Riga Technical University
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# HIGH-VOLTAGE ELECTRIC MOTORS AND GENERATORS

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This material is a summary of information on high-voltage motors and generators, passport data thereof, and the assembly requirements. In the material, introduction to damages or defects of motors and generators and suggestions for elimination thereof are presented.
The material can be used for studying electric machines as a part of qualification raising courses.

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# 1. Electric machine in a drive-train

Electrical equipment used in manufacturing and transport consists of various elements. Some of them make up electric drive — an electromechanical device that maintains motion and controls working machines in the necessary technological process. Electric drive converts electrical energy into mechanical energy and provides the manufacturing equipment control with electricity. An important part of this conversion is the electrical motor. And vice versa — conversion of mechanical energy into electrical energy is done by a generator.

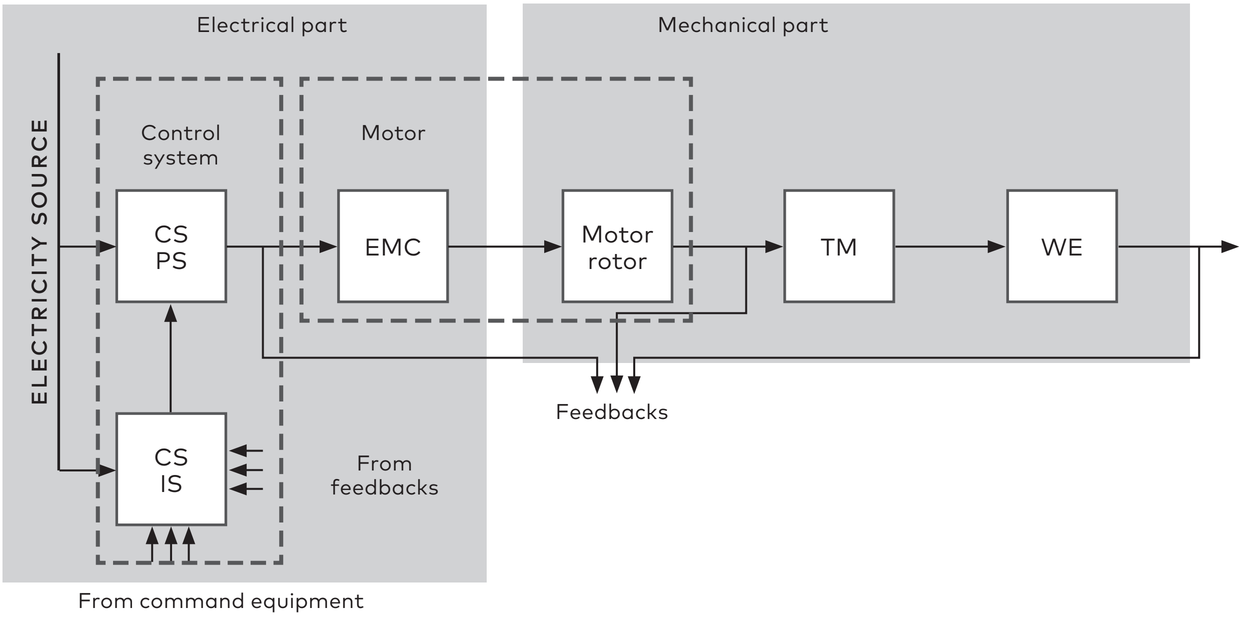


**Fig. 1.1.** Block diagram of a drive.

Figure 1.1 shows the block diagram of electric drive, which consists of the electrical and mechanical part. **Electrical part** includes electromechanical converter (EMC) of the motor, power and information section of the control system (CS). The control system converts the uncontrolled energy (parameters: $U_a$, $I_a$ and $f_a$) supplied by the electricity source into controlled energy (parameters: $U$, $I$ and $f$), and transmits it to the motor that performs electromechanical conversion of energy.

**Mechanical part** includes the rotor transmission mechanism (TM) and working element (WE). The torque $M$ generated by the motor affects the rotor and creates a corresponding angular speed $\omega$. Mechanical energy from the rotor is transmitted to the working element via the transmission mechanism. The parameters of electrical and mechanical part are controllable. Intensity of these signals is harmonised with the values of the respective quantities of the control system thus creating feedbacks that allow for automatic electric drive. The information section of the control system performs the brain functions of the automatic electric drive.

Key requirements for drive:

- reliability;
- work efficiency.

# 2. Passport data of motors

A lot of information about an electric machine is provided on the electric machine itself, namely on the informative plate or passport that is attached to the frame of the electric machine. Such plate presents the key rated parameters: rated power, rated current(s), rated voltage(s), power factor cosφ, efficiency factor η, and revolutions per minute.

A passport of an AC electric machine also gives information on the parameters related to heating and operating duty, as well as working conditions. Also the manufacture-related information is provided, like the year ad place of manufacture. An additional informative plate may also be attached giving information on bearings and greasing thereof (regreasing amount, regreasing intervals at specific temperature, grease brand).

## 2.1. Passport data of induction AC motor

Figure 2.1 presents the informative plates of induction AC motor *M3BM 355 LKA 4 B3* manufactured by the ABB Group: a) — motor passport, b) — information on motor bearing greasing.

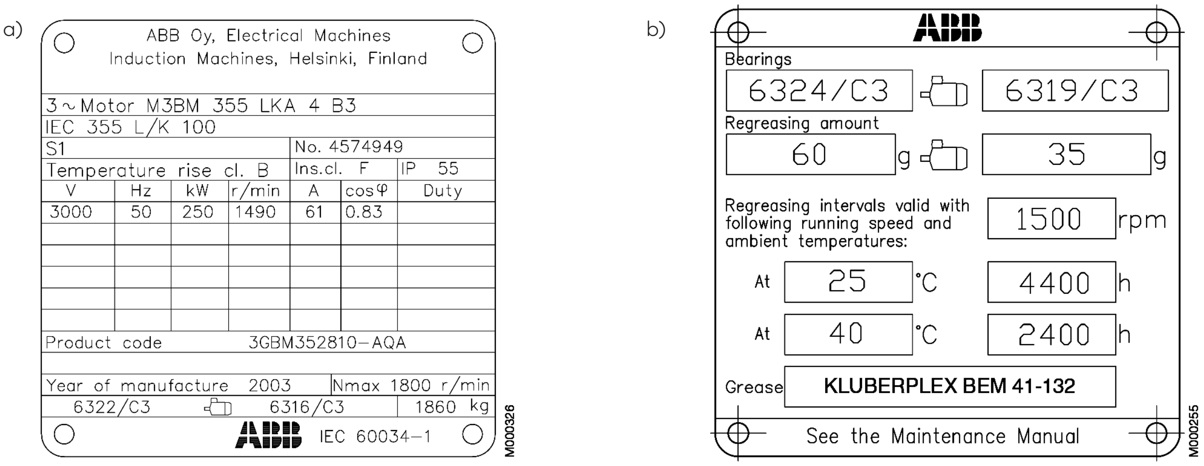


**Fig. 2.1.** Informative plates of induction AC motor: **a)** — motor passport; **b)** — greasing plate [1].

Data provided in the motor passport (from top): manufacturer and place of manufacture; type and model of motor; operating duty; number; temperature rise class; insulation class; international protection class; rated voltage; rated frequency; rated power; revolutions per minute; stator current; cosφ; information on duty; product code; year of manufacture; maximum revolutions per minute; bearings (number thereof) on the left in the load side, on the right in the fan side (motor pictogram shows the location of bearings); weight; compliance with the standard.

Motor greasing plate provides data on the type of bearings in the load and fan side (motor pictogram shows the location of bearings), as well as the necessary amount of regreasing for each of these bearings (in grams). This plate also shows regreasing intervals (in hours) if the temperature is 25 °C and 40 °C provided that the rotation speed as specified in the plate is observed (1500 revolutions per minute in this case). Also the grease is indicated (KLUBERPLEX BEM 41-132).

Table 2.1 lists the most widespread parameters indicated in the passports of electric machines. It is also stated which parameter corresponds with which type of machine.

Table 2.1

Parameters usually indicated in the passports of electric machines

| Parameter | DC | Synchr. | Induct. | Transf. | Notes |
|---|---|---|---|---|---|
| Manufacturer | ✓ | ✓ | ✓ | ✓ | |
| Rated voltage | ✓ | ✓ | ✓ | ✓ | |
| Rated current | ✓ | ✓ | ✓ | ✓ | Rated current for each speed of multi-speed machines, except for motors with shaded poles and capacitor motors |
| Rated frequency | | ✓ | ✓ | | |
| Number of phases | | ✓ | ✓ | ✓ | |
| Rotation rate at rated load | ✓ | ✓ | ✓ | ✓ | |
| Normalised temperature rise or insulation class, normalised ambient temperature | ✓ | ✓ | ✓ | ✓ | |
| Operating duty | ✓ | ✓ | ✓ | ✓ | 5 min, 15 min, 30 min, 60 min or continuous |
| Rated power | ✓ | ✓ | ✓ | ✓ | |
| Design code | ✓ | ✓ | ✓ | ✓ | |
| Secondary voltage | | | ✓ | ✓ | Induction motors with wound rotor |
| Secondary current | | | ✓ | ✓ | Induction motors with wound rotor |
| Excitation current and excitation voltage | ✓ | ✓ | | | Synchronous machines with DC excitement |
| Type of excitement | ✓ | | | | |

## 2.2. Adjustment of passport data

It is possible to adjust passport data of electric machines (and to order a new passport data plate) for individual needs by contacting the manufacturer in prior. It may be useful in situations when electric machines have to work at high temperatures or high elevation above sea. In this case, we will discuss an example from the literature [1]. Here, change in the motor power is possible, but it can only decrease. In case of changes in voltage it can be reduced by 10 % of the rated voltage. Condition for such adjustments is to avoid deterioration of machine's heating/cooling conditions.

## 2.3. Loads

Damages in insulation systems caused by transient processes and enhanced ageing mechanisms may have harmful impact on the stator and rotor windings of generator or motor. Mechanical loads that may cause and promote such impact on the insulation system can be described with the acronym TEAM (Thermal, Electric, Ambient, Mechanical). Each of the types of these four impacts will be discussed in detail hereafter. This subchapter is based on literature source [2].

Table 2.2

**Description of operating duties**

| | | |
|---|---|---|
| S1 | Continuous duty | The motor works at a constant load for enough time to reach temperature equilibrium. |
| S2 | Short-time duty | The motor works at a constant load, but not long enough to reach temperature equilibrium. The rest periods are long enough for the motor to reach ambient temperature. |
| S3 | Intermittent periodic duty | Sequential, identical run and rest cycles with constant load. Temperature equilibrium is never reached. Starting current has little effect on temperature rise. |
| S4 | Intermittent periodic duty with starting | Sequential, identical start, run and rest cycles with constant load. Temperature equilibrium is not reached, but starting current affects temperature rise. |
| S5 | Intermittent periodic duty with electric braking. | Sequential, identical cycles of starting, running at constant load and running with no load. No rest periods. |
| S6 | Continuous operation with intermittent load | Sequential, identical cycles of running with constant load and running with no load. No rest periods. |
| S7 | Continuous operation with electric braking. | Sequential identical cycles of starting, running at constant load and electric braking. No rest periods. |
| S8 | Continuous operation with periodic changes in load and speed. | Sequential, identical duty cycles run at constant load and given speed, then run at other constant loads and speeds. No rest periods. |

## 2.4. Thermal loads

Phase currents that flow in the conductor coils of stator windings cause heating in winding or the $I^2R$ loss (or the Joule heat loss). In combination with heat that is generated due to friction, bearings, or eddy-current loss, they can cause step-by-step deterioration of the thermal insulation system. It is also known that machine's load is directly related to changes in temperature, relating in particular to the insulation of stator windings. Thermal wear may lead to conductor delamination and other problems. Figure 2.3 presents an example of conductor delamination on winding due to thermal wear. It can be seen that several layers of the ribbon that is wrapped around the winding and forms insulation have been delaminated (on the left), possibly due to overheating of the binding agent thus resulting in delamination of various layers of electrical insulation paper.

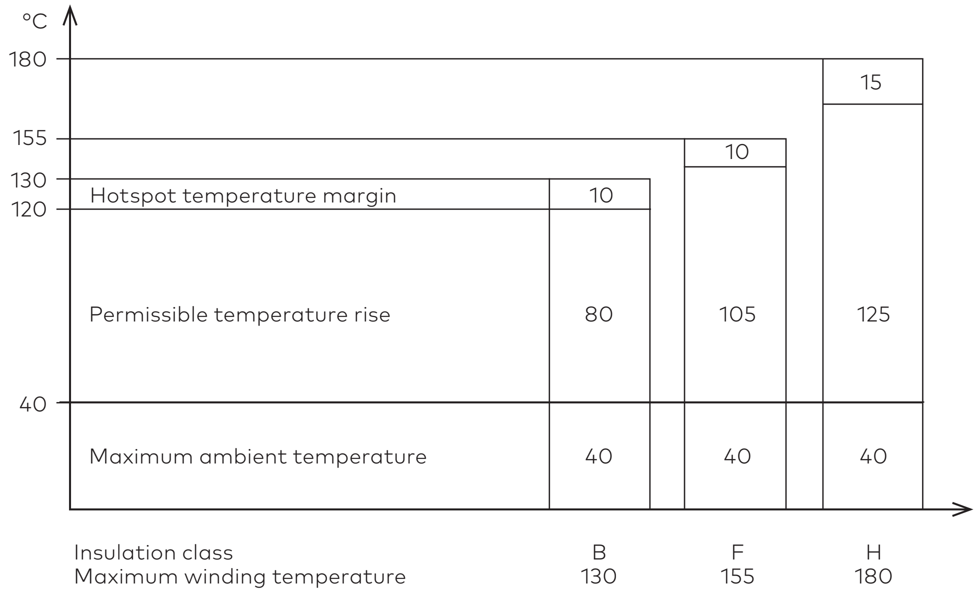


**Fig. 2.3.** Insulation classes and the limiting temperatures thereof.

## 2.5. Ambient loads

In the result of ambient medium in which a rotating electric machine operates loads are generated. There are various types of ambient medium impact: high humidity level, presence of sand, mud, and dust, presence of dangerous gases (usually related to explosive gases (EX) or explosive atmospheres (ATEX)); or impacts related to the location: locations with highly possibly burdensome conditions, like coastal areas where saline water is pumped or treated or specific zones at nuclear power plants. Although it is not always possible or necessary to control the ambient temperature or humidity, these factors, as known, have an impact on the partial discharge activity in stator windings and it can be together with the measurement data of power quality assessment and partial discharge.

Table 2.3

**Energy efficiency class (IE) of motors**
**Motor technologies and their energy efficiency potential**

| Motor type | | IE1 | IE2 | IE3 | IE4 | IE5 |
|---|---|---|---|---|---|---|
| Three-phase cage-rotor induction motors (ASM) | Random wound windings (all enclosures, all ratings) | Yes | Yes | Yes | Difficult | No |
| | Form wound windings; IP2x (open motors) | Yes | Yes | Difficult | No | No |
| | Form wound windings; IP4x and above | Yes | Yes | Yes | Difficult | No |
| Three-phase wound-rotor induction motors | | Yes | Yes | Yes | Difficult | No |
| Single-phase induction motors | Start capacitor | Difficult | No | No | No | No |
| | Run capacitor | Yes | Difficult | No | No | No |
| | Start/run capacitor | Yes | Difficult | No | No | No |
| | Split-phase | Difficult | No | No | No | No |
| Synchronous motors | Line-start permanent-magnet (LSPM) | Yes | Yes | Yes | Difficult | No |

## 2.6. Electrical load

Fast-fronted transient processes taking place in partial discharge of stator winding insulation that are caused by switching and overvoltage currents, as well as the upper harmonic in power system both together may contribute to the formation of electrical loads and insulation damage. Continuous online control of these factors can be included in a general control methodology. The main electrical loads that are present in operating rotating machines are shortly described in this chapter.

### 2.6.1. Partial discharge process

Degradation of semiconductors' case of stator core, not corresponding clearances of end windings /stress relief tape, insufficient use of epoxides in the process of vacuum pressure impregnation, as well as damage by a third party are just some of the causes for partial discharge process in the insulation system of stator windings of a rotating machine. Such damage to the insulation system may also be caused by transient pulsation that can be found on the machine leads or on the cable where the power switch is connected to it (in machines with cable supply). Over time, the partial discharge process will be the cause of complete and ultimate break-up of insulation, which often results in sudden failure of the machine. Overall, continuous online control of the partial discharge process is approved as the most appropriate method for determining the insulation status of rotor and stator windings.

### 2.6.2. Cable sheath currents

Voltage that is induced in a metallic sheath of high-voltage cables with one core can generate current flow in this sheath. Weak interconnection between the cable earthing may cause circulation of large currents in the cable sheath, and it is harmful to the current carrying capacity of phase conductors. The best solution is to determine the new current carrying capacity by using cable geometry and measurements of sheath currents.

### 2.6.3. Power quality

Power quality includes several aspects of electricity consumption and generation, including voltage stability, frequency, cosφ, balancing of total upper harmonic distortions and phases. This list does not mean that all these parameters must be controlled. In relation to the insulation of stator windings, the content of harmonics may affect the ageing of insulation in the electrical grid power curves due to the fact that $I^2R$ losses increase. In addition, presence of harmonics may cause also mechanical problems. Due to these reasons, it is necessary to ensure continuous control of the content of harmonics.

### 2.6.4. Analysis of current characteristics

Analysis of current characteristics is mainly used to establish damage that is related to the rotor of motor or generator. It is possible to establish if there is a problem with rotor by analysing dependence of the machine's current on frequency. This technique may also be applied to three-phase machines and used to establish such damage like problems related to rotor shape, bearings, as well as broken or cracked rotor bars.

## 2.7. Mechanical loads

The main mechanical loads that can generate large forces for the insulation system of AC machine are those caused by short-circuit currents, large angular speed, fluctuating magnetic forces, and regular changes in rotor speed. Mechanical loads include wide range of sources, including magnetic and centrifugal forces, vibrations caused by bearing wear, overvoltage and overload current; however, the most dangerous load are very large mechanical forces generated by short-circuit currents. It is necessary to perform control to establish the shaft bend and unbalance of rotor and other diminishing components.

# 3. Assembly of high-voltage electric machines

Further, the assembly of induction AC motors is described; although it can be generally applied to the assembly of any type of rotating electric machines [3].

## 3.1. Safety instructions

Staff that is involved in the operation of electrical installations, including handling, lifting, operating, and maintenance thereof, must be well-informed (also of the latest information) on the safety standards and principles that apply to the work and must comply with these standards and principles. Prior to work commencement, the person in charge of these works must make sure that the works will be fulfilled in due manner and must warn the staff on danger that might arise during the course of the work. Qualified staff must know how to:

- prevent contact with current-carrying circuits or rotating parts;
- prevent bypassing or non-operating explanation of protection measures or security measures;
- prevent continuous work with an equipment near high level of noise;
- take the necessary caution and procedures in the process of lifting, installing, operating, and maintenance of equipment;
- consequently follow all instructions and documentation accompanying the equipment when performing the aforementioned works.

To prevent electric shock, it must be verified that all power supplies are disconnected from the motor and its accessories before maintenance.

## 3.2. Unpacking

Before dispatch to a customer, motors are tested and balanced at factory. Corrosion-preventing agents are applied on control equipment and the sliding surfaces. At delivery, it is suggested to check the packaging to discover any damage that might have occurred during transportation. To prevent any damage to bearings, motors are transported by using a shaft lock mechanism. It is advised to keep this mechanism close at hand so that it can be used in future if necessary. It is necessary to identify the local workers that might be qualified for the performance of these works and to check the package weight and the crane lifting capacity.

Motors that are transported in wooden boxes always must be lifted using lifting eye bolts or by using fork-lift trucks, but never by the shaft. The box may never be turned upside down. Care must always be taken when lifting and lowering such boxes to prevent damage to bearings. It is also necessary to perform visual inspection following unpacking. Do not remove protective greasing from the shaft end and do not remove safety pins from the lead box. These protection devices must stay where they are until the installation is completed. Shaft locking devices, if there are such, are dismantled. It is necessary to perform manual rotation of the rotor several times if the motor is equipped with ball bearings. If any damage is established, the transport operator and the manufacturer must be contacted immediately.

## 3.3. Storage

If motors are not unpacked immediately, the packaging must be stored in normal upward position in dry place that is clean from mud, dirt, gasses, and corrosive atmosphere. Do not place other objects on the motor's packaging or opposite it.

Motors must be stored in place that is free from vibration to prevent bearing damage. If motors are equipped with motor space heater, then these devices must be switched on.

If the paint has been damaged, it must be reapplied to prevent corrosion. The same applies to treated surfaces when the protective grease is worn off.

Brushes on slip ring motors must be lifted and removed from the "pockets" to prevent oxidation between contacts and rings if these motors are stored for more than two months. Note: before starting the motor, brushes must be placed back in the "pockets".

### 3.3.1. Bearings

When a motor is stored for six months or less, it is not necessary to perform full inspection of bearings before starting the motor. For this, it is necessary to perform shaft rotation once a month. However, if the motor is stored for more than six months, bearings must be regreased before starting. And, if the motor is stored for some two years or even more, bearings must be dismantled and cleaned with ether and checked. All the previous grease must be removed. Following the repeated assembly, bearings must be regreased.

### 3.3.2. Insulation resistance

If the motor is not operated at once, it must be protected against humidity, high temperatures and dirt to prevent damage to insulation. Resistance of winding insulation must be measured before starting the motor. If there is high ambient humidity level, regular inspection during the storage is needed. Since resistance changes according to the type, size, rated voltage, condition of the insulation material, and construction of the motor, it is hard to define conditions for the actual value of motor insulation resistance. To determine if the motor is ready for operation, rich experience is needed. Regular notes will help to determine it, however.

The following guidelines show the approximate values of insulation resistance that can be expected at ambient temperature of 40 °C if the motor is clean and dry and if the test voltage is applied for a minute. Minimum insulation resistance (megohms at 40 °C) can be calculated as follows:

$$R_{\mathrm{min}} = U_{\mathrm{n}} + 1, \qquad (1)$$

where $U_{\mathrm{n}}$ — rated voltage of motor, kV. If the test is done at other temperature, measurements must be adapted to 40 °C by using the curve representing changes in insulation resistance according to the heat generated by the motor itself.

Table 3.1

**Standard values for insulation resistance in electric machines**

| Insulation resistance, MΩ | Insulation level |
|---|---|
| ≤ 2 | Bad |
| < 50 | Dangerous |
| 50–100 | Not normal |
| 100–500 | Good |
| 500–1000 | Very good |
| < 1000 | Excellent |

## 3.4. Assembly and the mechanical aspects thereof

Motors must be installed where they are freely accessible during test and maintenance. If there are humid, corrosive, or explosive substances or particles in the ambient air, adequate protection level must be ensured. Installation of motors in an environment with vapour, gasses or dust, combustible or highly flammable substances that may cause fire or explosion must be performed according to the standards ABNT NBR, NEC Art. 500 (National Electrical Code) and UL-674 (Underwriters Laboratories, Inc.). Motors with external surface cooling must be placed at least 50 mm above ground to ensure free circulation of air.

### 3.4.1. Foundations

The foundation under the motor must be even and free from any vibration. Concrete foundation is recommended due to this reason. The type of the foundation to be constructed depends on the soil at the site or the foundation capacity.

When designing foundation for motors, it must be considered that motor can be suddenly subjected to a torque that exceeds the rated value. If the design has not been accurate, vibration-related problems may arise to the foundation, motor, or the motor-driven equipment.

Figure 3.1 shows the forces on motor when it operates clockwise. The forces are opposite in case of anti-clockwise rotation. Based on Fig. 3.1, forces that act on the base can be calculated according to these equations:

$$F_1 = 0,5mg + \frac{4C_{\text{maks}}}{A}; \quad (2)$$

$$F_2 = 0,5mg - \frac{4C_{\text{maks}}}{A}, \quad (3)$$

where $F_1$ and $F_2$ — forces that act on the base, N;
$g$ — gravity acceleration, 9.81 m/s$^2$;
$m$ — weight of the motor, kg;
$C_{\text{maks}}$ — maximum torque, N m;
$A$ — geometric criterion (Fig. 3.1), m.

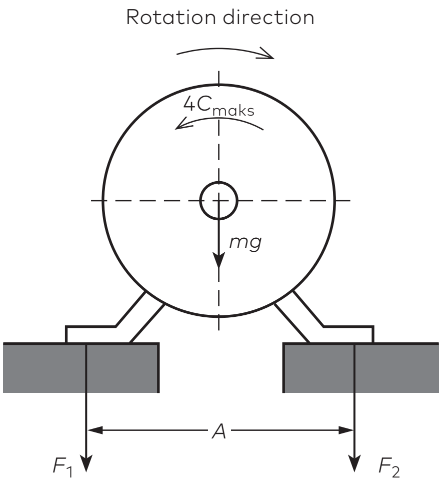


**Fig. 3.1.** Forces that act on a rotating electric motor.

To adjust motor feet, steel or iron base, or anchor base can be mounted to concrete foundation, as suggested in Fig. 3.2. It is important that the equipment is made so that it can move any force or torque that can occur during operation.

Note: a metal plate shall be placed on a concrete foundation to support the base levelling screw.

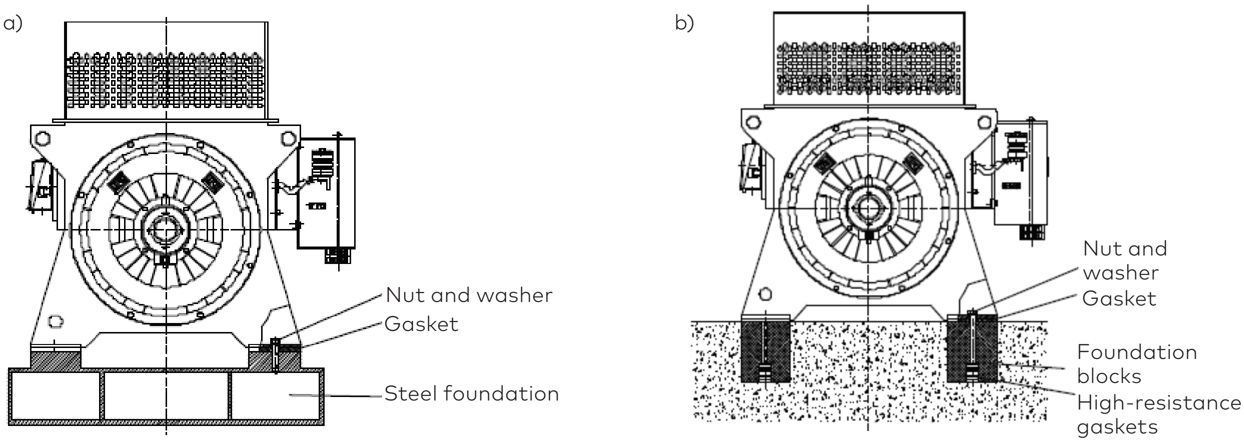


**Fig. 3.2.** Fastening of a motor to steel (a) and concrete (b) foundation.

## 3.4.2. Balancing and alignment

A motor must be carefully balanced with the motor-driven equipment, especially in case of direct coupling. Incorrect balancing may cause bearing defects, vibration, and even breaking of shaft. The best way how to ensure correct balancing is to use a bell indicator that is placed on each of the sides to be connected: one reads radially, the other — axially. Such simultaneous readings can reveal any parallel (Fig. 3.3. c)) or concentric deviations (Fig 3.3. b)) when rotating the shaft. The bell indicator must not exceed 0.05 mm. Measurements in four various circumference points may not differ for more than 0.03 mm.

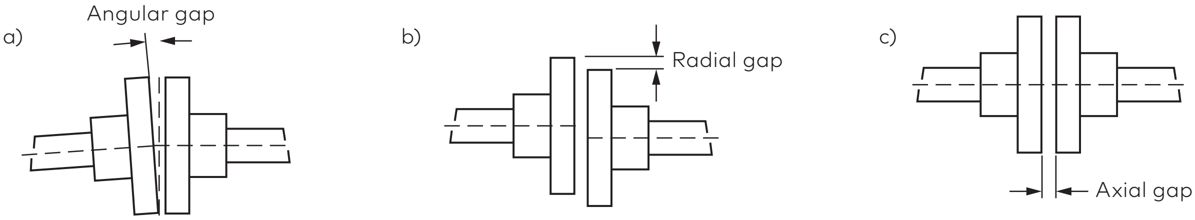


**Fig. 3.3.** Type of centring: a) — angular centring; b) and c) — radial centring.

It is crucial to take into account the surface temperature of motor and motor-driven mechanism in balancing and alignment. Different expansion levels of connected machines may affect the balance during the motor starting process.

When a motor is aligned with the foundation both in low and high temperatures, the motor must be screwed down as shown in Fig. 3.4.

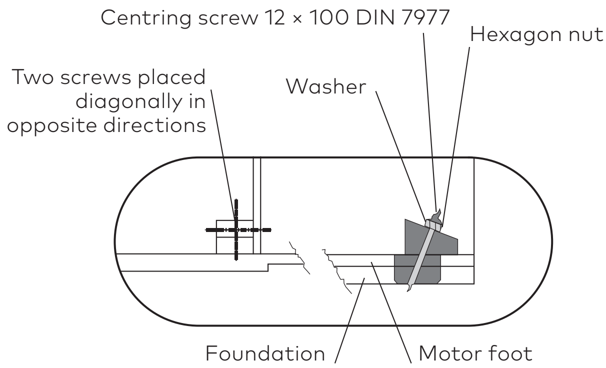


**Fig. 3.4.** Fastening of a motor to a foundation.

### 3.4.3. Connections

A) Direct connections

Whenever possible, direct connections should be used for their low price, little space needed, avoidance of belt slip, and reduced accident risk. When speed reduction is needed, direct connection is often made using transmission mechanism. Note: it is important to align shaft ends properly by using the flexible coupling if possible.

B) Connection using transmission mechanism

Poor-balanced connections with transmission mechanism usually cause cramped movements resulting in vibration in the connection and motor. In case of a direct reduction gear and a bevel gear of corresponding angle and in case of a spiral gear attention must be paid to shaft alignment (to ensure that it is straight). Connection of a transmission mechanism can be tested by placing a paper slip on which gear teeth marks after one rotation are left.

C) Belt and pulley connection

Belt transmission is often used when it is necessary to observe derating factor.

Table 3.2

**Comparison of motor protection systems**

| Causes of overheating | Current-based protection | | Protection with thermal probe in motor |
|---|---|---|---|
| | Fuse only | Fuse and thermal protection | |
| 1 Overload 1.2$I_N$ | Not protected | Fully protected | Fully protected |
| 2 Operating duties S1 to S8, EB 120 | Not protected | Partly protected | Fully protected |
| 3 Breaking, reversing and operation with frequent starting | Not protected | Partly protected | Fully protected |
| 4 > 15 starts in hour | Not protected | Partly protected | Fully protected |
| 5 Squirrel-cage rotor | Partly protected | Partly protected | Fully protected |
| 6 Damaged phase (phase loss) | Not protected | Partly protected | Fully protected |
| 7 Increased voltage fluctuation | Not protected | Fully protected | Fully protected |
| 8 Frequency fluctuation in power source | Not protected | Fully protected | Fully protected |
| 9 High ambient temperature | Not protected | Fully protected | Fully protected |
| 10 Surface heating due to bearings, belts, pulleys, etc. | Not protected | Not protected | Fully protected |
| 11 Blocked ventilation | Not protected | Not protected | Fully protected |

# 4. Maintenance of electric machines

## 4.1. Winding tests

Complete visual of windings check must be carried out every year, and all established defects or damages must be registered and repaired. Resistance measurements in winding insulation must be performed regularly and following longer periods of idleness. Attention must be paid to low values or sudden changes in insulation resistance. Winding insulation resistance can be raised to the necessary level in places where it is low (as a result of excess dirt and humidity), by cleaning the dirt and drying the humidity.

## 4.2. Cleaning of windings

To ensure more satisfying motor operation and longer service life of insulated windings, it is recommended to keep them clean of dirt, oil, metal scrap, slag, etc. Therefore, regular inspection of windings is necessary in line with the maintenance plan recommendations. Windings can be cleaned with an industrial vacuum cleaner or wet cloth. In more complicated cases a proper solvent may be used. Solvent must not be applied to the straight parts of windings as it may damage anti-corrosion protection.

After thorough cleaning of windings:

- insulation of windings and connections must be checked;
- interelements, bindings, sunk keys, bands, and connections must be checked for proper fixation;
- short circuit windings and connections between windings and with the frame must be checked for cracks;
- it must be verified that all cables are connected properly and that components fixing leads are properly tightened (or tightened if necessary).

If repeated impregnation is necessary, consult the manufacturer.

After completion of maintenance works and before repeated starting of the motor, measure the winding insulation resistance and check if the measured values match the specification.

## 4.3. Maintenance of cooling system

Air heat exchanger pipes must be kept clean and unclogged to ensure excellent heat exchange. To remove dirt accumulated in the pipes, a round brush with long handle can be used. In the case of water-to-air heat exchanger regular cleaning of radiator pipes is necessary.

## 4.4. Maintenance of radiator

To remove a radiator for maintenance:

1) all water inlet and discharge pipes must be closed following stopping of ventilation;
2) water must be drained through the drainage openings;
3) remove caps and leave bolts, washers, nuts, etc. in a safe place;
4) carefully clean the pipes from inside using nylon brushes to remove any remains; if any damage to the radiator is found during the cleaning, these must be repaired;
5) mount the tips and change washers if necessary.

## 4.5. Other maintenance

Other maintenance includes maintenance of separate units of the machine.

- Maintenance of ratchet wheel: check the wear of teeth and plugs of the anti-reverse ratchet wheel.
- Maintenance of slip rings: keep them clean and smooth, clean them once a month.

- Maintenance of brushes and brush supports: brush supports must be radial to slip rings not more than 4 mm from them to avoid ruptures and brush damage. Brushes must be checked once a week to verify if they can move freely in the brush support. Worn brushes must be replaced. If brushes are replaced, only proper brushes can be used. Do not mix brushes! If the motor rotates in one way only, the same applies to brushes. Brushes must ensure uniform pressure on slip rings. All brushes in the machine must have similar pressure (within the range of ±10 %) on the slip rings. Springs that ensure reduced pressure must be replaced. The manufacturer has adapted brushes to the motor rated mode; if the motor operates in another mode, brushes must be adapted accordingly.
- Shaft earthing device and maintenance thereof: this device provides protection against currents in motor bearings. This device includes brush that touches shaft. The device is earthed (through the frame), thus parasitic currents are removed from the machine. For this device to operate, there may be no objects or substances between the device and the shaft. Similarly to brush unit, this device must be checked regularly, and the brush must be replaced when worn.

# 5. Failures of electric machines and causes thereof

## Induction AC motors

| Type of failure | Possible cause | Measures to be taken |
|---|---|---|
| It is not possible to start the motor. | ○ At least two supply leads are damaged, there is no voltage supply.<br>○ The rotor is blocked.<br>○ Problems with brushes.<br>○ Damaged bearings. | ○ Check the control panel, switch, fuses, supply conductor leads, lead box, and the brush condition.<br>○ Brushes are worn or installed incorrectly.<br>○ Replace bearing. |
| Loaded motor starts operating very slowly and does not reach the rated speed. The motor is running without load but fails when load is connected. | ○ Too large load when starting.<br>○ Too low supply voltage.<br>○ Too large voltage drop on the supply conductors.<br>○ Damaged or interrupted rotor bars.<br>○ One of the supply conductors was terminated after starting. | ○ Do not load the machine when starting.<br>○ Control the supply voltage.<br>○ Check cross-section of supply conductors.<br>○ Check and repair the short-circuited rotor winding and the sliding contact system.<br>○ Check supply conductors. |
| Stator current changes with double slip frequency. Buzzing can be heard during starting. | ○ Interrupted rotor winding.<br>○ Problems in the brush unit. | ○ Check and repair the rotor winding and the sliding contact system.<br>○ Clean, rearrange, or replace brushes. |
| Too large no-load current. | ○ Too large supply current. | ○ Measure the supply current and adjust it as necessary. |
| Rapid overheating of rotor, buzzing can be heard during operation. | ○ Damaged windings connected in parallel or in phase. | ○ Measure resistance to all winding phases.<br>○ Replace the stator core with winding. |
| Some places get hot in the stator winding. | ○ Short circuit between windings.<br>○ Interruption of conductors of stator winding connected in parallel or in phase.<br>○ Weak connection. | ○ Rewind the motor.<br>○ Restore connections. |
| Some places get hot in the rotor. | ○ Interruption in rotor winding. | ○ Repair the rotor winding or replace it. |
| Unnatural noise in motor when loaded. | ○ Mechanic problems.<br>○ Electric problems. | ○ Usually, the noise reduces together with speed, see also “Noisy operation in disconnected mode”.<br>○ The noise disappears when the motor is started.<br>○ Contact the manufacturer. |

| Type of failure | Possible cause | Measures to be taken |
|---|---|---|
| Noise when coupled, no noise when not coupled. | o Damaged drive elements or motor-driven equipment.<br>o Damaged transmission.<br>o Problem in connection.<br>o Sagging foundation.<br>o Insufficient balancing in drive elements or motor-driven equipment.<br>o Too high supply voltage.<br>o Incorrect rotation direction. | o Check the power transmission, connection, and alignment.<br>o Balance the drive, check the gear position.<br>o Align the motor and the motor-drive equipment.<br>o Fix the foundation.<br>o Check supply voltage and no-load current.<br>o Switch two phases.<br>o Perform repeated balancing of the system. |
| Overheating of stator winding under load. | o Poor cooling due to dirty air pipes.<br>o Too large load.<br>o Excessive number of starting times or too large inertia.<br>o Too high voltage and thus too high loss in the metal.<br>o Interrupted one of the supply conductors or interrupted one of the winding phases.<br>o Rotor rubs against stator.<br>o Operational mode does not conform with the information in the motor passport.<br>o Not balanced electrical load (melted fuse, incorrect control).<br>o Dirty windings.<br>o Blocked cooling system.<br>o Dirty filter.<br>o Rotation direction is not proper for the used fan. | o Clean the air pipes in the cooling system.<br>o Measure voltage, reduce load, use larger motor.<br>o Reduce the number of starting.<br>o Do not exceed 110 % of the rated voltage, unless otherwise indicated in the passport.<br>o Check voltage supply and voltage drop.<br>o Check currents of all phases and make corrections.<br>o Check air gap, operational conditions, bearings, vibration.<br>o Ensure operational mode as indicated in the passport or reduce load.<br>o Check if there are unbalanced voltages and if only two phases are working.<br>o Perform cleaning works.<br>o Clean the filter tube.<br>o Investigate compatibility of the rotation direction of fan and motor. |
| Noisy activity when in disconnected mode. | o Unbalance.<br>o Interrupted one of the phases of stator winding.<br>o Foreign body in the air gap.<br>o Loose fastening bolts.<br>o Increased rotor unbalance after assembly of drive train.<br>o Unbalanced rotor.<br>o Foundation resonance.<br>o Deformed motor frame.<br>o Curved shaft.<br>o Irregular air gap. | o Noisy activity continues during stoppage after voltage disconnection. Repeat rotor balancing.<br>o Check the current fed to all supplying conductors.<br>o Remove dirt and clean the air gap.<br>o Fasten and block bolts.<br>o Check the balance.<br>o Level the foundation.<br>o Check the alignment.<br>o Shaft may be curved. Check the rotor balance and irregularity.<br>o Check if the shaft is curved and if bearings are faulty. |

| Type of failure | Possible cause | Measures to be taken |
|---|---|---|
| Motor with wound rotor operates with low speed without an externally connected resistance. | o Interrupted rotor circuit.<br>o Dirt between the brush and slip ring.<br>o Incorrect pressure on brushes.<br>o Uneven surface of slip rings.<br>o Eccentric rings.<br>o High current density on brushes.<br>o Incorrectly mounted brushes. | o Mount heavier conductors in the control circuit.<br>o Move the control closer to the motor.<br>o Check the circuit with magneto or other means and do the necessary repairs.<br>o Clean the slip rings and ensure insulation.<br>o Choose brushes of correct size.<br>o Clean, grind, and polish.<br>o Turn brushes on a lathe or with a portable tool without dismantling.<br>o Reduce the load or replace brushes.<br>o Carefully mount the brushes again. |
| Brush sparking. | o Poorly mounted brushes with improper pressure.<br>o Overload.<br>o Slip rings in bad condition.<br>o Oval slip rings.<br>o Too much vibration, rough surfaces, and bruised rings.<br>o Low load causing damage to slip rings. | o Check the position of brushes, adjust to the necessary pressure.<br>o Reduce load or install more powerful motor.<br>o Clean slip rings and install the brushes again.<br>o Polish slip rings and turn them on a lathe.<br>o Balance the rotor, check if brushes can move freely in the support.<br>o Find the cause for vibration and fix it.<br>o Adapt brushes to the actual load and grind slip rings. |

## Bearing failures and failures during operation

| Type of failure | Possible cause | Measures to be taken |
|---|---|---|
| Motor rumbles during operation. | o Damaged bearings. | o Replace bearing. |
| Noisy bearing, damage to bearing construction. | o Inaccurately mounted bearing. | o Align the bearing and turn bearing fit. |
| Big bearing noise and great heating of the bearing. | o Corrosion of the short-circuit cage, presence of small particles in the grease, starting failure due to improper grease, or improper cleaning. | o Clean and replace grease according to the specifications.<br>o Replace bearing. |
| Bearing overheating. | o Excessive amount of grease.<br>o Excessive axial or radial tension of the belt.<br>o Curved shaft.<br>o Lack of grease.<br>o Thickened grease causes blocking of balls.<br>o Impurities in the grease. | o Remove the excess grease and operate motor until the excess grease is removed.<br>o Reduce belt tension.<br>o Straighten the shaft and check rotor balance.<br>o Grease bearings.<br>o Replace bearing.<br>o Remove case and grease, place other (appropriate) portion of grease. |
| Dark spots on one side of the ball cage that may cause cavities. | o Excessive axial force. | o Check the connection of coupling and motor-driven equipment. |
| Dark lines on the ball cage or close transverse cavities. | o Current flows through bearings. | o Clean and replace bearing insulation. |
| Cavities in ball cages and hollows in parts of cylindrical elements. | o External vibration, mainly when rotor is stopped for a long time.<br>o Insufficient maintenance during the storage. | o If the motor is stopped for a long time, turn the shaft to another position time to time. This mainly applies to a reserve motor. |

## AC synchronous generator [4]

**Generator cannot be excited.**

| Type of failure | Measures to be taken |
|---|---|
| Excitation switch (if present) does not work.<br>Interruption in auxiliary winding. | o Check the switch.<br>o Check the clamp connection of additional actuator in the block that leads to the controller connection block. |
| Too low residual voltage. | o Apply external excitation with 12–20 V DC battery until excitation starts.<br>o Negative pole at K.<br>o Always disconnect the controller's clamps to avoid any damage.<br>o Positive pole at I.<br>**Warning!** When using a battery, earthing is optional. |
| Improper rotation speed. | o Measure speed and then perform repeated adjustment. |
| Interruption in the main excitation circuit. | o Perform measurements in the rotating diodes, replace all the damaged diodes or even the whole set. |
| Damaged relay or other part of the relay. | o Replace voltage regulator. |
| The adjustable external voltage regulator is broken, or the contact is interrupted. | o Check the lead and the regulator's connection. |
| Failure of protection varistor. | o Replace if damaged; if the necessary parts are not available, disassemble temporarily. |

**Generator does not excite to the rated voltage.**

| Type of failure | Measures to be taken |
|---|---|
| Damaged rotating rectifier. | o Perform measurements in each of the diodes, replace the damaged diodes or even the whole set. |
| Improper rotation speed. | o Measure the speed and adjust it. |
| The set value is below the rated value. | o Adjust the regulator. |
| The supply voltage of regulator does not match the necessary output voltage. | o Check if the connections comply with the instruction of voltage regulator. |

**In no-load mode, the generator excites to the rated voltage, but the voltage drops when load is added.**

| Type of failure | Measures to be taken |
|---|---|
| Damaged rotating diodes. | o Perform measurements in each of the diodes, replace the damaged diodes or even the whole set. |
| Considerable decrease in voltage. | o Perform control of the switch of the motor-driven machine. |

**Generator excites with increased voltage when in no-load mode.**

| Type of failure | Measures to be taken |
|---|---|
| Damaged power thyristor.<br>Damaged transformer supplying the regulator. | o Replace the regulator. |
| The supply voltage of regulator does not match the necessary output voltage. | o Re-establish connections.<br>o Check the manual of voltage regulator. |

**Increased voltage fluctuation in the generator.**

| Type of failure | Measures to be taken |
|---|---|
| Incorrectly set stability. | o Adjust the regulator's stability. |
| Changes in speed of the motor-driven machine. | o The frequent fluctuation occurs in the motor-driven machine, it must be fixed. |

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Annex No. 1

## Maintenance plan during storage [3]

| Measure | Every month | Every 2 months | Every 6 months | Every 2 years | Before starting | Notes |
|---|---|---|---|---|---|---|
| **PLACE FOR STORAGE** | | | | | | |
| Evaluate the level of cleanness. | | ✓ | | | ✓ | |
| Evaluate humidity and temperature. | | ✓ | | | | |
| Evaluate signs of insect invasion. | | ✓ | | | | |
| **PACKAGING** | | | | | | |
| Check for possible damage. | | | ✓ | | | |
| Check the relative core moisture content. | | ✓ | | | | |
| Replace drying agents (if there are any). | | | ✓ | | | As necessary |
| **HEATER** | | | | | | |
| Check the working conditions. | ✓ | | | | | |
| Measure circuit voltage and current. | ✓ | | | | | |
| Check the functionality of warning system. | | | ✓ | | | |
| **MOTOR IN GENERAL** | | | | | | |
| Clean from outside. | | | ✓ | | ✓ | |
| Evaluate the painting quality. | | | ✓ | | | |
| Check the condition of anti-corrosion agent on open and treated surfaces. | | | ✓ | | | |
| Reapply the anti-corrosion agent. | | | ✓ | | | |
| Check the rubber seals and gaskets. | | | ✓ | | | |
| Complete the scheduled maintenance. | | | | | | |
| **WINDINGS** | | | | | | |
| Measure temperature in windings. | | ✓ | | | ✓ | |
| Measure insulation resistance. | | ✓ | | | ✓ | |
| Measure polarisation index. | | ✓ | | | ✓ | |
| **LEAD BOX AND EARTH TERMINALS** | | | | | | |
| Clean the inside of lead box. | | | | ✓ | ✓ | |
| Evaluate the condition of seals and gaskets. | | | | ✓ | ✓ | |
| **ROLLING BEARINGS WITH GREASE OR OIL** | | | | | | |
| Perform shaft rotation. | | ✓ | | | | |
| Regrease (reapply grease or oil). | | | | | ✓ | |
| Dismantle and clean the bearing. | | | | | | If the storage time exceeds 2 years. |

| Measure | Every month | Every 2 months | Every 6 months | Every 2 years | Before starting | Notes |
|---|---|---|---|---|---|---|
| **SOLID BEARING** | | | | | | |
| Perform shaft rotation. | | ✓ | | | | Minimum 10 full rotations at 30 $min^{-1}$. |
| Apply anti-corrosion agent. | | | ✓ | | | |
| Clean bearings | | | | | ✓ | |
| Replace oil | | | | | | If the storage time exceeds 2 years. |
| **BRUSHES** | | | | | | |
| Lift brushes. | | | | | | During storage. |
| Lower brushes and check the T contact with slip rings. | | | | | ✓ | |

Annex No. 2

## Maintenance plan [3]

(Warning! This maintenance plan is only manufacturer's recommendation.)

| Measure | Every week | Every month | Every 3 months | Every 6 months | Every year | Every 3 years | Notes |
|---|---|---|---|---|---|---|---|
| **STATOR** | | | | | | | |
| Visual inspection of stator. | | | | | ✓ | | |
| Cleanness control. | | | | | ✓ | | |
| Inspection of sunk keys. | | | | | | ✓ | |
| Inspection of stator lead fastenings. | | | | | ✓ | | |
| Measure insulation resistance in windings. | | | | | ✓ | | |
| **ROTOR** | | | | | | | |
| Visual inspection. | | | | | ✓ | | |
| Cleanness control. | | | | | ✓ | | |
| Inspection of shaft (wear, mud). | | | | | | ✓ | |
| **BEARINGS** | | | | | | | |
| Control of noise, vibration, oil flow, leaks, and temperature. | ✓ | | | | | | |
| Grease quality control. | | | | | ✓ | | |
| Inspection of bearing case and solid bearing. | | | | | | ✓ | |
| Replace grease. | | | | | | | According to the schedule indicated in the motor passport. |
| **AIR-TO-WATER HEAT EXCHANGER** | | | | | | | |
| Inspection of radiators. | | | | | ✓ | | |
| Cleaning of radiators. | | | | | ✓ | | |
| Inspection of the condition of radiator's sacrificing anodes (if there are such). | | ✓ | | | | | Increase the inspection frequency in case corrosion increases. |
| Replacement of radiator's head gaskets. | | | | | ✓ | | |
| **AIR-TO-AIR HEAT EXCHANGER** | | | | | | | |
| Cleaning of ventilation leads. | | | | | ✓ | | |
| Inspection of ventilation. | | | | | ✓ | | |
| **BRUSHES, BRUSH SUPPORTS, AND SLIP RINGS** | | | | | | | |
| Inspection and cleaning of brush unit. | ✓ | | | | | | |

| Measure | Every week | Every month | Every 3 months | Every 6 months | Every year | Every 3 years | Notes |
|---|---|---|---|---|---|---|---|
| Verification of contact area of slip rings. | | | ✓ | | | | |
| Verification of brush wear and the possible replacement. | | ✓ | | | | | |
| Inspection of the brush lifting system (if there is such). | | | | | | | |
| **AIR FILTER** | | | | | | | |
| Inspection, cleaning, replacement if necessary. | | | | | | | Every 2 months. |
| **PROTECTION AND CONTROL EQUIPMENT** | | | | | | | |
| Registration of parameters. | ✓ | | | | | | |
| Inspection of operation. | | | | | ✓ | | |
| Dismantling and inspection of operation. | | | | | | ✓ | |
| **CONNECTIONS** | | | | | | | |
| Evaluation of alignment process. | | | | | ✓ | | Check after the first week of operation. |
| Evaluate fastenings. | | | | | ✓ | | |
| Evaluation of the ratchet wheel (if there is such). | | | | | ✓ | | |
| **MOTOR IN GENERAL** | | | | | | | |
| Evaluation of noise and vibration. | ✓ | | | | | | |
| Removal of condensate. | | | ✓ | | | | |
| Repeated tightening of bolts. | | | | | ✓ | | |
| Cleaning of lead boxes. | | | | | ✓ | | |
| Repeated tightening of electric and earthing contacts. | | | | | ✓ | | |