Design Evaluation and Temperature Rise Test of Flameproof Induction Motor

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Abstract: The ignition of flammable gases, vapours or dust in presence of oxygen contained in the surrounding atmosphere may lead to explosion. Flameproof three phase induction motors are the most common and frequently used in the process industries such as oil refineries, oil rigs, petrochemicals, fertilizers, etc. The design of flameproof motor is such that it allows and sustain explosion within the enclosure caused by ignition of hazardous gases without transmitting it to the external flammable atmosphere. The enclosure is mechanically strong enough to withstand the explosion pressure developed inside it. To prevent an explosion due to hot spot on the surface of the motor, flameproof induction motors are subjected to heat run test to determine the maximum surface temperature and temperature class with respect to the ignition temperature of the surrounding flammable gas atmosphere. This paper highlights the design features of flameproof motors and their surface temperature classification for different sizes.

Keywords: *Flameproof, enclosure, motor, surface temperature.*

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1. Introduction

Three phase induction motors are the backbone of the modern day's process industries. Flameproof three phase induction motors are the most common and frequently used in the process industries such as oil refineries, oil rigs, petrochemicals, fertilizers, etc. The mechanical design of flameproof motors is strong enough to withstand the high explosion pressure developed inside the enclosure. The flame of the explosion is not transmitted outside the enclosure and quenched inside it. The testing of such induction motors to determine the temperature rise along with the power dissipated inside the machines as heat is a matter of interest to both customers and manufacturers. Power dissipation leads to temperature rise in electrical machines and plays vital role which affects the insulation materials, the cooling systems and eventually the efficiency of the machine.

2. Design of Flameproof motors

The flameproof motors are designed in such a way that flame path and gaps do not allow the flame of explosion to transmit outside the enclosure. It consist of several flameproof joints such as joint between inner bearing cap and shaft, inner bearing cap and motor body (drive end shield and non-drive end shield), motor body and terminal box, terminal box and its cover, terminal box and cable gland plate etc. All the flame paths and gaps work as heat sinking channels and their dimensions (length, width, clearance) are important to sufficiently reduce the temperature of the flame of the explosion of gas air mixture present inside. The temperature and intensity of heat vary for different mixture of gas and air, therefore, the heat sinking channel dimensions (flame path and gaps) are different with respect to different gas groups. The length of flame path and gap (or diametrical clearance) shall never be less than the minimum value mentioned in the standard IS/IEC 60079-1:2007. It should also be noted that the minimum flame path and gap (or diametrical clearance) depends on the volume of the enclosure. Details of flame path and gap required as mentioned in Tables-1 and 2

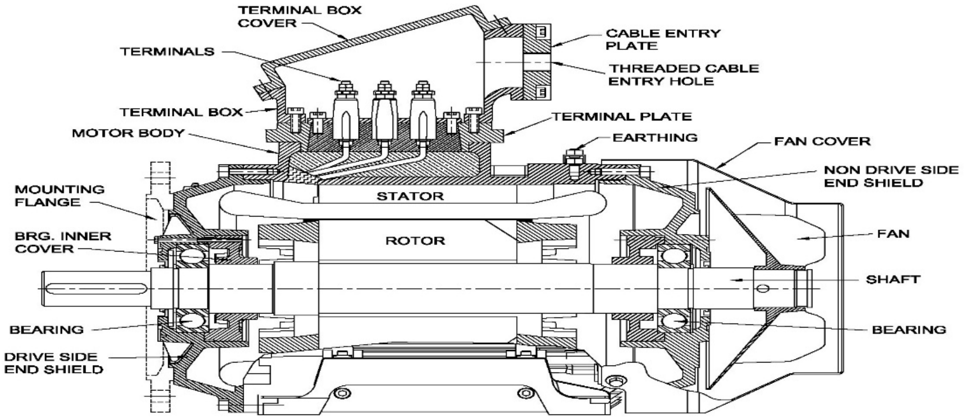


Fig 1. Enclosure of flameproof motor

Table-1: Minimum width of joint and maximum gap for enclosures of groups I, IIA and IIB

Type of joint		Min. width of joint L (mm)	Maximum gap (mm)											
			Volume (cm^3) $V \le 100$			Volume (cm^3) $100 < V \le 500$			Volume (cm^3) $500 < V \le 2000$			Volume (cm^3) $V > 2000$		
			I	IIA	IIB	I	IIA	IIB	I	IIA	IIB	I	IIA	IIB
Flanged, Cylindrical or Spigot		6	0.30	0.30	0.20	-	-	-	-	-	-	-	-	-
		9.5	0.35	0.30	0.20	0.35	0.30	0.20	0.08	0.08	0.08			
		12.5	0.40	0.30	0.20	0.40	0.30	0.20	0.40	0.30	0.20	0.40	0.20	0.15
		25	0.50	0.40	0.20	0.50	0.40	0.20	0.50	0.40	0.20	0.50	0.40	0.20
Cylindrical joints for shaft glands of rotating electrical machines with	Sleeve bearings	6	0.30	0.30	0.20	-	-	-	-	-	-	-	-	-
		9.5	0.35	0.30	0.20	0.35	0.30	0.20	-	-	-	-	-	-
		12.5	0.40	0.35	0.25	0.40	0.30	0.20	0.40	0.30	0.20	0.40	0.20	-
		25	0.50	0.40	0.30	0.50	0.40	0.25	0.50	0.40	0.25	0.50	0.40	0.25
		40	0.60	0.50	0.40	0.60	0.50	0.30	0.60	0.50	0.30	0.60	0.50	0.25
	Rolling element	6	0.45	0.45	0.30	-	-	-	-	-	-	-	-	-
		9.5	0.50	0.45	0.35	0.50	0.40	0.25	-	-	-	-	-	-
		12.5	0.60	0.50	0.40	0.60	0.45	0.30	0.60	0.45	0.30	0.60	0.30	0.20
		25	0.75	0.60	0.45	0.75	0.60	0.40	0.75	0.60	0.40	0.75	0.60	0.30
		40	0.80	0.75	0.60	0.80	0.75	0.45	0.80	0.75	0.45	0.80	0.75	0.40

Table-2: Minimum width of joint and maximum gap for group IIC enclosure

Type of joint		Minimum width of joint L mm	Maximum gap mm			
			Volume (cm^3) $V \le 100$	Volume (cm^3) $100 < V \le 500$	Volume (cm^3) $500 < V \le 2000$	Volume (cm^3) $V > 2000$
Spigot joint (Figure 2a)	$c \ge 6$mm $d \ge 0.5 L$ $L = c+d$ $f \le 1 mm$	*12.5*	0.15	0.15	0.15	-
		25	0.18^{b}	0.18^{b}	0.18^{b}	0.18^{b}
		40	0.20^{c}	0.20^{c}	0.20^{c}	0.20^{c}
Cylindrical joints Spigot joints (figure 2b		6	0.10	-	-	-
		9.5	0.10	0.10	-	-
		12.5	0.15	0.15	0.15	-
		25	0.15	0.15	0.15	0.15
		40	0.20	0.20	0.20	0.20
Cylindrical joints for shaft glands of rotating electrical machines with tolling element bearings.		6	0.15	-	-	-
		9.5	0.15	0.15	-	-
		12.5	0.25	0.25	0.25	-
		25	0.25	0.25	0.25	0.15
		40	0.30	0.30	0.30	0.20

[b] Maximum gap of cylindrical part increased to 0.20 mm if $f < 0.5$mm

[c] Maximum gap of cylindrical part increased to 0.25mm if $f < 0.5$ mm

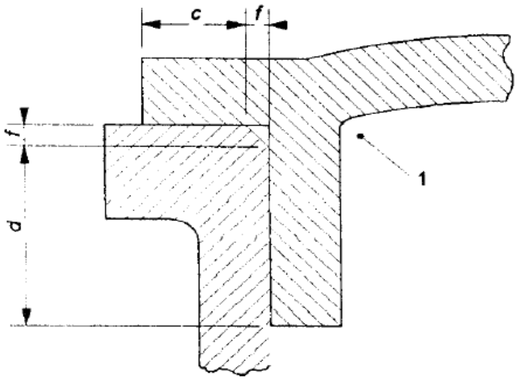


Figure 2a – Cylindrical part and plane part

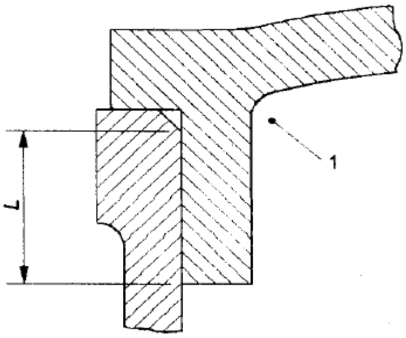


Figure 2b – Cylindrical part only

Key

$L = c + d$ (I, IIA, IIB, IIC)
$c \geq 6,0$ mm (IIC)
$\geq 3,0$ mm (I, IIA, IIB)
$d \geq 0,50\ L$ (IIC)
$f \leq 1,0$ mm (I, IIA, IIB, IIC)

1 Interior of enclosure

2.1 Requirements for shafts and bearings

2.1.1 Joints of shafts

Flameproof joints of shafts of rotating electrical machines shall be arranged so that it must not be subjected to wear in normal service. The flameproof joints may be a cylindrical joint or a labyrinth joint or a joint with a floating gland (Fig. 5). Cylindrical joint (Fig. 3) contains grooves for the retention of grease, the region containing the grooves shall neither be taken into account when determining the width of a flameproof joint nor interrupt it. The minimum radial clearance *k* (Fig. 6) of shafts rotating electrical machines shall not be less than 0.05 mm.

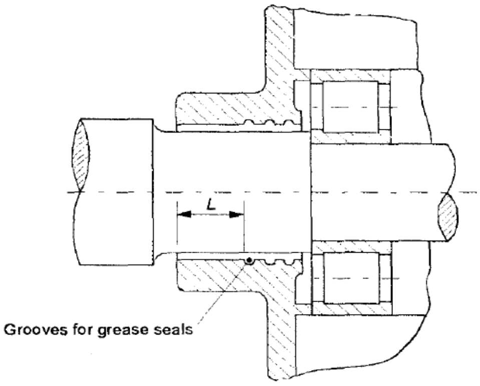


Fig. 3: Cylindrical joint for shaft of rotating electrical machine

Labyrinth joints (Fig. 4) which do not comply with the requirements of Tables 1 and 2 may nevertheless be considered as complying with the requirements of this standard if the tests criterion of external ignition test, reference pressure test and hydraulic test. The minimum radial clearance *k* (Fig. 6) of shafts of rotating electrical machines shall not be less than 0.05 mm.

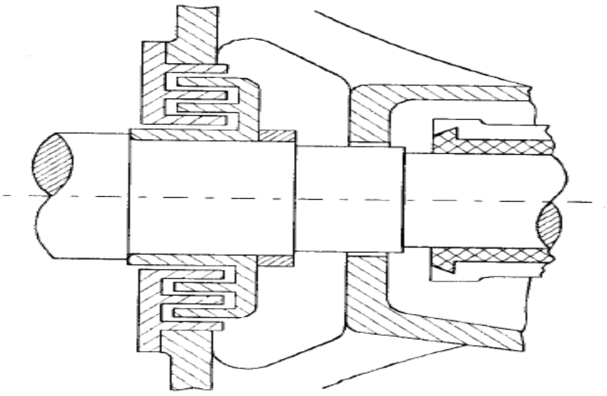
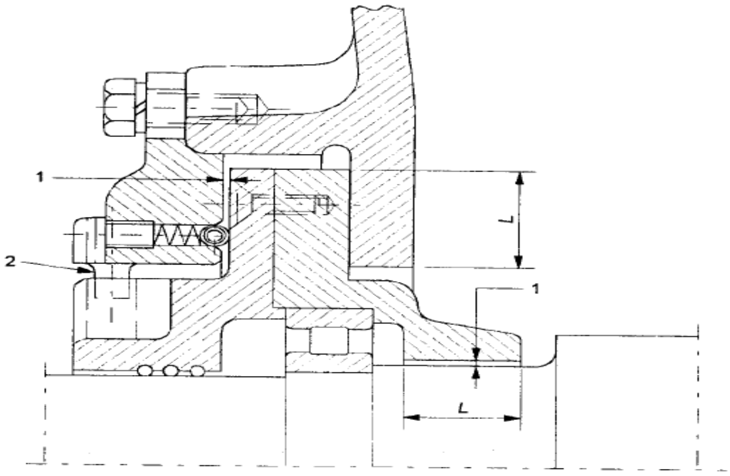


Fig. 4: Labyrinth joint for shaft of rotating electrical machine

In the case of Joints with floating glands the determination of the maximum degree of float of the gland shall take account of the clearance in the bearing and the permissible wear of the bearing as specified by the manufacturer. The gland may move freely radially with the shaft and axially on the shaft but it shall remain concentric with it. A device shall prevent rotation of the gland (Fig.5). Floating glands are not permitted for electrical apparatus of Group IIC.

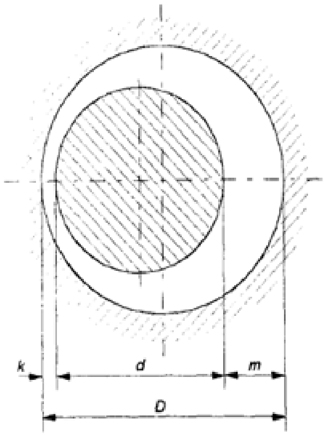


Key
1 gap
2 stop to prevent rotation of gland

Fig. 5: Joint with floating gland for shaft of rotating electrical machine

2.2 Types of Bearing

Sleeve bearing and rolling-element bearing are generally found in three phase flameproof motors. A flameproof joint of a shaft gland associated with a sleeve bearing shall be provided in addition to the joint of the sleeve bearing itself and shall have a width of joint at least equal to the diameter of the shaft but not exceeding 25 mm. If a cylindrical or labyrinth flameproof joint is used in a rotating electrical machine with sleeve bearings, at least one face of the joint shall be of non-sparking metal (for example, leaded brass) whenever the air gap between stator and rotor is greater than the minimum radial clearance k (Fig. 6) specified by the manufacturer. The minimum thickness of the non sparking metal shall be greater than the air gap. Sleeve bearings are not permitted for rotating electrical machines of Group IIC. In shaft glands equipped with rolling-element bearings, the maximum radial clearance m (Fig. 6) shall not exceed two third of the maximum gap permitted for such glands in Tables 1 and 2.



Key:
K minimum radial clearance permissible without rubbing
m maximal radial clearance taking k into account
D-d diametrical clearance

Fig.6: Joint with floating gland for shaft of rotating electrical machine

3. ASSESSMENT OF SURFACE TEMPERATURE RISE OF INDUCTION MOTORS

3.1 Conditions during Temperature Rise Test

3.1.1 Coolant Temperature

A machine may be tested at any convenient value of coolant temperature. If the temperature of the coolant at the end of the temperature-rise tests differs by more than 30°C from that specified for operation on site, the corrections shall be made.

3.1.2 Measurement of Coolant Temperature during Tests

The value to be adopted for the temperature of the coolant during a test shall be the mean of readings of the temperature detectors or thermometers taken at equal intervals of time during the last quarter of the duration of the test. In order to avoid errors due to the time-lag between the temperature of large machines and the variations in the temperature of the coolant, all reasonable precautions shall be taken to reduce these variations.

3.1.3 Open Machines or Closed Machines (Cooled by Without Heat Exchangers Surrounding Ambient Air or Gas)

The ambient air or gas temperature shall be measured by means of several temperature detectors or thermometers placed at different points around and half-way up-the machine at a distance from 1 m to 2 m from it and protected from all heat radiation and draughts.

3.1.4 Machines Cooled by Air or Gas from a Remote Source through Ventilation Ducts and Machines with Separately Mounted Heat Exchangers

The temperature of the primary coolant shall be measured where it enters the machine.

3.1.5 Closed Machines with Machine-Mounted or Internal-Heat Exchangers

The temperature of the primary coolant shall be measured where it enters the machine. For machines having water-cooled or air-cooled heat exchangers, the temperature of the secondary coolant shall be measured where it enters the heat exchanger.

3.2 Measurement of Temperature using various methods and means

3.2.1 Resistance Method

In this method, the temperature-rise of the windings is determined from the increase of the resistance of the windings.

3.2.2 Embedded Temperature Detector (ETD) Method

In this method, the temperature is determined by means of temperature detectors (for example, resistance thermometers, thermocouples or semiconductor negative coefficient detectors) which are built into the machines during construction, at points which are inaccessible after the machine is completed.

3.2.3 Thermometer Method

In this method, the temperature is determined by thermometers applied to the accessible surfaces of the completed machine. The term ‘thermometer’ also includes non-embedded thermocouples and resistance thermometers provided they are applied to the points accessible to the usual bulb thermometers. When bulb thermometers are used in places where there is a strong varying or moving magnetic field, alcohol thermometers shall be used in preference to mercury thermometers.

3.2.4 Superposition Method

In this method, the resistance measurements used for determination of temperature rises of ac windings are made without interruption of the ac load current by applying a small dc measuring current superposed upon the load current.

4. Tests Methods of Motor for Temperature Rise Measurement

The various methods of temperature rise test of flameproof motors are direct loading test, back-to-back test, phantom loading test, forward short circuit test, variable inertia test and mixed-frequency test. The most accurate and basic heat run of the induction machine is to load the machine shaft directly with a mechanical or an electrical load. This test is capable of producing the full-load current flowing into the machine and the full-load mechanical losses occurring inside the machine as well as the full-load rotor current flowing in the rotor bars at rated rotor speed.

4.1 Experimental Determination of Surface Temperature Rise Test Using Direct Loading of Motors

I. Induction motors of different ratings in different frame size 63 to frame size 315 are chosen for surface temperature rise measurement, motors are run with direct loading method. The motors are run at rated voltage and full load current for several hours until thermal stabilization is attained. Reading of all parameters and temperature of motor body, bearing housing, NDE and DE at every half an hour interval are taken. When the surface temperatures rise of motor enclosure body between two consecutive readings with respect to ambient temperature are found same it was confirmed that the motor is thermally stable.

The locations at which the surface temperature is observed maximum for these motors are listed in Table 3.

Table 3: Details of experimental observations

Frame size	KW	RPM	Voltage (Ac)	Full Load Current (Amp)	Max. Surface temp. (^{o}C)	Location of max. temp	Temp. class
63	0.25	2790	415	0.67	84.2	DE-Bearing cover	T6
71	0.37	1380	415	1.05	89.1	Motor body Rib top	T5
80	0.75	1415	415	1.75	104.5	Motor body Rib top	T4
90L	2.2	2880	415	4.36	102.1	DE end-shield	T4
100L	3.7	2900	415	7.10	90.1	DE Bearing cover	T5
112M	5.5	2905	415	10.0	87.5	Motor body Rib top	T5
132M	9.3	2920	415	16.5	79.5	DE Bearing cover	T6
160L	18.5	2930	415	32.00	81.1	DE Bearing cover	T6
180L	22	1460	415	39	82.0	DE Bearing cover	T6
200L	37	2955	415	62.9	79.6	DE Bearing cover	T6
225M	45	1480	415	77	92.3	DE Bearing cover	T5
250M	55	1475	415	92	89.0	DE Bearing Cover	T5
280M	90	1482	415	155	95.0	DE End-shield	T5
315M	132	1486	415	218	96.0	DE End-shield	T5
315L	200	4150	415	326	104.0	DE Bearing cover	T4

5.0 RESULTS AND DISCUSSION

From the results of temperature rise test of motors, it is observed that location of highest surface temperate measurement is DE bearing cover or DE end shield. In few cases (frame size 71, 80 and 112M) the highest temperature observed is on motor body. The maximum temperature classification of the above motor is observed to be T4 (100 to 135 °C).

Mechanically coupling of large machines on the test-bed (especially in the case of vertical machines) is very difficult and expensive. The mixed-frequency test does not require an extra machine or mechanical load. The conventional mixed-frequency test requires the use of two different power supplies of different frequencies and amplitudes. This method can be applied for testing all types of machine with the advantages of being economic and accurate. However coupling of a load to the machine shaft is not easy and hence the test becomes expensive because of the following reasons:

- The different size of half-couplings is needed for the different shaft size of machines.
- The load for the large machines occupies space and costs a lot of money.
- The load consumes energy.
- A large amount of current is drawn from the supply during the test.

6.0 Conclusions

The most accurate and basic heat run of the induction machine is to load the machine shaft directly with a mechanical or an electrical load. This test is capable of producing the full-load current flowing into the machine and the full-load mechanical losses occurring inside the machine as well as the full-load rotor current flowing in the rotor bars at rated rotor speed. During the testing of flameproof motors, it should be noted that the maximum surface temperature of the above motors at DE End shield side or DE Bearing cover found maximum temperature.

7.0 Acknowledgement

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