Installation and maintenance of electric motors

Contents

10.1 Installation of bearings and pulleys 10/269
10.2 Important checks at the time of commissioning 10/270
10.3 Maintenance of electric motors and their checks 10/270
10.4 Maintenance of bearings 10/272
   10.4.1 Cleaning of bearings 10/272
   10.4.2 Re-lubricating interval 10/272
   10.4.3 Quantity of re-grease 10/272
   10.4.4 General precautions 10/272
   10.4.5 Prevention from shaft currents 10/273
   10.4.6 Reasons for high bearing temperature 10/276
10.5 General problems in electric motors and their remedy 10/276
10.6 Winding temperature measurement at site 10/278
   10.6.1 Temperature correction 10/278
10.7 Analysis of insulation failure of an MV motor at a thermal power station 10/278

Relevant Standards 10/280
List of formulae used 10/280
Further Reading 10/281
One can adopt a suitable procedure of installation, grouting, type of foundation and alignment etc., depending upon the size of motor, the duty it has to perform and the location of the installation (such as hazardous or seismic, etc.). Here we discuss briefly only the important aspects of installation and maintenance of electric motors.

10.1 Installation of bearings and pulleys

Special care needs be taken when mounting or removing the pulley or the bearing from the motor shaft. Carelessness in using a correct procedure or proper tooling may be detrimental to the bearing’s life. It may even damage the end shield of the motor at the other end. Any hammer blows on the bearing, directly or indirectly, can cause irreparable damage to the bearing and the end shield at the other end of the motor. In view of a bearing’s delicate nature, the following methods are recommended to carry out such tasks.

![Mounting of the pulley](image)

**Mounting of a bearing or a pulley**

Bearings up to medium sizes can be driven on the shaft seat with the aid of a tubular drift, supported on the inner race of the bearing, then by hammering it gently with a mallet, to transmit the blows at the other end to a rigid support. For large motors or pulleys, however, a fixture as shown in Figure 10.1 can be used. The purpose of this fixture is to grip the inner race of the bearing and cause no thrust on the balls or the rollers of the bearing. ISO 286-1 recommends the tolerances and fits for pulley bores and these may be followed for an ideal fit. Table 10.1 gives tolerances in the pulley bore for different shaft diameters and Table 10.2 those in the bearing housing (end shield) bore diameter, where the bearing’s outer race fits, as well as the motor shaft diameter, on which the inner race of the bearing is mounted. The bearing fits are thus governed by the dimensional tolerances permissible for the end shield bore diameter and the diameter of the motor shaft. These are called tight fit or shrink fit. It may be seen that any slip between the end shield bore and the outer race of the bearing or the diameter of the motor shaft and the inner race (bore) of the bearing, during transmission of load, may cause undue heating, vibrations and noise. This may also adversely influence the efficiency of power transmission, and cause severe damage to the bearing inner and outer races, the shaft and the bearing housing (end shield) due to friction, heat, abrasive wear, fretting, corrosion and cracks. All these effects must therefore be eliminated by a proper fit in all mating parts.

**Dismounting of a bearing or a pulley**

A claw-type puller, as shown in Figure 10.2, with adjustable jaws must be used when pulling out the bearing

<table>
<thead>
<tr>
<th>Shaft diameter (mm)</th>
<th>Tolerance</th>
<th>Value of tolerance (mm)</th>
<th>Tolerance for pulley bore HT&lt;sup&gt;a&lt;/sup&gt; (microns)</th>
<th>Bore size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>JS6</td>
<td>±0.0045</td>
<td>+15</td>
<td>9.015</td>
</tr>
<tr>
<td>11</td>
<td>JS6</td>
<td>±0.0045</td>
<td>+18</td>
<td>11.018</td>
</tr>
<tr>
<td>14</td>
<td>JS6</td>
<td>±0.0055</td>
<td>+18</td>
<td>14.018</td>
</tr>
<tr>
<td>19</td>
<td>JS6</td>
<td>±0.0065</td>
<td>+21</td>
<td>19.021</td>
</tr>
<tr>
<td>24</td>
<td>JS6</td>
<td>±0.0065</td>
<td>+21</td>
<td>24.021</td>
</tr>
<tr>
<td>28</td>
<td>JS6</td>
<td>±0.0065</td>
<td>+21</td>
<td>28.021</td>
</tr>
<tr>
<td>38</td>
<td>K6</td>
<td>+0.018</td>
<td>+25</td>
<td>38.025</td>
</tr>
<tr>
<td>42</td>
<td>K6</td>
<td>+0.018</td>
<td>+25</td>
<td>42.025</td>
</tr>
<tr>
<td>48</td>
<td>K6</td>
<td>+0.018</td>
<td>+25</td>
<td>48.025</td>
</tr>
<tr>
<td>55</td>
<td>m6</td>
<td>+0.030</td>
<td>+30</td>
<td>55.030</td>
</tr>
<tr>
<td>60</td>
<td>m6</td>
<td>+0.030</td>
<td>+30</td>
<td>60.030</td>
</tr>
<tr>
<td>65</td>
<td>m6</td>
<td>+0.030</td>
<td>+30</td>
<td>65.030</td>
</tr>
<tr>
<td>75</td>
<td>m6</td>
<td>+0.030</td>
<td>+30</td>
<td>75.030</td>
</tr>
<tr>
<td>80</td>
<td>m6</td>
<td>+0.030</td>
<td>+30</td>
<td>80.030</td>
</tr>
<tr>
<td>90</td>
<td>m6</td>
<td>+0.035</td>
<td>+35</td>
<td>90.035</td>
</tr>
</tbody>
</table>

<sup>a</sup>There is no lower limit of tolerance in holes. 1 micron = 0.001 mm (1 μm).

*Note*

For larger sizes refer to ISO 286-1 or IEC 60072-2.
or the pulley from its seat. The claws are so set that they do not bear against the outer ring of the bearing while pulling out and thus exert no thrust on the balls or the rollers of the bearing. Figure 10.3(a) and (b) illustrate the correct method.

10.2 Important checks at the time of commissioning

- Clean up the motor.
- Check all the components for their positioning and tightness.
- Check for pre-lubrication/grease and its monitoring attachment (provided in large machines).
- Check for free rotation of the rotor.
- Check for motor grounding.
- Check for winding insulation.

Additional checks for large motors

- Check for proper connection and circulation of fluid or gas in the coolant circuit (Section 1.16).
- Check for satisfactory operation of auxiliary oil pump and fan.
- Check all safety devices such as temperature sensors in the windings and the bearings, PTC thermistors, vibration probes, space heaters and coolant circuit, for their correct fitting, wiring and functioning of the alarm, annunciation and tripping circuit of the protective switchgear (Section 12.8).

Table 10.2 Shaft and bearing housing diameters and their tolerances, to provide a tight or shrink fit to the bearings

<table>
<thead>
<tr>
<th>Deep groove ball bearings</th>
<th>Cylindrical roller bearings</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Shaft diameter</td>
<td>(A) Shaft diameter</td>
</tr>
<tr>
<td>Tolerance</td>
<td>Tolerance</td>
</tr>
<tr>
<td>Up to 18 mm</td>
<td>Up to 40 mm</td>
</tr>
<tr>
<td>j5</td>
<td>k5</td>
</tr>
<tr>
<td>Above 18–100 mm</td>
<td>Above 40–160 mm</td>
</tr>
<tr>
<td>k5</td>
<td>m5</td>
</tr>
<tr>
<td>Above 100–160 mm</td>
<td>Above 160–200 mm</td>
</tr>
<tr>
<td>m5</td>
<td>n5</td>
</tr>
<tr>
<td>(B) Housing bore diameter</td>
<td>(B) Housing bore diameter</td>
</tr>
<tr>
<td>All sizes</td>
<td>All sizes</td>
</tr>
<tr>
<td>h6 or j6</td>
<td>h6 or j6</td>
</tr>
</tbody>
</table>

Based on ISO 286-1

10.3 Maintenance of electric motors and their checks

Only important aspects have been considered here:

- Check for satisfactory functioning of all gauges, indicators and recorders.
- Check for bearing insulation (dealt with separately in Section 10.4.5).
- Check for bearing housing grounding.
- Check for winding insulation by polarization index (Section 9.5) and dissipation factor, tan δ (Section 9.6).

Figure 10.2 Dismounting of the pulley

Note: The jig can also be motor operated

Figure 10.3(a) Wrong method of dismounting the bearings, as the forces travel through the balls

Figure 10.3(b) Correct method of dismounting the bearings

Figure 10.2 Dismounting of the pulley

Note: The jig can also be motor operated

Figure 10.3(a) Wrong method of dismounting the bearings, as the forces travel through the balls

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Figure 10.3(a) Wrong method of dismounting the bearings, as the forces travel through the balls

Figure 10.3(b) Correct method of dismounting the bearings

Figure 10.2 Dismounting of the pulley

Note: The jig can also be motor operated

Figure 10.3(a) Wrong method of dismounting the bearings, as the forces travel through the balls

Figure 10.3(b) Correct method of dismounting the bearings
• Check the protective equipment for any worn out parts or contacts and their tightness.
• Check the condition of the cable insulation, its termination and jointing. Motor connections should always be made through cable lugs to ensure a proper grip as shown in Figure 10.4. A poor cable termination will mean arcing and localized heat and may lead to joint failure.
• For oil-filled control equipment such as autotransformer starters or oil circuit breakers (BOCBs or OCBs, Chapter 19), insulating oil should be checked periodically for its insulating properties. Leading manufacturers of this equipment indicate the number of switching operations under different conditions of load and fault, after which the oil must be replaced and these must be followed.
• Each electric motor and connected control gear is grounded separately at least at two points. The ground resistance should be checked to ensure continuity of ground conductors. Refer to Chapter 21 for more details on grounding requirements.
• Insulation resistance of the motor windings between phases and phase to ground should be checked and made up in the event of deficiency, according to Section 9.5.
• Slip-ring motors need a regular and meticulous check of brushes, brush holder unit and slip-rings for cleanliness, accurate contacts, brush curvature, wear and tear of slip-rings and arcing (Figure 10.5). The following procedure may be followed:
  – Spring pressure to be maintained around 150–200 g/cm² for proper contact of the brushes with the slip-rings.
  – Cleanliness of slip-rings and the brushes.
  – Slip-rings, if roughened by arcing, must be cleaned with fine glass paper, having a similar curvature to the rings using a wooden block on which the glass paper can be wrapped. Emery cloth should not be used.
  – The grade of brush should be as recommended by manufacturer. For further details IEC 60136 is quite informative otherwise brush manufacturer catalogue may be referred to for brush properties.
  – When replacing with the new brushes, the new brushes must be first ground to acquire a curvature similar to that of the rings.
  – Brush lifting and short-circuiting devices can be employed for motors required to run continuously for a long period to minimize wear and tear of slip-rings and brushes. However, when speed
control is required or switching operations are frequent, continuous contact brush gear assembly must be employed.

## 10.4 Maintenance of bearings

The major causes of bearing failures can be misalignment, vibration, excessive radial and axial forces as discussed in Sections 8.6 and 8.7 and of course poor lubrication. Below we discuss about recommended lubricating procedures.

Grease may leave skin effect on the races of the bearings if the motor is stored idle for a long period. This may cause noise during operation and over-heating of the bearings. After a long period of storage grease may also dry and crack, and produce these effects. To detect this, bearing covers may be opened and the condition of the grease and any skin effects checked. If such marks are visible, the bearings must be taken out and washed thoroughly in petrol or benzene to which is added a few drops of oil, and then re-greased with a recommended grade and quantity of grease. Quantities of grease above recommended levels may cause heat the same way as quantities below recommended levels.

Recommended grades of lithium-based rust-inhibiting bearing grease conforming to IS 7623 are given below for a few manufacturers. The same would vary from manufacturer to manufacturer in different countries.

- IMP2 and IMP3
- MP greases 2 and 3
- Lanthax EP1 and 2 for large motors
- Servogem-2 and 3
- Titex HT – for large motors
- Lithon-2
- Lithoplex-2 for large motors
- NLGI-2 and NLGI-3

These grades possess a high drop point, of the order of 180°C, and a working temperature range from – 30°C to +130°C.

### 10.4.1 Cleaning of bearings

For cleaning bearings and bearing housings, before applying the grease, only the following fluids should be used: benzone, white petrol and benzole (white petrol is the most recommended).

### 10.4.2 Re-lubricating interval

The re-lubricating interval depends upon the running conditions of the bearing, such as the bearing type, size, speed, operating temperature and also the type of grease used. The re-greasing time is thus related to the service conditions of the grease and is represented by

\[ R_G = K \cdot \left( \frac{14 \cdot 10^6}{N_r \cdot \sqrt{d}} - 4d \right) \text{hours} \]  
(10.1)

where

- \( K \) = factor as noted below
- for ball bearings \( K = 1 \)
- for cylindrical roller bearings \( K = 5 \)
- for spherical roller bearings or taper roller bearings \( K = 10 \)
- \( d \) = bearing bore diameter in (mm).

The re-lubricating period obtained from this expression is valid for operations up to 70°C, when measured at the outer ring. This interval should be halved for every 15°C rise in temperature above 70°C, which is unlikely to occur in an electric motor. For operating in areas that are hazardous or contaminated which may affect the life of the grease, the regreasing interval may be reduced, depending upon the installation’s environment.

A more generalized graph from a leading bearing manufacturer is reproduced in Figure 10.6, and covers practically all sizes and types of bearings to determine the re-lubricating period. These periods are for ideal conditions and operating temperature not exceeding 70°C. Some margins may be considered to account for operating and environmental conditions and quality of grease etc. Table 10.3 provides more practical regreasing intervals for electric motors with these parameters in mind. To arrive at more prudent intervals depending upon type of bearing, load and load ratio one may refer to the latest catalogues of bearing manufacturers.

When in operation, the bearings should be re-greased through the grease nipples or grease injectors, if provided on the motor, after the recommended number of running hours (Table 10.3). If grease nipples are not provided, the motor may be temporarily stopped, bearings taken out and washed thoroughly as prescribed above and fresh grease applied. The bearing covers and the bearing housing should also be washed.

### 10.4.3 Quantity of re-grease

\[ G_w = 0.005 D \cdot B \text{ grammes} \]  
(10.2)

where

- \( G_w \) = quantity of re-grease in grammes. This does not include the grease initially placed in the covers and other spaces
- \( D \) = bearing outside diameter (mm)
- \( B \) = bearing width (mm).

Table 10.3 provides a ready reference for the quantity of grease and its regreasing interval as prescribed by a leading motor manufacturer.

**Note**

1. For larger frames contact the manufacturer.
2. The free space in the bearing should be completely filled while the free space in the bearing housing should be filled between 30–50%.
3. For more details refer to the product catalogues published by the leading bearing manufacturers.

### 10.4.4 General precautions

1. When long idle storage is foreseen, arrangements may be made to rotate the rotor periodically by hand by
90° or so to shift the position of balls or rollers. This will prevent the grease from leaving any marks on the races and avoid any static indentation on the bearings.

2 For dust- and chemical-laden atmospheres as in cement plants, chemical industries and refineries and areas in alkaline and saline environments reduce the regreasing intervals by roughly 30%.

### 10.4.5 Prevention from shaft currents

**Bearing currents due to internal causes:**

In an electric motor the stator windings are in a circular form. Each phase is wound identically and spaced equally to each other. Under ideal conditions the electric field produced by these current-carrying conductors must be balanced and neutralized, as in a three-core cable, producing no residual field. (For more details see Section 28.8.) But this is not always so. While some field in space may always be present in all ratings, it assumes cognisable strength in large LV and MV machines (>1.5 MW), using circular laminations and all machines using segmented stator punchings.* Such space fields induce an e.m.f. between the two shaft ends. This is not a direct result of proximity but may be due to asymmetry in the magnetic circuit because of harmonics present in the system, a non-ideal flux distribution, due to slight disorientation or variation in the punching for the slot positions, or an eccentric air gap between the stator and the rotor. The phenomenon of disorientation in the punchings for the slot positioning is independent of motor current and influences large LV and MV machines equally.

In MV motors even electrostatic effects due to stator voltage may activate the lumped capacitances:

- Between stator windings and ground – $C_{sg}$
- Between rotor and ground via stator core – $C_{rg}$
- Between stator and rotor windings through the air gap – $C_{sr}$

\[
C_{sg} >> C_{sr} < C_{rg}
\]

(Figure 10.6(a) illustrates these capacitances)

*Segmented stator punchings are made in multiple segments and are used for very large machines (>1.5 MW). The number of segments to form complete circle is 2, 3, 4, 5, 6 etc. depending on sheet sizes.

---

Figure 10.6 Curves to determine relubricating periods for different types and sizes of bearings at different speeds.
Stator winding to ground leakage $C_{sg}$ may cause a capacitive (electrostatic) coupling between the stator windings and the rotor and induce a shaft voltage that may be enough to cause a shaft current and which may find its way through the bearings and complete its circuit through the motor body. There being little contribution by $C_{rg}$ and $C_{sr}$ being too small.

Both these effects cause circulating currents to flow through the motor frame, forming a complete electric circuit via the bearings (Figure 10.7). These currents are detrimental to the life of bearings due to arcing and consequent pitting and heating effects. Such currents, if not prevented, may cause indentation (pitting) on the

Table 10.3 Quantity of grease and regreasing intervals

<table>
<thead>
<tr>
<th>Bearing bore dia. $d$ (mm)</th>
<th>To be injected after running hours</th>
<th>Quantity of grease (g)</th>
<th>Quantity of initial grease (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed r.p.m $\rightarrow$</td>
<td>750</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>45</td>
<td>8000</td>
<td>8000</td>
<td>8000</td>
</tr>
<tr>
<td>50</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
</tr>
</tbody>
</table>

*Courtesy: Siemens*

![Figure 10.7](image1.png) Even if both the bearings of the motor are insulated, there will be a current path as shown
inner races of the bearings, as well as on their balls or rollers. The pitting may not only cause noise but may also loosen the motor shaft within the bearing, causing heating and chattering, so that a stage may arise when the rotor may start rubbing the stator laminates and cause damage. These shaft currents, therefore, must be prevented while installing such motors and the following are some preventive measures:

1. One of the bearings should be insulated inside its housing by providing a layer of thin insulation as indicated at location 3 in Figure 10.8 to prevent circulating current through the motor bearings. To accomplish the same prevention one can also insulate the bearing housing and use standard bearing.

2. Insulation of both the bearings will not prevent the circulating currents, as illustrated in Figure 10.7. Therefore only one bearing is insulated and a sheet of insulating material (rubber lining or Bakelite) is provided between the motor’s feet and the base frame, and insulated holding-down fasteners used for fixing the motor. This will prevent the eddy current or leakage current paths forming a closed circuit through the bearings, as indicated at location 1 in Figure 10.8. One of the bearings, generally the driving end, may also be grounded as illustrated, to prevent a build-up of electrostatic currents in the rotor.

3. Sometimes a coupling insulation as indicated at location 2 in Figure 10.8 may also be necessary to prevent circulating currents in the bearings of the driven equipment also.

The insulation, as discussed above, must be protected during normal operation to avoid any damage to it otherwise the circuit may defeat the purpose of shaft insulation. It is advisable to check the insulation periodically. Creepage of oil, water, moisture, dirt or metallic particles may also short-circuit the insulation and defeat its purpose. Therefore, the insulating lining, wherever provided, must be protected and kept clean.

**Summary**

1. Cognisable shaft currents may exist in large LV and MV motors of 2000 kW and above, using circular laminations and all motors with segmented laminations due to the magnetic field caused by asymmetries.

2. The problem of shaft currents may also be due to dielectric leakages that may take cognisance in MV motors of 3.3 kV and above. This can be prevented by grounding one of the bearings to prevent the leakages.

3. The bearing insulation is therefore determined by the manufacturer while checking the shaft voltage at the works. This forms a routine in-house test for all MV and large LV motors.

4. The grease lubricating film inside the bearings is too thin, of the order of 1 μm – 20 μm and may break down at very very low induced voltages, causing bearing circulating currents and arcing between the races and the rolling elements. The situation getting worse with non-uniform film thicknesses and presence of foreign conducting particles inside the bearing. To detect shaft currents, the normal procedure of leading manufacturers is to measure the shaft voltage end to end, with a full voltage applied to the motor terminals. If this is 300–350 mV or more, it will indicate that the bearings require insulation, as illustrated in Figure 10.8. On very large motors, using segmented punchings, shaft voltages even of the order of 1 to 2 V have been noticed. These voltages are highly detrimental to the life of bearings and are undesirable. As standard practice, all such motors are provided with a bearing insulation by the motor manufacturers.

**Prevention from shaft currents caused by PWM inverter drives**

This phenomenon is discussed in Section 6.14. The
measures to prevent shaft currents (frames above 315 and switching frequencies above 10 kHz) are similar to those noted above. If it is possible to break the return path through the bearings such as by providing a low impedance parallel ground return path so that the ground current may return through to the motor body rather than the bearings, the bearing currents can be eliminated. It can be achieved by connecting the motor body through a low impedance conductor with the driven equipment.

PWM drives would call for either screened cables (recommended to eliminate EMC effects) between the inverter and the motor or the cable be properly grounded through the inverter so that the high frequency leakage currents may not find path through the motor bearings and worsen the situation.

10.4.6 Reasons for high bearing temperature

This may be due to

- Excessive quantity of grease causing churning
- Inadequate grease due to deterioration or leakage
- Misalignment, causing friction and excessive axial forces
- Loose fit of the bearing housing, causing both inner and outer races of the bearing to rotate inside the housing
- Indentation, corrosion or the presence of foreign matter in the bearing.

Any of the above reasons may result in noise and an increase in temperature and must be corrected. Critical installations such as a refinery, a petrochemical plant, a chemical plant or a petroleum pipeline may require special precautions and control to avert any excessive heating of the bearings, which may become fire hazard. For these installations, bearing temperature detectors with a relay and alarm facility may also be installed in the control circuit of the switching device to give warning or trip the motor if the temperature of the bearing exceeds the preset safe value.

10.5 General problems in electric motors and their remedy

Only the most general types of problems are discussed here:

1. Bearings make a churning noise or over-heat:
   Check condition and level of grease as well as any skin effects or watermarks on the races, balls or rollers. If there are watermarks, the bearings should be replaced. Otherwise wash and re-grease them, as explained earlier.

2. For creaking and harsh noises, check for misalignment and belt tension.

3. For steady humming noise check for uneven air gap with feelers between the stator and the rotor. It is possible that the bearings have lived their lives. If so replace the bearings.

4. Motor not picking up speed:
   - Check all phases for supply continuity.
   - Check the voltage.
   - Check the starter connections and contacts in all three phases. Also check proper contacts and brush pressure in slip-ring motors. If these are satisfactory and the motor still does not pick up, check the suitability of the motor for the type of load and switching method.
   - Fault in the switching device. Sometimes, the switching device may not be functioning properly. To give an instance, one 150 h.p. squirrel cage motor was selected for a centrifugal air compressor. The motor starting torque was adequately chosen to start the compressor through an autotransformer starter with a 40% tapping. The motor started but locked up somewhere in the middle of the full speed and did not accelerate further. The supply voltage and the transformer tapping were in order. A thorough check revealed that the voltage at the motor terminals was much less than 40%. A long cable drop from the A/T to the motor was suspected but when the voltage was measured at the A/T outgoing terminals, it was almost the same as at the motor terminals, thus eliminating the possibility of a longer cable drop. In fact the A/T was faulty or not properly connected so that it was producing only 25% voltage instead of 40% in the secondary circuit thus seriously affecting the torque and the motor’s starting performance.

5. Motor not taking up load. This may be due to incorrect stator connections. In general, motors of 3 h.p. and above, except MV motors, are wound for delta connections and all the six terminals are located in the terminal box to facilitate Y/Δ starting. These terminals are connected in delta through metallic links (Figure 10.9). If the motor is inadvertently connected in star, each motor phase will receive only 1/\sqrt{3} times the rated voltage. This will reduce the torque to one third of the rated torque (Section 4.2) which may not be adequate to pick-up the load. It may even damage the windings if the motor remains energized for a while due to excessive load current (I^2R losses).

6. Reversed phase. It is possible that one of the phases is inadvertently reversed due to human error or wrong terminal marking at the manufacturer end, as shown in Figures 10.9(c) and (d) for star and (e) and (f) for delta connected stator windings. Now the motor shall behave erratic like on a single phasing, make noise, fail to start or crawl and cause severe current unbalance. To locate the reverse phase first identify the three phases (a1a2, b1b2, c1c2) and then connect them in star or delta for which the motor is designed. Reverse each phase one by one and check the running of the motor. Thus, identify the reverse phase and correct the connections.

7. While connecting a delta-wound motor through a Y/Δ starter, the metallic shorting links should be removed. Otherwise the starter will have a dead short-circuit at the motor terminal box and may burn the starter, damage the motor terminal box and even line cables.
8 Motor takes longer to pick up. When conditions 4 and 5 above have been checked but this problem still exists, then motor selection may not be appropriate for the type of load or the method of switching. Just for illustration, a ball mill at a thermal power station required a 75 kW motor employing a Y/Δ switching (an old installation). The method of switching was overlooked at the time of motor selection. The motor burnt during the start while the starter was still in the star position. The stator was found to be completely charred and the rotor damaged to the extent that its short-circuiting rings also melted due to excessive starting heat and some molten metal was splashed over the stator overhangs causing extensive damage. The reasons for such a failure can be attributed as follows:

- The starter was manually operated and thus the changeover time, from star to delta, largely depended upon the skill of the operator, who may have been unaware of the implications of a longer starting period in the star position. Moreover, on load, the starting heat in a Y/Δ starting is much more than on a DOL starting as discussed in Section 2.7.3.

**Note**
A similar situation may be found in an automatic Y/Δ starter also when the setting of the timer, to changeover from star to delta, is at a higher value to allow a longer starting time to pick up speed. Then also the motor would meet the same fate if the starting time exceeded the thermal withstand time of the motor.

- The fuse rating, if used before the starter, may have been inadvertently high, inconsistent with the thermal withstand capacity of the motor. Thus the fuse did not blow which would have protected the motor from such severe and persistent over-loading.

- The over-current relay selection or its setting may not have been appropriate, otherwise the starter would have tripped under such a faulty condition. Selection and over-current setting of the relay should have been consistent with the motor’s thermal capacity.

- A ball mill requires a high starting torque (Section 2.5 and Table 2.3) to accelerate its heavy masses. In the star position, the motor torque diminishes to one third the starting torque as on DOL. The mill would take a long time to accelerate and the ammeter would show almost a constant starting current. The operator, possibly also judging the speed of the ball mill, may have paused in the star position before changing it over to delta but by then the motor had failed. Thus, it was a wrong application of the switching device for the type of load.

9 Motor trips and/or fuses blow during start

- Check selection of fuses for the type of load and switching. Perhaps they are under-rated for the starting inrush current and its duration. For selection of fuse ratings see Section 12.10.4.

- Supply voltage may be low, causing the motor to take longer to start.

- Starter relay selection or relay setting may not be matching the starting requirements. The relay thermal characteristics must match motor characteristics. In heavy drives with prolonged starting times the relay may operate if it is not properly selected. For heavy loads, with large moments of inertia and requiring a longer starting time, a timer can be introduced into the relay circuit, to bypass this until the motor accelerates to a reasonable speed. Then the relay circuit is reactivated. The most common practice is to provide a CT-operated thermal over-load relay (Figure 13.54; see also Section 12.4.1). The CTs have a low saturation point. In the event of a high starting current, they become saturated at two to three times the full load current and bypass the excessive starting current. Then the relay kicks through the relay and thus avoid a false trip during a prolonged start.

10 Motor vibrates. A motor already tested at the manufacturer’s works for vibration limits, as shown in Table 11.3, may still appear to have more vibrations at site during operation. This may be due to the following reasons:

- The foundation bed or the structure on which the motor is mounted is not rigid, is tilted or is uneven. Tighten foundation bolts and check for proper alignment of the motor and the drive. Make the foundation or structure as rigid as possible.

- Single phasing, in which case the motor may make a humming noise and cause vibrations due to uneven flux distribution.

- Bearing-end play may also cause such vibrations.

- It is possible that the driven equipment to which the motor is coupled has a higher vibration level than
10 The motor makes rumbling noise and the stator current fluctuates. It is possible that the rotor speed is also slowed down. The rotor circuit may be broken and should be repaired. If the motor also over-heats, there may be an inter-turn fault or a short-circuit between the phases. Detect these and rectify if possible, otherwise rewind the motor.

12 If heavy rain causes a flash flood at the site of installation, the motor may be submerged in water for some time. A reasonably good motor, with good insulation impregnation and baking, can be washed and dried, to work again. Dismantle the motor, take out the rotor and bearings. Wash the stator and rotor with clean water to remove all the mud and silt. Pad it dry with cloth. Blow warm air over the stator and the rotor and heat them gradually, adopting the procedure in Section 9.5. Unless they show permanent watermarks or rust or scratches, the bearings can also be washed dry and re-greased as shown in Section 10.4.

13 Cast iron body, feet or ribs etc. found broken or cracked during transit or otherwise. Replacement of the motor in such cases may not be practical. However, using the motor may not be advisable in view of a weaker foundation and insufficient cooling. In such cases the broken parts can be welded using cast iron electrodes. Cracks, however, cannot be remedied. Unless the cracks are wide and may cause extensive damage during operation, the body may still not require replacement. Minor cracks, however, which do not impair the motor’s performance or cause development of further cracks, may be compromised.

10.6 Winding temperature measurement at site

Sometimes the motor may appear to be running overheated. In fact it may not be so. The easiest way to measure the temperature at site is by a thermometer which can be conveniently inserted into the hole of the lifting hook. In very small motors where a lifting hook may not have been provided, a small oil cavity can be drilled in between the top fins allowing the thermometer to be embedded there (Figure 10.10).

10.6.1 Temperature correction

When the temperature is measured by a thermometer as noted above it obviously does not measure the temperature of the hottest spot inside the stator. The readings may, at best, reflect the temperature of the stator housing instead of the stator winding. As a rough estimate, we can take a temperature gradient of 30% between the surface and the windings to obtain a near-realistic temperature of the winding. If \( \theta \) is the thermometer reading, then the winding temperature may be around \( (\theta/0.7) \, ^\circ C \) and it should be less than the safe working limits. For example, for class E insulation \( \theta/0.7 \leq 105^\circ C \) or \( \theta \leq 74^\circ C \), and for class B insulation \( \theta/0.7 \leq 110^\circ C \), i.e. \( \theta \leq 77^\circ C \).

This illustration is for general guidance when the motor is checked at site for its operating temperature. The thermometer reading should not exceed the above figures. However, a few degrees above these figures may be permissible, and this will depend upon the wall thickness of the stator housing, the air duct between the housing and the stator core, the design of the cooling ribs and the effectiveness of the cooling fan etc., which only the manufacturer can confirm.

Corollary
A surface temperature as high as 70\(^\circ\)C or more is obviously a very high temperature for the human body to touch. It is therefore natural for a human hand to feel very hot when touching the surface of a running motor. But to derive a conclusion from this may be misleading.

10.7 Analysis of insulation failure of an MV motor at a thermal power station

A powerhouse (thermal) application is the most stringent application, as discussed in Section 7.19. Based on field data collected from various installations by different agencies the general insulation failures observed may be attributed to the following.

**Electrical failures**

1 Failure at overhangs
   - In protected motors failure may be due to accumulation of fly ash at the overhangs (modern installations use only enclosed motors). Fly ash becomes an extremely good conductor when damp.
The failure will generally occur when a motor is switched on after a prolonged shutdown. 
• The motor may also fail due to system over-voltages, such as during a fast bus transfer (Section 7.19) or due to voltage surges (Section 17.3).

2 \textit{Failure of a coil}

Coil puncture is also a cause of insulation failure. It may be a result of poor impregnation at the manufacturing stage, or due to over-voltages, voltage surges and ageing. In resin-poor insulations, where the whole stator and rotor, after impregnation, becomes a solid mass, the chances of an insulation failure are remote. In a formed coil (resin-rich) design, however, there may be a differential expansion (thermal effect) between the insulation, the copper conductor and the iron core during normal running. This may cause loosening of bondage between them, leading to vibrations and shrinkage of the insulation on cooling. This can result in cracking of the insulation, exposing it to the environmental pollution discussed later, and eventual failure.

\textit{Prevent insulation failures}

• With the use of surge arresters and surge capacitors (Section 17.10)
• By monitoring the insulation condition of the windings during maintenance, at least once a year, which can be carried out by measuring (a) the polarization index (Section 9.5.3) and (b) the dielectric loss factor, \( \tan \delta \) (Section 9.6) and making up the insulation as in Section 9.5.2, when the condition of the insulation is acceptable and only its level is less than permissible.

A d.c. insulation resistance test or polarization index reveals only the surface condition of the insulation and does not allow a realistic assessment of internal condition. Loss tangent values are true reflections of the insulation condition to detect moisture content, voids, cracks or general deterioration. The \( \tan \delta \) versus test voltage curve may be drawn and compared with the original curve provided by the manufacturer, and inferences drawn regarding the condition of the insulation. The different starting \( \tan \delta \) values will reveal the condition of the insulation in terms of amount of contamination, as noted in Table 10.4 (See IEE, Vol. 127, May 1980).

3 \textit{Flash-over in terminal box}

This may be due to fly ash, over-voltages or voltage surges. For prevention see Section 7.18.

\textit{Mechanical failures}

1 \textit{Rotor rubbing the stator}

• Sometimes, as a result of an unbalanced magnetic field, causing an air gap eccentricity or excessive shaft deflection, the motor is not able to maintain the small air gap between the rotor and the stator and this may lead to failure.
• It is also possible that after long running hours the balls or the rollers of the bearing have given way.
• As a consequence of misalignment in the coupling.

\textit{Prevention}

• Ensure that the supply voltage is balanced.
• Check bearings and air gap during maintenance, at least once a year.
• Ensure an accurate alignment of load.

2 Rotor stampings are loose or rotor bars are damaged

• Misalignment causes vibrations, which may eventually lead to failure. The vibrations may also cause cracks between the rotor bars and the end rings.
• Frequent starts and stops may also cause this because of excessive heat.

\textit{Prevention}

• Check for accurate alignment.
• Check the rotor’s condition during the annual maintenance.

3 \textit{Environmental pollution}

• Failure may be caused by coal dust, fly ash and moisture. Pollution may weaken the insulation, particularly of a protected type motor and result in a failure at some stage.

\textit{Prevention}

• Blow the surface clean with air at brief intervals.

4 \textit{Ageing}

Over-voltages, voltage surges and over-heating of windings over many years of operation may dry and shrink the insulation and develop cracks. Through these cracks, moisture and dust can penetrate and destroy the insulating properties of the insulation resulting in an eventual failure of the insulation.

Field experience has revealed that one of the major causes of failure of an MV motor is weak insulation, caused by environmental pollution and ageing.
List of formulae used

Re-lubricating interval

\[ R_G = K \cdot \frac{14 \times 10^6}{N_t \cdot \sqrt{d}} - 4d \]  \hspace{1cm} (10.1)

\[ R_G \] = re-lubricating interval in hours of operation

\[ K \] = a factor depending on type of bearing

\[ d \] = bearing bore diameter (mm)

Quantity of re-grease

\[ G_w = 0.005D \times B \] grammes (g)  \hspace{1cm} (10.2)

\[ G_w \] = quantity of re-grease (g)

\[ D \] = bearing outside diameter (mm)

\[ B \] = bearing width (mm)
Further Reading


