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LATEST EXPLOSION-PROOF ELECTRIC MACHINERY AND APPARATUS FOR FACTORY USE (I)

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I. PREFACE

The explosion accident in industrial works is considered very serious and the precaution against explosion has a great importance on the viewpoint of safety in industries. Accordingly, in case electric equipment are installed in the hazardous areas of explosion in factories or other works, strict measure should be taken on the electric equipment not to be an ignition source.

Recently, the demand for the explosion-proof machinery and apparatus has considerably increased in response to the remarkable development of chemical industries and our Company has been engaging design and manufacture of these explosion-proof machinery and apparatus with the up-to-date techniques and our long experiences.

Taking opportunity of revision of various rules concerning the explosion-proof machinery and apparatus for factory use recently performed internationally and internally, writer wishes to introduce hereinafter the explosion-proof machinery and apparatus of our Company for factory use. For the explosion-proof construction for factory use, there are two kinds at present, one is a gas and vapor explosion-proof construction and the other is a powder and dust ex plosion-proof construction, however, in this paper the former is mainly described.

II. STANDARDS AND RULES

The standards or rules concerning the construction of explosion-proof electric machinery and apparatus for factory use in our country is nows only " Recommendations for Electric Equipment and Wirings for use in Explosive Atomospheres in Factories " (hereinafter referred to as " the Recommendations ") established by the Industrial Safety Research Institute, Ministry of Labor, and our Company is manufacturing the electric equipment just conforming to this Recommen dations.

The Recommendations are now consisting of the volume for gas and vapor explosion-proofing and that for powder and dust explosion-proofing, and the latest edition of the former is enacted as " Gas and Vapor Explosion-proofing-1961 " in January, 1961 by revising the former Recommendations issued in October, 1955. It is not too much to say that the contents of the Recommendations stand on the international level because they are mainly derived from German explosion-proof standards VDE 0171/ 9.57 (Verband Deutscher Electrotechniker) and standards of IEC (International Electrotechnical Commission) and also referred to the explosion-proof regulation in coal mine (JIS-C0901) and NEC(National Electrical Code), with the revisions based on the experience of the former Recommendations.

Furthermore, in the Japanese Electric Machinery Industries Association, consideration is being taken in order to enact the Recommendations as JIS (Japanese Industrial Standards) in the near future, and it will become JIS-C 0903 : Standards for General Explosion-proof Construction of Electric Machinery and Apparatus.

On the other hand, " Powder and Dust Explosion-proofing-1961 " is also newly established as a part of the Recommendations for the safety of electric equipment in power and dust hazardous areas as the esac of the Gas and Vapor Explosion-proofiing, and referring to different standards in western countries as well as NEC.

N. B. Regarding the measuring instrument as explosion-proof machinery and apparatus, the details are now under consideration in the Measuring Instrument Association and the revised recommendation on test is under discussion in the Explosion-proof Commission.

The connection between the Ordinance on Industrial Safety and Health established by the Ministry of Labor (hereinafter referred to as " the Ordinance ") and the explosion-proofing on equipment is as follows.

The former Ordinance so far existed as a law was not provided with the items of explosion-proofing, but in November, 1960 revision was performed to include the explosion-proofing in conjunction with other items on safety by the Ordinance of Ministry of Labor No. 25.

The prevention of fire and explosion accident is specified in Article 140 to Item 7 in the same Article,

in which Item 3, 4, 5, and 7 are much concerned with the manufacture of machinery and apparatus. In these items, the service of explosion-proof construction of various machinery and apparatus is stipulated and especially in Item 7, it is specified that the explosion-proof construction should conform to the Notification of Explosion-proof Construction also executed by the Minister of Labor.

However the contents of the Recommendations are superior or equivalent to the contents of the Ordinance, and the principal differences of the Ordinance from the Recommendations are that the Ordinance is mainly concerned with the facilities installed in the place corresponding to the first class hazardous areas classified in the Recommendations, the Ordinance is applied only on the users of facilities though the manufacturers should be indirectly concerned, and as the Oridinance is a law, the facilities should be checked by the inspectors authorized by the Labor Standard Office, the Ministry of Labor. (The above-mentioned Article and Items in the Ordinance were effectuated in October, 1961.)

The construction specified in the former Recomendations is still acceptable, but the ignition point should be adjusted on the application in conformity with the new Recommendations.

The progress of standardization on explosion-proofing is as mentioned above, and the following descriptions are all based on the new Recommndations.

III. GENERAL OF EXPLOSION-PROOF CONSTRUCTION FOR FACTORY USE

Since the details on standards of explosion-proof construction for factory use are described in the Recommendations, they are limited to the minimum extent in this paper except some description, symbols, terminal box system and the other common items. Accordingly, regarding the dimensions, pressure values and the construction partially specified etc. to satisfy the explosion-proof construction, please refer to the Recommendations newly revised.

1. Classification of Inflammable Gas and Vapor

Inflammable gas and vapor are classified in ignition grade and explosion class determined in accordance with their dangerous conditions. Ignition grade is classified as shown in *Table 1* in accordance with the ignition point determined by the result of ignition test. Explosion class is classified into three classes as shown in *Table 2* according to the value of clearance to produce ignition propagation in explosion test with standard enclosures.

Classification examples of typical explosive gases in accordance with the ignition grade and the explosion class are shown in *Table 3*.

2. Ambient Temperature

Unless otherwise specified, ambient temperature is considered 40°C for machine designing and manufacturing. When a machine is specified to operate with ambient temperature higher than 40°C, the permissible temperature rise should be reduced by the amount by which the specified ambient temperature exceeds 40°C.

In case of water cooling system, temperature rise limit is generally determined on the basis of cooling water inlet temperature, and it should be specified beforehand by the agreement between user and manufacturer for each case.

3. Types of Explosion-proof Construction

There are five types of explosion-proof construction as follows. The narrow clearance explosion-proof construction specified in the explosion-proof regulation in coal mine is omitted here because this is not recognized in the Recommendations in accordance with VDE 0171/9.57.

1) Flame-proof construction
   Totally enclosed construction capable of withstading internal pressure even in case explosion occures inside the enclosure and of preventing ignition propagation to outside explosive gasses. This construction is marked as " d ". As can be seen in the definition, this construction has an important factor in the strength of enclosure and clearance and creeping distance of adjoining surface of enclosure.
2) Oil-immersed explosion-proof construction
   The construction in which sparking part, arcing part and other parts possible to generate high temperature are kept in oil not to ignite the explosive gasses existing above the oil surface. This construction is marked as " o "

Table 1 **Classification of ignition grade**

Ignition grade	Range of ignition point
G 1	Higher than 450°C
G 2	Higher than 300°C but 450°C or lower
G 3	Higher than 200°C but 300°C or lower
G 4	Higher than 135°C but 200°C or lower
G 5	135°C or lower

Table 2 **Classification of explosion class**

Explosion class	Joint surface's clearance communicating the internal ignition to the external inflammable gas or vapor where flanges of 25 mm depth were used.
1	More than 0.6 mm
2	More than 0.4mm but 0.6 mm or less
3	0.4mm or less

Table 3 **Classification of explosive gasses**

Explosion class \ Ignition grade	G 1	G 2	G 3	G 4	G 5
1	Acetone Ethan Ethyl acetate Ammonia Benzole (pure) Acetic acid Carbon monoxide Methane Methyl alcohol Propane Toluole	Ethyl alcohol Amyl acetate (iso) Butane Butyl alcohol Ethylene oxide Acetic anhydride	Gasoline Hexane	Acetaldehyde Ethyl ether	
2	Ethylene Coal gas				
3	Water gas Hydrogen				Carbon disulfide

3) Pressurized explosion-proof construction
The construction in which the explosive gasses entered into enclosure before starting operation is expelled and consecutively prevented from invasion during operation by filling the protection gas such as clean air, inactive gas etc. into the enclosure. This construction is marked as "f", and has such a great advantage that it can be used regardless of explosion class only if both conditions of protection gas and interlock are satisfied. Consequently, when the machine which generates spark or arc in the surrounding atmosphere of explosion class 3 has big size and flame-proof construction is difficult to be adopted, pressurized construction should be always adopted. Cost of pressurized construction is relatively low comparing with flame-proof construction as the size increases.

4) Increased safety construction
The construction which increases the safety on the view-point of construction and temperature rise so as to prevent the specified parts from spark, arc or overheat during course of operation. This construction is marked as "e", and has been adopted in Germany for a long time. The defect of this construction is that the explosion-proof cannot be ensured when some fault occurs in the machine itself. However, since such chance is determined at the rare possibility of abnormal condition that the surrounding atmosphere comes to have a dangerous concentration of explosive gas and at the same time some fault occurs in the machine, it is not dangerous if the application of location is proper. And it is advantageous in cost and delivery time comparing with other explosion-proof construction so far as the machine is not to be located in an extremely low ignition degree atmosphere.

5) Special explosion-proof construction
The construction of other than above 1)~4), confirmed by test or other method to be capable of preventing the outside explosive gasses from ignition. This construction is marked as "s".

4. Connection between Electric Equipment and External Wirings

There are two methods, one is connecting through a terminal box attached to the body and the other is connecting the external conductors directly to the body inside. The connection of external wirings to flame-proof type machine should be made through a terminal box by all means, while the connection of external wirings to pressurized explosion-proof type machines or increased safety explosion-proof type or oil-immersed explosion-proof machine fixedly used in the second class hazardous areas may be made either directly or through a protection box.

The draw-in system of conductor penetrating part from outside to terminal box (penetrating part I) and that between terminal box and body enclosure (penetrating part II), as shown in *Fig. 1*, are specified in the new Recommendations according to flame-proof construction and increased safety construction.

1) Connection system by terminal box
Fig. 2 is to show diagramatically the relation between explosion-proof construction of external wirings, that of terminal box and that of machine body. For both flame-proof construction [d] and increased safety construction [e] of the penetrating part I, applicable systems are

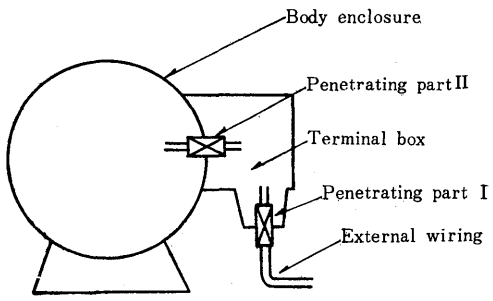


Fig. 1 **Explanatory diagram of terminal box**

specified as shown in *Table 4* corresponding to the external wiring system. There is of course difference in details of construction between [d] and [e].

For both [d] and [e] of the penetrating part II, stud system or packing system are required, while clamp system is available only for [e].

As can be seen in *Fig. 2*, the terminal box connected with thickly made conduit pipe (i. e., flame-proof external wiring works) is required

Table 4 **Draw-in system of terminal box**

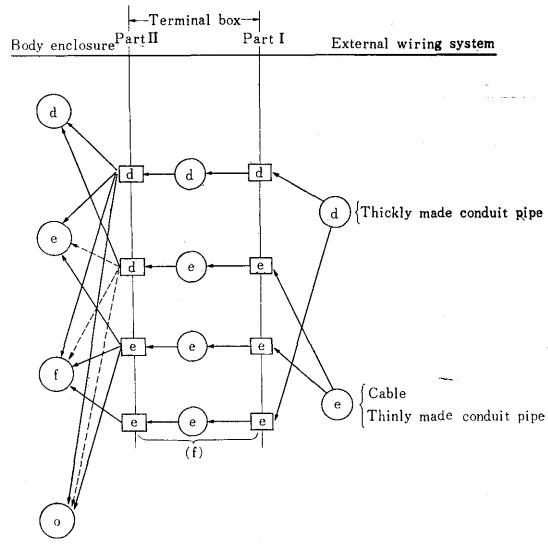
Draw-in system	External wiring			
	Conduit pipe	Steel tape armoured cable	Chroro-plane sheathed cable	Cabtyre cable for movable service
Screwed connection system	○	—	—	—
Packing system	—	—	○	○
Compound filling system	—	○	○	×

N.B. Mark ○ is applicable, × is not applicable.
It should be noted that such method of cable draw-in system as having short conduit pipe only for mechanical protection of which the end is opened in the main cable pit is not applicable to any system mentioned above, and is against the Recommendations.

to be of flame-proof construction (or increased safety type with pressurized construction) regardless of the explosion-proof construction grade of machine body.

2) Direct draw-in system
It is classified as shown in *Fig. 3*. As for cables, direct drawn-in system of steel tape armoured cable is not accepted. As to [e] of penetrating part I′, conduit pipe screwed-in system, dust-proof packing system, dust-proof bushing system etc. are applicable.

3) Draw-in system by protection box
It can be applied as shown in *Fig. 4*, but the drawing-in of steel tape armoured cable is not applicable.
At penetrating part I′, the same draw-in systems



N.B. 1) ○ means explosion-proof construction
2) □ means explosion-proof character of penetrating part I or II.
For example, [d] and [ē] mean flame-proof character and increased safety character, respectively, ⓔ (f) is increased safety type with pressurized construction,
3) Thickly made conduit pipe works are performed in the 1st class hazardous areas.
Thinly made conduit pipe works can be performed in the 2nd class hazardous areas so far as fixedly used.
4) Explosion-proof construction grade of terminal box is occupied by the lower grade of either penetrating part I or II.
5) Application of dotted line .... is applicable.

Fig. 2 **Application of explosion-proof construction of terminal box**

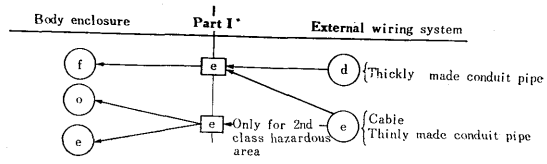


Fig. 3 **Application of direct draw-in system**

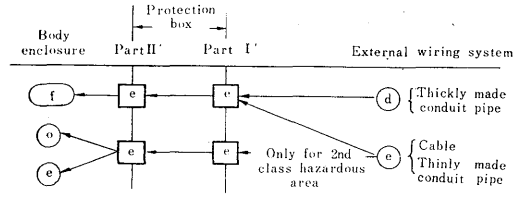


Fig. 4 **Application of draw-in system by protection box**

as the case of 2) are applicable, and at penetrating part II′ dust-proof clamp system and dust-proof bushing system etc. are applicable.

5. Temperature Rise Limit at Major Parts

1) Temperature rise limit of the parts contacting with outside dangerous gasses (the other parts than specified in the items 2)~4))
Table 5 shows the temperature rise limits specified for the following parts, i.e., outside of

Table 5 **Temperature rise limit (deg.)**

Ignition grade	G 1	G 2	G 3	G 4	G 5
Limit of temperature rise	320	200	120	70	40

Table 6 **Temperature rise limit of oil (deg.)**

Ignition grade	G 1	G 2	G 3	G 4	G 5
Limit of oil temperature rise	60	60	60	60	40

enclosure for flame-proof construction or oil-immersed explosion-proof construction, outside of enclosure and exhaust air for pressurized explosion-proof construction and all costituting parts for increased safety construction.

2) Temperature rise limit at oil surface
Table 6 shows the temperature rise limit of oil at oil surface for oil-immersed explosion-proof construction.

3) Temperature rise limit of electric machinery and apparatus contained in explosion-proof enclosure.
It conforms to respective standards of the electric machinery and apparatus. However, the temperature rise limit of insulating windings for increassed safety construction should be reduced from the value specified in respective standards by 10 deg.

4) Temperatuae rise limit for permissible locking time of increased safety cage rotor type induction motor
It is specified as shown in *Table 7*, and generally applied to cage rotor. Permissible locking time should be not less than 5 seconds and preferable more than 10 seconds except the motor guaranteed to be operated within the temperature rise stipulated in *Table 7*.

6. Marking

Marking of explosion-proof construction is very important because it represents the explosion-proof performance of electric machinery and apparatus. Symbols for type of explosion-proof construction and for explosion class and ignition grade of explosive gasses to be used should be indicated. However, in the electric machinery and apparatus with such construction that can be applied regardless of explosion class (e.g., pressurized explosion-proof construction), symbols for explosion class may be omitted. In case of electric machinery and apparatus in which more than two types of explosion-proof construction are combined, symbols of respective explosion-proof construction should be indicated together if it is necessary for maintenance or in order to guarantee the safety. In this case, explosion class and ignition grade are respectively determined by the lowest class and grade of constituting constructions. The symbols of explosion-proof construction can be indicated en bloc in the order of type of explosion-proof construction, explosion class and ignition grade, and in case of combined explosion-proof construction the symbols for main part should be marked ahead.

As for explosion grade 3, marking is not made only by 3 but made by combination with suffixes corresponding to objective gasses as follows.

3 *a*.....for water gas and hydrogen
3 *b*.....for carbon disulfide
3 *c*.....for acetylene
3 *n*.....for all gasses

The following are examples of symbol marking for explosion-proof electric machinery and apparatus.

- DC motor of pressurized explosion-proof construction against acetylene.....$d\ 3\ a\ G_1$
- Magnetic switch of flame-proof construction against hydrogen.....$d\ 3\ a\ G_1$
- Cage rotor type induction motor having body enclosure of increased safety construction (eG_1) and terminal box of flame-proof construction (d_1G_1).....ed_1G_1

Table 7 **Temperature rise limit for permissible locking time (deg.)**

	Insulation class	Temperature rise limit				
		G 1	G 2	G 3	G 4	G 5
Stator winding and insulated rotor winding	A	120–θ	120–θ	120–θ	85–θ	50–θ
	E	135–θ	135–θ	135–θ	85–θ	50–θ
	B	145–θ	145–θ	140–θ	85–θ	50–θ
	F	170–θ	170–θ	140–θ	85–θ	50–θ
	H	195–θ	195–θ	140–θ	85–θ	50–θ
Non-insulated rotor		360–θ	230–θ	140–θ	85–θ	50–θ

N.B. θ is temperature rise of winding under continuous running at rated load.

IV. COMPARISON OF EXPROSION-PROOF CONSTRUCTIONS OF MOTOR

In case the motors having explosion-proof construction are installed in hazardous areas, several kinds of explosion-proof construction can be generally considered for each machine. In such a case, most suitable construction should be selected considering cost, delivery time, reliability, noise, maintenance and inspection, work cost of building and foundation, operation cost, and other conditions required for ecch case. As a reference of such a selection, several major comparisons are introduced in the following columns. These are mainly for cage rotor type induction motors and though they are not always enough to make comparison in all respects, it can be understood that the rational installation of motors depends on the synthetical consideration on whole

facilities.

1. Increased Safety Construction and Flame-proof Construction

Fig. 5 shows the output reduction tendency of increased safety motors and flame-proof motors in the same frame size of standard motor, changing the ignition point as parameter. As shown in this figure, increased safety construction causes considerable output reduction as the ignition point becomes lower and output goes higher, while flame-proof construction has only a little output reduction. In other words, it means that the increased safety construction requires considerably bigger size of frame to get the same output.

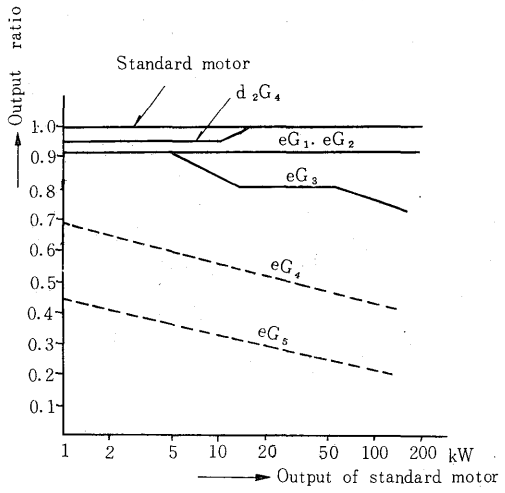


Fig. 5 Comparison of output for explosion-proof motors

Though this figure is not to show the comparision of cost, it is needless to say that the frame size has a large factor of cost. There may be such a sense generally that increased safety motor is lower in cost than flame-proof motor, but it should be understood that actually it is not always so as the change of ignition point and output capacity. When purchasing motors, ignition grade should be properly determined by users after thorough considerations.

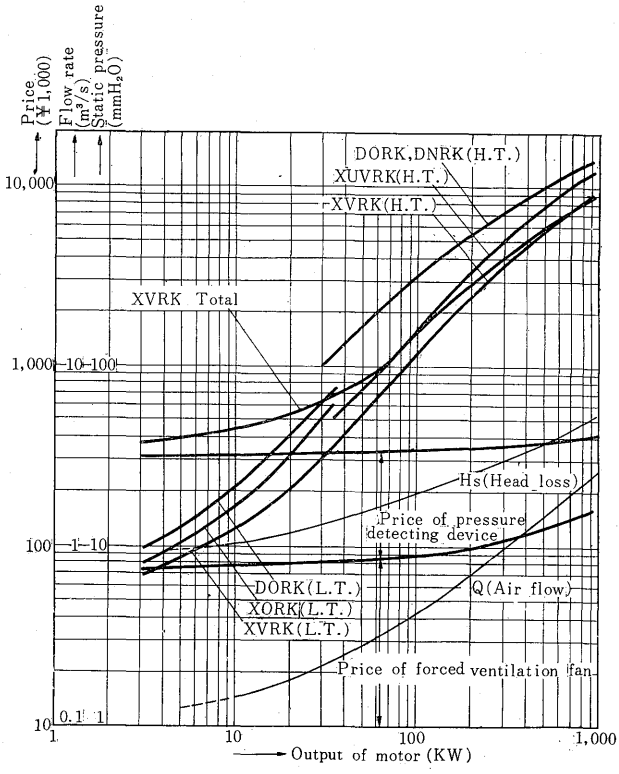
2. Flame-proof Construction and Pressurized Explosion-proof Construction

Fig. 6 shows the cost comparision of 4 pole cage-rotor type induction motors of various explosion-proof constructions. In this figure, both ventilating system and sealing system are taken out for pressurized explosion-proof construction, and as for the cost of machines themselves it is generally understood to be more economical to adopt the pressurized explosion-proof construction of ventilating system for above 30 kW and that of sealing system for above 50 kW, comparing with flame-proof construction. However, since this comparision is made excluding wind tunnel, air filter in dusty place, fundation and other materials, special work cost required for pressurized construction etc., the cost increase by these provisions should be taken into consideration in practice (furthermore operation cost, if necessary) to get rational decision. The cross point of the courve of pressurized construction including these cost increases and the curve of flame-proof construction is the economical boundary of the both constructions.

Since it is difficult for us to settle the cost increase on user's side, only the costs of machines proper up to 1,000 kw are shown in the figure for the reference of consideration at users.

Specifications of machines in *Fig. 6* are as follows.

1) Motors
   Flame-proof construction: d_2G_4 Indoor use
   Pressurized explosion-proof construction: fG_4 indoor use
   Above 37 kW: HT 3,000 V class
   Less than 37 kW: LT 200 V class
   Insulation class: Class A



N. B.
- XVRK: Ventilating system pressurized construction
- XUVRK: Sealing system pressurized construction (totally enclosed air circulated water cooled type)
- DNRK: Flame-proof construction (totally enclosed with outside fan air pipe cooled type)
- DORK: Flame-proof construction (totally enclosed with outside fan air rib cooled type)
- XORK: Sealing system pressurized construction (totally enclosed with outside fan air rib cooled type)

Fig. 6 Cost comparision of explosion-proof motors

2) Forced ventilation fans
Indoor use non-explosion-proof turbo type.
Driving motor: Non-explosion-proof totally enclosed outside fan cooled, 200 V 50 c/s.
Head: Compensating the total loss of 60 mm H_2O, including loss of fan proper, wind tunnel of suction side and that of exhaust side.

3) Magnetic switch for fan motor
Indoor use non-explosion-proof.

4) Internal pressure detecting device
Including transmitter, receiver, time relay for necessary interlock and auxiliary relays.

Sealing system pressurized explosion-proof air circulated water cooled type motor, Model XUVR, is out of standard for small size less than 50 kW. Accordingly, for the sealing system less than 37 kW, price of totally enclosed with outside fan air rib cooled type motor, Model XOR, is taken in the figure.

3. Water Cooled type Explosion-proof Motor and Air cooled type Explosion-proof Motor

Noise of motors is recently taken up as social problem and this is also important problem for explosion-proof motors. As the countermeasure against noise, there have been so far various methods by which noise has been suppressed to some extent. However, for air cooled type motors, especially for totally enclosed outside fan cooled type motors, effective noise suppression could not be obtained without special measures. For this demand, water cooled type explosion-proof motors were newly developed by our Company, which permit small size and light weight as well as having low noise level.

Though the details of its construction and characteristics will be described in the next chapter, the comparisons of cost etc. between the air cooled explosion-proof construction and various water cooled constructions of outdoor use induction motor: 500 kW 3 kV 4-poles 60 c/s, are listed up in *Table* 8, In this *Table*, it is understood that the water cooled type is highly effective for low noise level. Besides, it is noticeable that the cost scarecely changes between air cooled type and water cooled type. As a cooling water of air circulated water cooled type, Model XUVR, sea water can be used, while, as a cooling water of direct water cooled type, Model WPRK, and stator water cooled type, Model QR, industrial water is now served, but in the near future sea water will be permitted.

4. Gas and Vapor Explosion-proof Construction and Powder and Dust Explosion-proof Construction

The explosion-proof construction specified in the Recommendations for Powder and Dust Explosion-proofing is not for usual powder but for such a dangerous powder and dust as to inflict an injury on person when explosion occurs. Accordingly, this construction much differs from the general dust-proof construcion and is rather similar to the Gas and Vapor Explosion-proof construction. In the case of small size induction motor, comparision of these constructions can be mentioned as follows.

1) Special dust-proof construction
It corresponds to flame-proof construction. By adding necessary packings to the flame-proof constauction, special dust-proof construction is available except the difference of pressure resisting strength.

2) Usual dust-proof construction
Practically, it has not so much difference from the increased safety construction except such a problem that a part of adjoining surface should have enough width. Accordingly, much difference in practice cannot be recognized between them for rather small size motors.

V. FLAME-PROOF MOTORS

Only flame-proof construction and performance for induction motors are introduced in the following columns, because flame-proof construction is applied more to induction motors than to synchronous motors and DC motors etc.

1. Standard Construction

Following application standard of explosion-proof construction is specified for flame-proof motors.

$d_2 G_4$.....LT (including HT below 600 V AC)
$d_2 G_4$.....HT (excluding HT below 600 V AC)

Standard system of terminal box is as shown in

Table 8 **Comparison of air cooled and various water cooled explosion-proof motors**

	Direct water cooled flame-proof construction Model ODWPRK	Stator water cooled flame-proof construction Model ODQRK	Air circulated water cooled pressurized explosion-proof construction Model OXUVRK	Pipe air cooled with outside fan flame-proof construction Model ODNRK
Noise level	70 phon	75 phon	80 phon	90 phon
Prcie (%)	100~105%	100~105%	85%	100%
Cooling water quantity	45 *l*/min	65 *l*/min	75 *l*/min	—

Table 9 **Standard system of terminal box (for flame-proof motor)**

	Penetrating part II	Explosion-proof constuction of terminal box	Penetrating part I	External wiring system for standard construction
Low tension	Stud system (moulding)	Flame-proof	Screwed connection system	Thickly made conduit pipe
High tension	Stud system (porcelain)	Flame-proof	Compound filling system	Cable

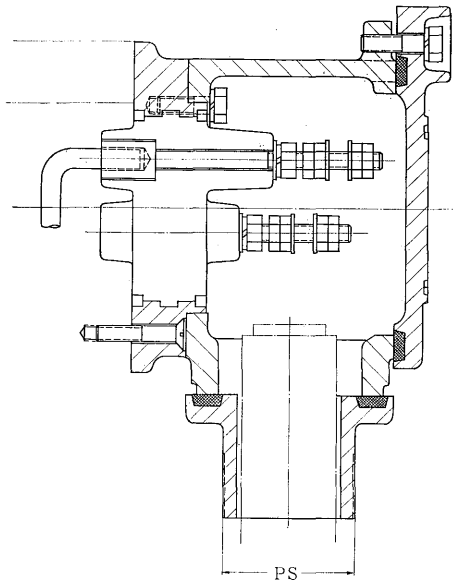


Fig. 7 Terminal box of L.T. flame-proof construction

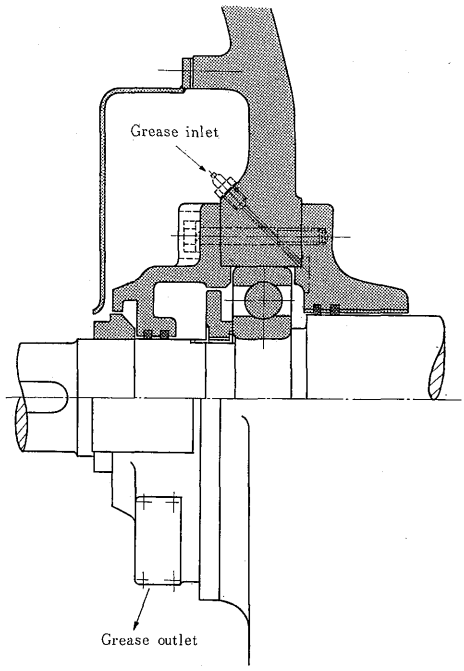


Fig. 8 Sectional view of ball or roller bearing for outdoor use flame-proof motor

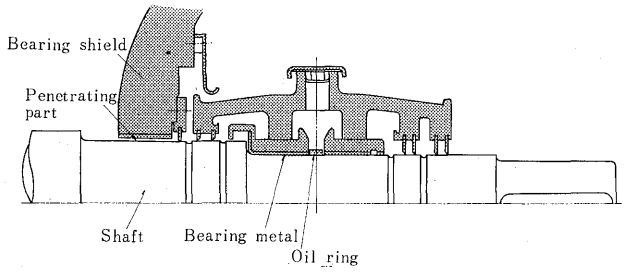


Fig. 9 Sectional view of sleave metal bearing for outdoor use flame-proof motor

Table 9.

The terminal box for LT motor is shown in *Fig. 7*. The terminal box for HT motor is similar to that of HT increased safety construction described later but it becomes farely big size because of having pressure-resisting strength.

Cable draw-in system for LT terminal box and screwed connection system for HT terminal box are also available.

Bearing part is the most important part as flame-proof motor. The standard constructions of ball or roller bearing and sleave metal bearing for outdoor use flame-proof motor of our Company are shown in *Fig. 8* and *Fig. 9*, respectively. For water-proofing, double or triple sealing is adopted to make assurance, and continuous grease exchange under running operation is possible for ball or roller bearings.

In the installation of equipment in chemical plant, corrosion-proof treatment against various corrosive gases has been so far problemable and as increasing outdoor installation of electric equipment recently, this problem is taken up seriously together with the problem of noise. In our Company, corrosion-proof treatment is classified into four grades, N_1, N_2, C_1 and C_2, C_1 and C_2 are of high grade corrosion-proof characters against strongly corrosive service conditions and since the motors of these corrosion-proof treatment are required practically only in very rare and very few cases, only conventional corrosion-proof treatments, N_1 and N_2, are introduced in *Table 10*.

2. Flame-proof (Rib or Pipe cooled) Induction Motors (Model DOR or DNR)

Fig. 10 shows the section view of our typical outdoor use air pipe cooled flame-proof induction motor.

This motor has such a special construction that the inner wall as stator frame and the outer wall

Table 10 **Application of corrosion-proof treatment**

Kind	Special corrosion-proof (Grade N_1)	Usual corrosion-proof (Grade N_2)
Application	Where the condition is rather severe	Where the condition is not so much severe
End cover	Acid-proof construction for outer end cover Standard construction for inner end cover	Standard construction
Fan	Cast iron made, or standard (iron-plate) with lead-metalicon treatment	Standard, iron plate with lead-metalicon treatment
Fan cover	Cast iron	Standard (iron plate) with lead-metalicon treatment
Bolt and nut	Iron with zinc coating, except brass (without coating) for terminal conductive parts	
Name plate	Embedded into brass made frame with unsoluted varnish	Standard
Painting	Vinyl chloride paint	

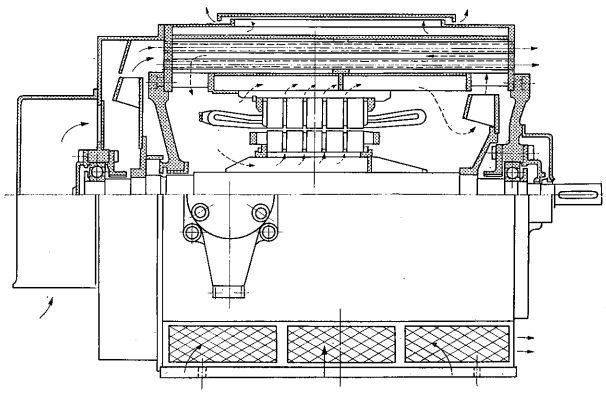


Fig. 10 Section view of outdoor use air pipe cooled flame-proof induction motor

as iron plate cover are composed together to build the double wall, and ventilating holes are provided in the top and the bottom of the outer wall. The cooling pipes are running in the stator core. The features of this construction are as follows.

1) Temperature rise by direct sunbeam can be prevented. The influence of direct sunbeam on the body enclosure concerning the cooling of water inside can be avoided. Heated air by direct sunbeam goes upward inside the double walls and be naturally ventilated.
2) Non-drive side suction cover has a noise suppression effect and for the requirement of further low noise level, a silencer cover is attached to the pipe air exhausted side and respective covers for suction and exhaust are lined with noise absorbing materials to reduce effectively the noise level.

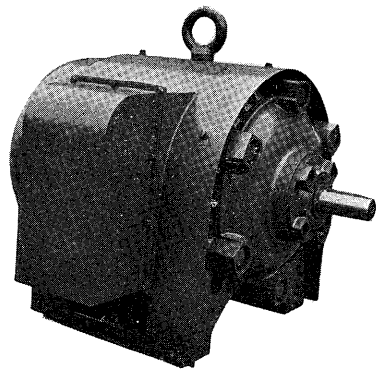


Fig. 11 Outer view of air rib cooled flame-proof induction motor

Generally, air rib cooling system is adopted for small size and over the limit of this cooling system, air pipe cooling system is adopted.

Fig. 11 shows the outer view of air rib cooled flame-proof induction motor.

3. Water Cooled Flame-proof Motors

1) Direct water cooled flame-proof induction motor, Model DWPRK

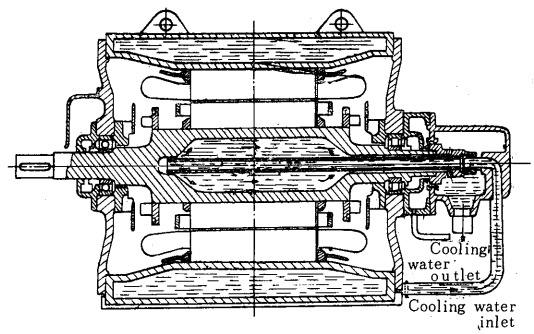


Fig. 12 Section view of direct water cooled flame-proof induction motor, Model DWPRK

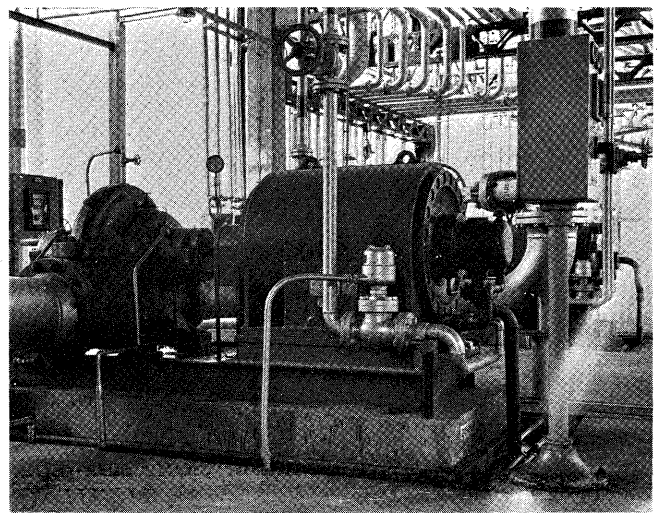


Fig 13 Outdoor use direct water cooled flame-proof induction motor, 1,000 kW, 3,000 V 60 c/s 1,200 rpm

Fig. 12 shows the explanatory section view of this motor, and *Fig. 13* shows the motor under operation. The flame-proof motors of this construction were developed by the Siemens-Schuckertwerke A. G. and the first one in our country was manufactured by our Company.

It has such an epock-making construction that cooling water at first passes the stator frame to cool the stator and then goes into the shaft in series to cool the rotor directly by water.

The features of this motor can be enumerated as follows.

(1) Very easy and natural to make it flame-proo construction.

(2) Low noise level can be obtained by removing the cooling fan because of direct water cooling of motor body. The actual result of maximum 64.5 phon for 100 kW 1,200 rpm flame-proof motor was confirmed.

(3) Having high cooling effect, motor size can be extremely minimized and weight lightened. *Fig. 14* shows the size comparison of 370 kW 4 P motors between pipe cooled type and direct water cooled type.

(4) Far less cooling water is necessary than in the case of other water cooling system.

(5) Effective even in case of surrounding atmosphere having high temperature and being heavily corrosive.

For the further details regarding the water cooling system, please refer to the Fuji Electric Journal Volume 32 No. 5 (100 kW 6 P) and Volume 34 No. 2 (2,350 kW 4 P).

As stator windings, the coils having moisture-proof ins ulationspecially strengthened in their moisture-proof characteristics are adopted, and furthermore they are constructed to be suitable for water cooling system. The windings of this type are adopted by our Company not only for water cooled type motors but also for outdoor use motors, as standard.

2) Stator water cooled flame-proof induction motor, Model DQR

Fig. 15 shows the explanatory section view of stator water cooled flame-proof motor. This motor has the cooling system of passing the cooling water through

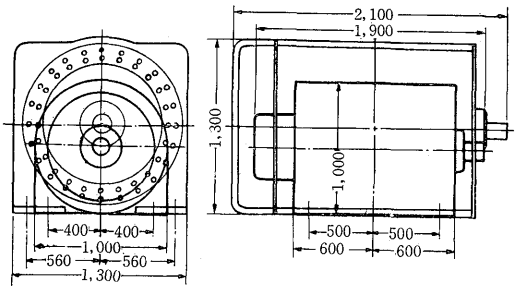


Fig. 14 Size comparison of 370 kW 4 P motor between pipe cooled type and direct water cooled type

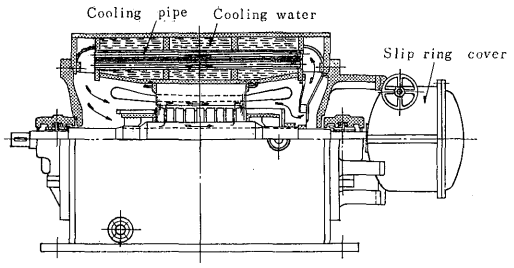


Fig. 15 Explanatory section view of stator water cooled flame-proof induction motor

only stator frame, having high cooling effect next to direct water cooled type. Since it is difficult to apply the direct cooling system to wound rotor type motor, this system is adopted for the wound rotor type motor in place of direct cooling system.

Fig. 16 is appearance of stator water cooled flame-proof wound rotor type induction motor. To raise the cooling effect of this construction, the outside circumference of stator core is machined to fit the stator frame without any gap between them, and furthermore ductless construction of stator core is adopted.

The stator water cooled type motor has low noise level next to the direct water cooled type, and the actual result of 75 phon for 520 kW 3,600 rpm is obtained.

4. Other Flame-proof Type Rotary Machines

The above-mentioned flame-proof constructions are mainly for induction motors. In the following columns, several kinds of machines modified from induction motor and relatively widely used are introduced.

1) Water cooled flame-proof KS coupling, Model DQKS

KS coupling is an eddy current system variable speed coupling and widely adopted to extruder etc. as a speed changing device. Water cooled flame-proof

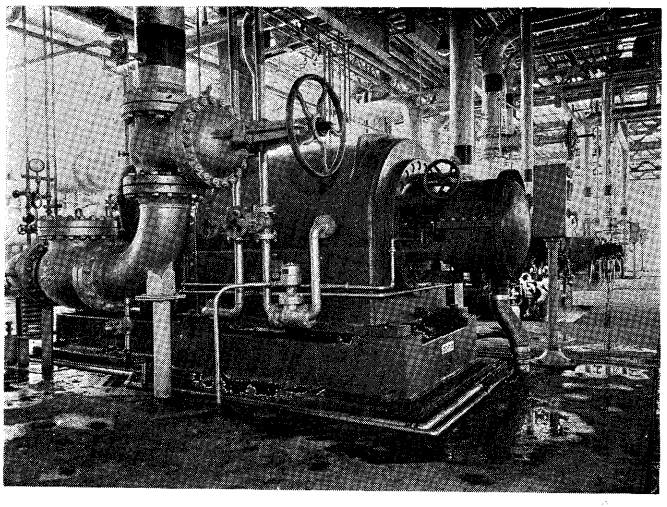


Fig. 16 Outdoor use stator water cooled flame-prcof induction motor

KS coupling is available for large output (40 kW to 300 kW) and wide variable speed range (top speed 1,250/1,500 rpm 50/60 c/s 10 : 1), and standard application of explosion-proof construction is $d_2 G_4$.

The feature of water cooled KS coupling is that the sliprings are omitted by adopting the fixed type exciter winding in place of the rotary type so far provided on the spider, high cooling effect can be obtained because of water cooling system and machine size is minimized, and increased safety construction is easily available for the surrounding condition having ignition grade G_1, G_2 and G_3.

2) Flame-proof tachometer dynamo, Model aDPRC 36/1.6–4

The tachometer dynamo is used as a transmitter of speed-meter or automatic speed controlling apparatus for the above-mentioned KS coupling etc., and the standard application is $d_2 G_4$. This machine is two-phase induction generator having two windings of excitation and has such features that no slipring is provided and output voltage can be taken out at a constant frequency (input power frequency) regardless of rpm. The machine having output of 200 W, exciting winding input voltage of 200/220 V 50/60 c/s is our standard.

VI. PRESSURIZED EXPLOSION-PROOF MOTORS

Pressurized explosion-proof construction can be classified into two systems, ventilating system and sealing system.

Standard application of our pressurized explosion-proof motor is $f G_4$ of explossion-proof construction, and our standard system of terminal box for this kind is either increased safety construction capable of internal pressure or direct draw-in system with inside pressurized.

1. Pressure Distribution

Pressure distribution of ventilating system is generally considered as shown in *Fig. 17*. Though the necessary internal pressure for ventilating system or sealing system pressurized explosion-proof construction specified in the Recommendations is higher than 5 mm

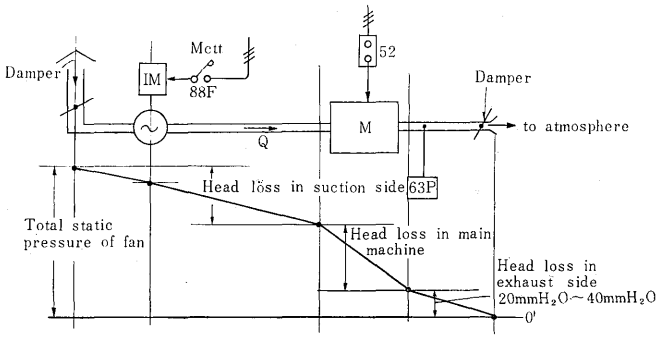


Fig. 17 Pressure distribution of pressurized explosion-proof type motor

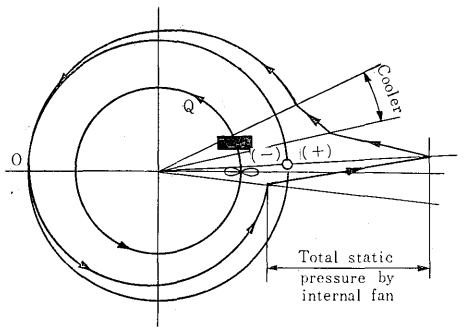


Fig. 18 Pressure distribution of sealing system pressurized explosion-proof construction

H_2O at the minimum pressure point, our Company settles the value as standard at 20~40 mm H_2O under normal operation. The Recommendations also specifies that the interlocks between the pressure-down value and the stopping operation or alarming should be determined considering each service condition and machinery construction.

Fig. 18 shows the principle diagram of pressure distribution of sealing system pressurized explosion-proof motor.

Without supplying make-up air, when internal air circulation is performed by self-provided fan, negative pressure may appear on some points, as shown in the figure, caused by the small leakage of air from the enclosure inside. Accordingly, to prevent the invasion of outside hazardous gases into the enclosure it is necessary to compensate the air leakage and raise the pressure potential in the closed circuit to maintain the static pressure at every point in the enclosure above atmospheric pressure. For this purpose, clean air is supplied into the enclosure for leakage compensation and is called make-up air. The required make-up air volume is nearly 1~2% vol./sec. to maintain the lowest pressure potential at about 20 mm H_2O, in which vol. means the inside volume of enclosure.

2. Ventilating System Pressurized Explosion-proof Motors

Two types can be considered in this system, one is that the exhaust air is led to outdoor through air duct and the other is that the air is directly exhausted to the motor surroundings. Our Company adopts as standard the former, i.e., exhaust air just passed inside of motor is led through the exhaust air duct to undangerous place.

Since this ventilation is common with the ventilation for motor cooling, so many big holes for ventilation should be provided on the motor enclosure in case of the direct exhaust to surroundings, and when overheat, short-circuit, burn-out etc. occur inside by any chance, forced ventilation will expell the heat, spark etc. generated inside to the hazardous atmosphere, which involves the danger of explosion accident especially in case the gas of low ignition point exists

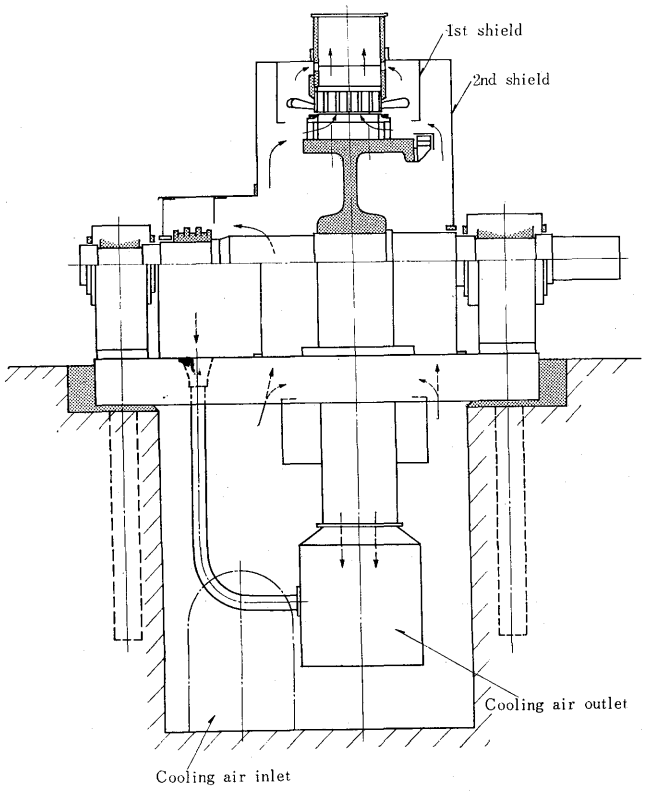


Fig. 19 **Section view of ventilation system pressurized explosion-proof synchronous motor**

in surroundings, and furthermore, such construction having many and big ventilation holes involves the problem in maintaining the minimum internal pressure against the atmospheric pressure.

Fig. 19 shows a construction example of large size synchronous motor for reciprocating compressor. In the figure, stator displacing device is provided, but in case not necessary, shaft span of motor can be much reduced. The features of pressurized explosion-proof synchronous motor are as follows.

1) Enclosure having 2 nd shield as well as 1 st shield usually provided is deemed to be totally enclosed type, and rotating parts are completely shielded not to be exposed outside.
2) Since the foundation pit can be reasonably constructed for the purpose of suction and exhaust of ventilating air, air duct installation on the floor is not necessary.
3) Since the ventilating air is decided in the main body into two streams, for the cooling of main body and for the cooling of slipring, fear of invasion of carbon brush powder into the windings of body is precluded. The air passed through the slipring chamber joins together with the main stream and then exhausted outside. In general, ventilating system motors have no self-provided fan.
4) Provided the terminal parts being installed at the bottom of stator, more reliable draw-in method of external wirings can be aquired by

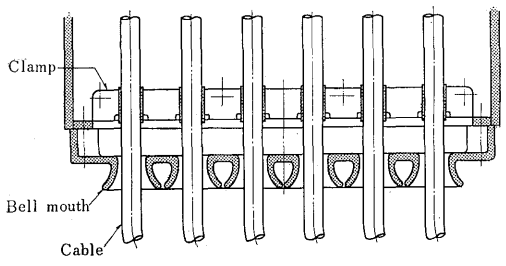


Fig. 20 **Explanation view of direct draw-in system**

pressurizing the external wirings together with motor body, in case of direct draw-in system. As for the terminals, either terminal box system or direct draw-in system is available, but as increasing the capacity as the case of large size synchronous motor for compressor, size of multi-core power cable and space required for its end treatment are become large, which causes size of terminal box extremely big and attachment of terminal box difficult on the viewpoint of construction and wiring.

On the other hand, stator displacing device is generally required for the large size motor for compressor, and stator displacing work becomes very difficult if big size multi-core power cable is fixed to the terminal.

To solve such problem, our Company has adopted for large size motor the direct draw-in system using single core flexible BN cable as a lead cable as shown in *Fig. 20.*

5) Necessary turning pinion device required for reciprocating compressor is provided. This pinion is self-release screw type pinion, in which clutching is made manually and releasing is effected automatically when relative speed of pinion to main machine becomes inverse and the torque of main machine forces to rotate the pinion to release the clutch. Consequently, floating automatic start can be performed, by

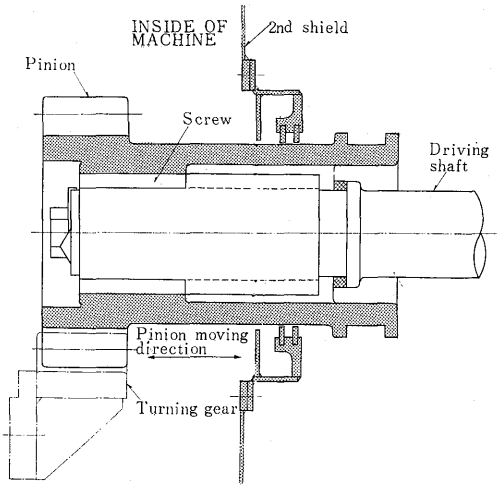


Fig. 21 **Explanatory view of 2nd shield and pinion for turning**

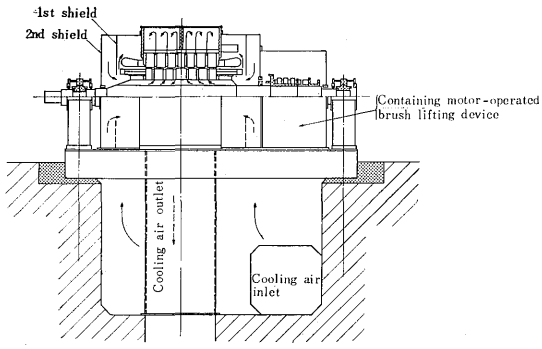


Fig. 22 Section view of ventilating system pressurized explosion-proof wound rotor type induction motor

which the main machine can be started at any time during the course of turning operation.

Fig. 21 shows the pinion and its penetrating part of 2 nd shield. The movement of its penetrating part is easily managed to prevent air leakage because only a horizontal penetration by screw mechanism housed in the pinion boss should be considered, and the pressurized air leakage and pressure-down are prevented by providing Rabyrinth packings as shown in the figure.

Fig. 22 shows the section view of ventilating system pressurized explosion-proof wound rotor type induction motor.

This figure is also an example of induction motor for large capacity turbo compressor or SRM compressor, and having ventilation system rationally using the foundation pit as the case before.

The cooling air supplied from the pit goes into the main machine through both ends of stator in shaft direction and exhausted after passing along circumference of stator frame.

Since the motor in this figure is provided with brush lifting and 2 ry short-circuiting device, only static pressure is effective arouned sliprings. However, in the case of carbon brushes being continuously in service as the case of speed control system, slipring chamber should be also ventilated as in the case of *Fig. 19.*

It is also possible to install an air cooler (water cooled type) in the pit to make circulation cooling, but in this case filling-in of make-up air is necessary and it is regarded as a sealing system pressurized explosion-proof construction.

For cage rotor type induction motor, similar ventilating construction can be adopted. *Fig. 23* shows the appearance of the cage rotor type induction motor.

The pressurized explosion-proof construction of DC motor is omitted in this paper, but it is similar to that shown in *Fig. 22*, except ventilating system, i.e., instead of parallel ventilation the cooling air is directed to the commutators after passing the main body in series.

3. Sealing System Pressurized Explosion-proof Motors

Sealing system pressurized explosion-proof motors can be classified as follows according to the cooling system of the motors to which make-up air is supplied.

- Totally enclosed with outside fan, air rib or pipe cooled type
- Totally enclosed air circulated water cooled type
- Totally enclosed stator water cooled type
- Totally enclosed direct water cooled type

For every type, it is necessary to change the air

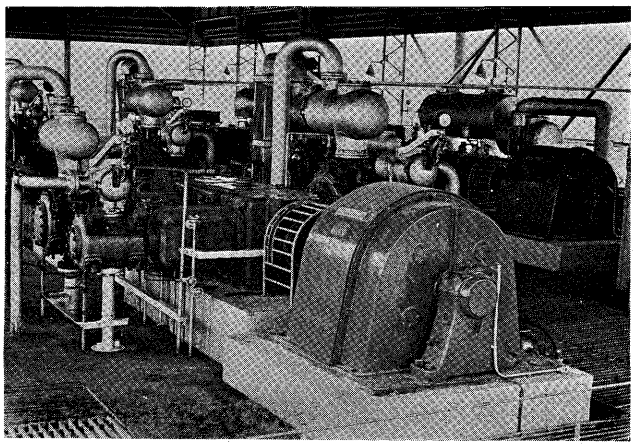


Fig. 23 Pressurized explosion-proof cage rotor type induction motor

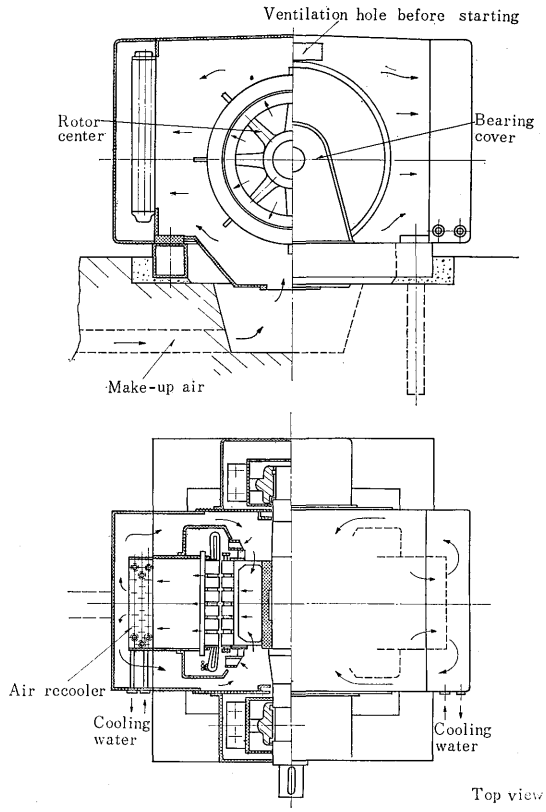


Fig. 24 Section of outdoor use totally enclosed air circulated water cooled sealing system pressurized explosion-proof induction motor

before starting operation, and to make it perfectly and rapidly the ventilating hole for starting operation is generally provided.

Economical application of sealing system pressurized explosion-proof construction is deemed to be totally enclosed type with make-up system for rather small capacity (about 40～50 kW) and totally enclosed air circulated water cooled sealing system pressurized explosion-proof construction for larger capacity motors.

Fig. 24 is a explanatory diagram of our typical outdoor use totally enclosed air circulated water cooled sealing system pressurized explosion-proof cage rotor type induction motor.

The main features of this motor are as follows.

1) Only a small quantity of make-up air (or other protecting gas) is required because it is only for maintaining of internal pressure potential. Accordingly, cooling air can be easily replaced by inactive gas such as nitrogen because of small consumption.
2) Since air cooler is installed on side of main body, maintenance, inspection and handling of cooler are very easy. When removing the cooler, it can be simply taken out to horizontal direction. And there is no possibility of dew drop trouble as in the case of top installation.
3) Since foundation pit can be omitted, it is especially suitable for outdoor use explosion-proof motor in conjunction with the following features.
4) Low noise level can be obtained because of totally enclosed type. Since outside fan is not provided but only internal air circulating fan is installed inside, noise can be effectively suppressed. The casings such as cooler cover etc. are light and easy to be free for the purpose of noise suppression because they are made of thin sheet iron different from usual motor frame, and furthermore, by lining the noise absorbing materials on inner surface, considerable decrease of noise level can be effected.
5) Since the upper cover has a slight slant, there is no possibility of dew drop accumulation.

4. Control of Pressurized Explosion-proof Motors

1) Sequence

Fig. 25 shows an example of sequence diagram for controlling a ventilating system pressurized explosion-proof motor.

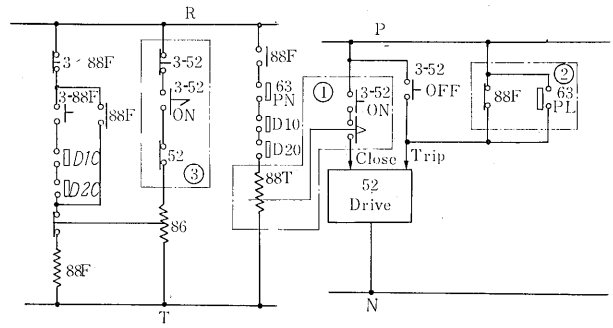


Fig. 25 Sequence diagram for controlling

In this diagram only the controls concerning with explosion-proofing are illustrated though in practice the controls other than that are interconnected together. The equipment to which this sequence diagram is applied is provided with the damper in its suction and exhaust air duct capable of actuating perfect open to perfect close for facilitating the starting operation of forced ventilation and for prevention from invasion of moisture, foreign substances etc. during rest of operation.

The interlocks expressed by this sequence diagram consist of the following.

1) Main machine cannot be started until a certain duration has passed after ventilating fan started. (a certain duration means the time required for ventilating the air as much as more than 5 times of enclosure volume of main machine.)
2) When the internal pressure goes down below

Table 11 **Internal pressure detection system**

	Transmitter	Receiver
1	Model PUF-N_2 Pneumatic-pnenmatic converter Output pressure 0.2～1.0 kg/cm² Detecting pressure 0～50 mm H_2O Air supply 1.1 kg/cm²	Model QPA-1/K_1K_2 Pressure indicator with alarm contacts Pressure detection (lower and upper limit)
2	Model RAD/F Ring-balance type pressure transmitter Output Change of resistance Detecting pressure 0～50 mm H_2O	Model TZ Transistor system pressure indicator with alarm contacts DC AC aux. supply Pressure detection (lower and upper limit)

the specified value or the fan motor stops by any chance, the main machine should be stopped.

3) When the main machine stops (mainly caused by the action of protective relays on short-circuiting, overload, etc.), the ventilation fan should be stopped successively. This is to avoid the support for accident sometimes established by forced ventilation.

4) Internal pressure detecting device

Since the internal pressure of pressurized explosion-proof type machine is extremely low as much as 10 mm H_2O, it is difficult to detect the pressure by conventional pressure gauge. Consequently, special instrument of high sensitivity for low pressure should be used, which envolves a problem of pressurized explosion-proof construction.

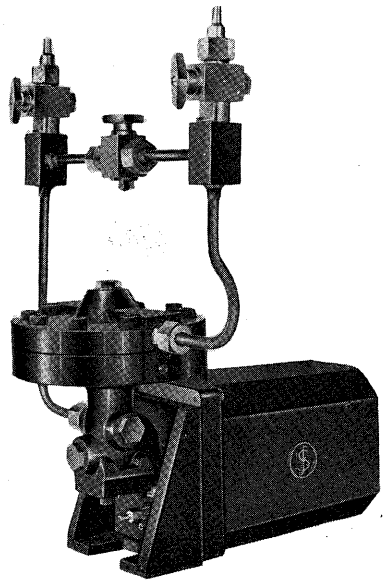


Fig. 26 Pneumatic pressure transmitter

Our Company has been adopting the two systems as shown in *Table 11* by making the best use of our process instrument technics. System 1 is widely adopted in case the instrument air is easily available and has such an advantage that there is no electrical part in hazardous areas, while System 2 is mostly adopted in case the System 1 is not adoptable. The costs of both systems are nearly same. *Fig. 26* shows the appearance of transmitter of System 1.

VII. INCREASED SAFETY MOTORS

Increased safety construction is generally applied to induction motors and synchronous motors. Though it is also applicable to DC motors, commutator motors and other motors if required, commutator parts of these motors should be of either flame-proof construction or pressurized explosion-proof construction, and as such parts occupy major part of motor bodies, whole body is generally made flame-proof construction or pressurized construction.

1. Increased Safety Induction Motors

Application standard of explosion-proof construction and standard system of terminal box are shown in *Table 12* and *Table 13* respectively.

Table 12 **Application standard of increased safety motor**

	Explosion-proof construction		Insulation class
	Cage rotor type	Wound rotor type	
Low tension	e G 2	e G 4	class E
High tension	e G 2	e G 4	class B

Table 13 **Standard system of terminal box (for increased safety motor)**

	Penetrating part II	Explosion-proof construction of terminal box	Penetrating part I	External wiring system for standard construction
Low tension	Dust-proof clamp system	Increased safety	Dust-proof packing system	Cable
High tension	Dust-proof stud system	Increased safety	Dust-proof compound filling system	Cable

Terminal box constructions are shown in *Fig. 27* (for low tension) and *Fig. 28* (for high tension). The head part of terminal box is interchangeable which permits screwed connection of conduit pipe (thick steel or thin steel), and preparing for the screwed connection of thick steel conduit pipe in case of flame-proof work, interchangeability of complete terminal box is also considered.

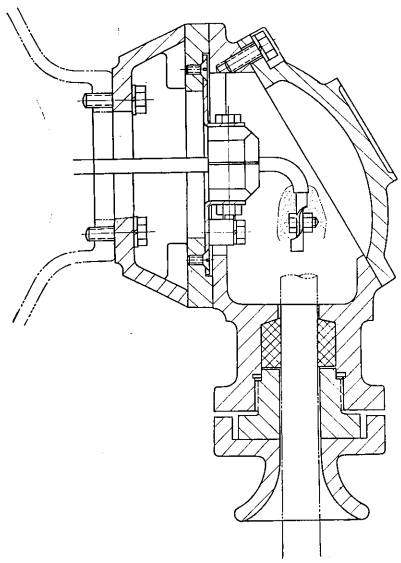


Fig. 27 Terminal box of LT increased safety motor

Fig. 29 shows the group of increased safety motors under operation at petroleum refining plant.

Increased safety motors are generally classified as follows on the basis of cooling system.

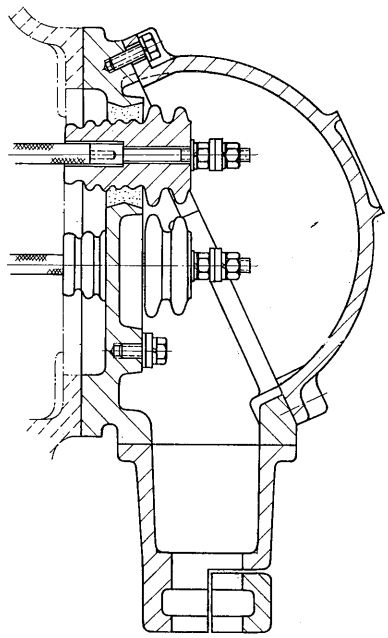


Fig. 28 Terminal box of HT increased safety motor

- Totally enclosed with outside fan, air rib or pipe cooled type.....Model AOR, ANR
- Totally enclosed air circulated water cooled type .....Model AUVR
- Totally enclosed stator water cooled type..... Model AQR
- Totally enclosed direct water cooled type..... Model AWPR
- Enclosed self-ventilated cooled type.....Model AVR

In the case of wound rotor type induction motor, slipring part is of either flame-proof construction or pressurized explosion-proof construction. *Fig. 30* shows the appearance of increased safety induction motor having slipring part of flame-proof construction.

2. Increased Safety Synchronous Motors, Model AF

Synchronous motors of this construction are generally of enclosed self-ventilated type for main body and of either flame-proof or pressurized explosion-proof type for slipring part, and generally used in rather light hazardous areas.

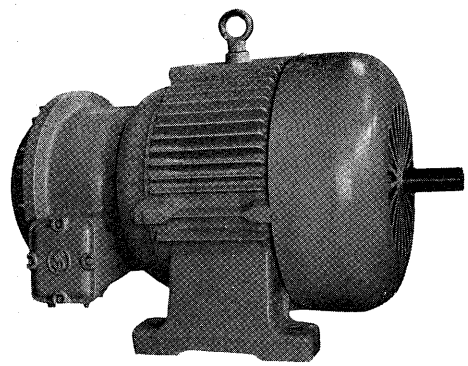


Fig. 30 Increased safety wound rotor type induction motor, Model AORW

Fig. 31 shows an example of increased safety synchronous motor for reciprocating compressor, having slipring part of pressurized explosion-proof construction.

The special consideration is paid on the following points similar to the case of increased safety cage rotor type induction motor.

1) Protective construction is higher than the protect type specified in the standards JEC–146, though it is not totally enclosed type.
2) The temperature rise limit of windings is less than that specified in the standards by 10 deg. centigrade.
3) Creepage paths and clearance distance specified in the standards concerned are applied.
4) Since the damper winding for starting corresponds to the cage rotor of induction motor, temperature rise limit for the duration of allowable locking time is assured.

As for terminal, direct draw-in system is adopted for this motor as illustrated in *Fig. 19* because of large capacity machine for reciprocating compressor.

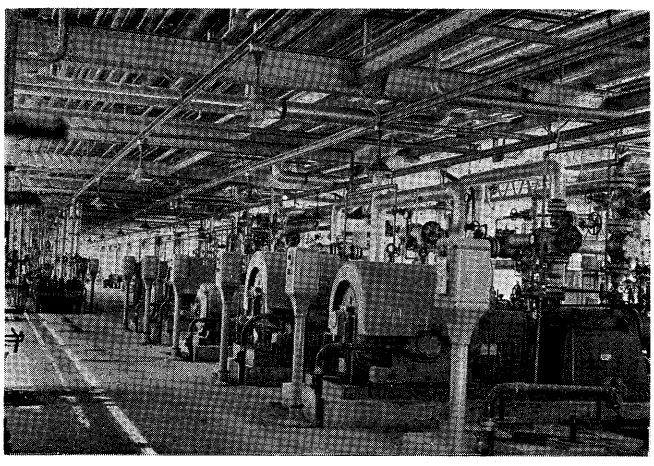


Fig. 29 Group of increased safety motors

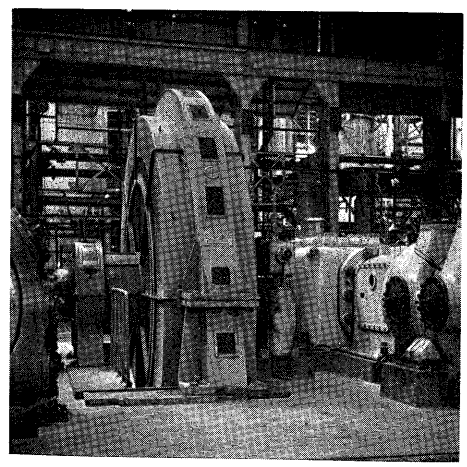


Fig. 31 Increased safety synchronous motor

(To be continued)