rotor type motor. *Fig. 11* shows a photograph of a outdoor-use cage rotor type motor of 400 kW, 6600 V, 1180 rpm.

Fuji Denki's standard type motor, because of its suitable fan design and use of a silencer, has a minimum of noise. For example, a 2-pole 500 kW cage rotor type motor running at 60 c/s no load has sound pressure level of 89 db which is very low for the motors of this type. Moreover, because of the use of turbo-fan as its internal fan, its external fan is small to decrease windage loss and increase its efciency by making mechanical loss small.

Further, the tube-cooled type, (3 kV, 6 kV class), the normal type, outdoor-use and increased safety explosion-proof type motors, can be delivered promptly upon request. *Table 1* shows the output of 3 kV class and its outline dimensions.

V. CONCLUSION

These totally enclosed fan-cooled motors, having the merits of easy maintenance and high reliability, are greatly in demand, due to the enlarged service range and the spreading use of outdoor types. Our company has already completed standard totally enclosed fan-cooled motors up to the output of 1000 kW, capable of supplying these demands. This includes outdoor type, increased safety explosion-proof type and 6 kV class motors for both the cage and wound rotor type. Only a partial change of specifications is necessary for manufacturing special designs such as the pressure resisting explosion-proof of corrosion-resisting types.

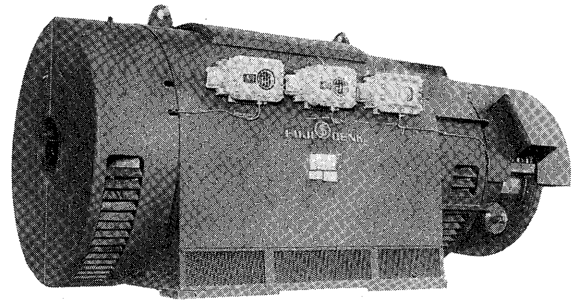


Fig. 10 Outdoor-use explosion-proof wound rotor type motor

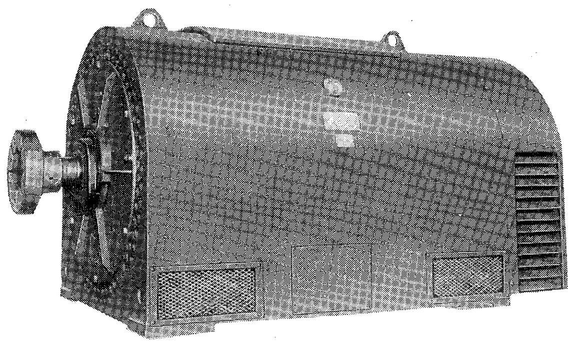


Fig. 11 Outdoor-use cage rotor type motor

We appreciate customer remarks and communications concerning our totally enclosed fan-cooled type motors.

Reference

1) H. Weissheimer: Oberflächenbelüftete Drehstrommotoren, Jubiläumschrift der S.S.W. S. 291 (1953).