AMP224 ELECTRICAL MOTORS NOT SUBJECT TO ENVIRONMENTAL QUALIFICATION REQUIREMENTS (2021)

**Programme Description**

The purpose of the AMP is to provide a programme to address the ageing of motors operated in nuclear power plants (NPPs). Most of the motors in NPPs are squirrel cage induction motors. Typically, the motors are categorized as large motors of 500 Horsepower (HP) or more and small motors below 500 HP. Large motors play roles in plant operation from production point of view and are mostly not important to safety [1], while small motors are used in both plant safety and production systems. Therefore, motors can be either important to safety or not important to safety.

Electrical motors operating inside or outside of the containment building may be exposed to radiation, elevated temperatures, and high humidity. Motors inside the containment may also be exposed to high vibration, containment spray, moisture impingement and/or submersion, high pressure, and other environmental stresses.

Motors on the conventional island may also face unique operating environments for example, they may be exposed to high temperature and humidity, water or chemical spray impingement, submergence, and vibration during operation. Motors of water intake structures pumps located adjacent to rivers, lakes or the ocean can be exposed to a humid and salty atmosphere throughout their service life, and the possibility of flooding exists in these locations.

Although the motors designed for NPPs are manufactured and tested for operation in the above mentioned environments but still with time, impact of operation and environment need to be monitored for safe operation to preserve their qualified status.

This programme addresses the motors ageing due to the above environments and operating conditions. Ageing of main components and subcomponents is considered in this programme, as all components may contribute to the ageing or failure of a motor.

All ageing management actions should be prepared according to the limitations, instructions, monitoring methods and tests defined in operation and maintenance documents, final manufacturing tests and commissioning reports by motor manufacturers and plant designers according to motor size and usage.

Regulatory guidelines and national/international good practices should also be considered where applicable or required for the AMP development and improvement.

Evaluation and Technical Basis

1. Scope of the ageing management programme based on understanding ageing:

This AMP applies to the motors, its subcomponents and support structures. This includes the stator, rotor, frame, shaft, bearings, motor housing, motor mounting, cooling air fans and filters, lubricating oil system, bearing cooling, stator and rotor cooling, terminations, component cooling lines at the machine, heaters, and instrumentation sensors.

Supporting equipment and associated equipment can influence or directly contribute to large motors failure and are therefore also be included in this AMP.

The most significant stressors which affect the motors are temperature, chemicals, steam, radiation, mechanical fatigue, humidity/water dripping, electromagnetic cycling, vibration and foreign object intrusion.

1. Preventive actions to minimize and control ageing degradation:

This is a condition monitoring programme and therefore no direct actions are taken as part of this programme to prevent ageing degradation. However, the operating instructions in particular the limited number of starts in defined time for MV motors, limitations and service conditions provided by the plant designer and manufacturer of the motors are to be followed as preventive measures to minimize and control ageing degradation. Main areas of preventive actions recommended by manufacturers are:

* Control and monitor the environment;
* Maintain winding insulation;
* Maintain bearings lubrication system;
* Control and monitor vibration.

These actions may be part of preventive maintenance, routine inspections, adjustments and condition monitoring test.

1. Detection of ageing effects:

Detection of ageing effects of squirrel cage induction motor can be possible by testing, monitoring and trending. Different parameters may be measured to detect the ageing mechanisms/degradation effects. These parameters include electrical (power, voltage, current), resistance (winding), mechanical (power, speed and slip), temperature (liquid thermometers, embedded/local detectors, resistance of winding) as per national or international practices. IEEE Std. 112- 2017 “IEEE Standard Test Procedure for Poly phase Induction Motors and Generators” [4] may be used for detailed testing and calculations instructions for motor health to detect ageing/degradation/failure. The sections below list the motor components and possible detection methods [1]:

* 1. Stator winding assembly

Stator winding assembly includes windings, laminated core, stator leads and coil cross-ties, and stator surge ring, blocks, spacers, and winding end supports. One of the components, which cause most of the failures, is the stator winding in induction motors and the major cause is insulation weakness or breakdown. Conditions which impact insulation life includes normal service temperatures, high temperature, high voltage, mineral or chemical particle/liquid contaminations, insulation damages due to mechanical shock, vibration, over speed, short-circuit, frequent starts, foreign materials and temperature cycling [3].

Loss of insulation of stator winding is possible due to the thermal degradation of insulation, mechanical loading, ohmic heating, surface contamination, vibration, chemical contaminations and electrical transients. Stator core heating may occur due to mechanical vibration of metallic laminations or degradation of organic materials/insulation of laminations.

Ageing/failure detection methods include comparative surge test, insulation resistance /polarization index, motor circuit analysis, internal visual inspection, AC hipot test, insulation power factor test, infrared thermography and partial discharge test.

* 1. Rotor core assembly

Rotor core assembly includes rotor core, squirrel cage assembly, shaft assembly, air cooling slots and spacers, and vanes.

Rotor heating may occur due to the mechanical vibration of metallic laminations and thermal degradation of organic materials used as insulation of laminations.

Ageing/failure detection methods include visual or borescope inspection, vibration monitoring, motor current signature analysis, static rotor test, infrared thermography, Growler test, shaft alignment check and Non Destructive Evaluation (NDE) techniques.

* 1. Bearings

It includes bearings, seals, and lubricating system (oil or grease).

Bearing failure may occur due to mechanical vibration, thermal cycling or elevated temperatures, moisture intrusion, surface contamination or chemical contamination in lubricant.

Ageing/failure detection methods include bearing temperature monitoring, vibration monitoring, bearing inspection, lube oil level, temperature, filtration monitoring, lube oil sampling and analysis, bearings and seals inspection, periodic check of lube oil system parameters (visual inspection, level, temperature, flow, periodic check of component cooling water(CCW) filter’s delta pressure and supply to lube oil heat exchanger. In case of greases, lubrication ageing/failure detection methods include vibration monitoring, temperature, bearing inspection, seals inspection, visual inspection of grease for its colour change or dust particles.

* 1. Motor frame, enclosure and mounting

It includes bearing supports, terminal box and connections, and ground connections.

Motor failure may occur due to the mechanical vibration and elevated temperatures of above components.

Ageing/failure detection methods include visual inspection, vibration monitoring, monitor winding temperature, monitor bearing temperature, polarization index check and motor circuit analysis.

* 1. Monitoring sensors and heaters

It includes stator winding and bearing Resistance Temperature Detectors (RTDs) or thermocouples, vibration monitoring, lube oil system monitoring instrumentation, and the motor space heaters.

Motor failure, loss of winding temperature indication or loss of vibration indication/alarm may occur due to the lack of continuity of sensor wires. Motor failure or loss of insulation may also occur due to the moisture intrusion if heater is faulty.

Ageing/failure detection methods include checking:

* loss of or faulty temperature indication channel;
* loss of or faulty vibration monitoring channel;
* loss of or faulty lube oil system indication or monitoring channel;
* space heater status indication;
* blown fuse etc.

1. Monitoring and trending of ageing effects:

Initial design conditions/parameters cover the service conditions for the motor. Monitoring and trending are required to verify that the actual service conditions do not exceed certain specific design parameters and that the motor is operated within design parameters.

Monitoring parameters are mentioned under Section 3 “Detection of ageing effects”. These parameters may be transmitted to indicators, recorders, alarms, or computer data acquisition systems. Following are some monitoring techniques [1] and trendable parameters/tests [2] which are used worldwide according to each Member State’s practices:

4.1 Infrared thermography

Infrared thermography detectors can be used to identify hot spots and images from periodic surveys of equipment that can be digitalized and electronically stored for future trending comparison and analysis.

Infrared thermography surveys of operating motors can be used to monitor the condition of motor connections, cables, external surfaces, heat exchangers, bearings, ventilation inlets/outlets, and couplings. It can detect high resistance connections due to corrosion, looseness, or dirt, clogged or dirty air filters, hot couplings, high bearing temperatures, or abnormally high current flows.

4.2 Motor current signature analysis (MCSA)

During motor operation the time dependent load variations, vibrations, and other periodic motor resonances are fed back to the line current as electrical noise. The MCSA technique can detect broken rotor bars, cracked rotor bars, cracked end ring, static and dynamic rotor eccentricity, bearing problems, and other cyclical loading problems.

The MCSA testing is simple to execute and it can be performed remotely from the motor, at the motor switchgear breaker or other points where the motor feeder cables can be accessed. The current data are collected and the motor's current signatures where they can be analysed and trended with the help of software for the analysis of the motor current signature spectra.

4.3 Motor circuit analysis (MCA)

This method uses precision measurements of motor phase to phase resistance, phase to ground resistance, motor coil inductance, and capacitance of each phase to establish baseline values for these motor parameters. Trending of the changes in these parameters over time can provide a tool for monitoring the condition of the motor. Imbalances in any of the motor parameters over time can be trended to monitor motor degradation.

* 1. Trendable parameters and tests

**System voltage:**Motor standards allow operation within a voltage range of rated motor voltage. Motor manufacturer also provides the operating voltage range of supply voltage. Operation on the low end of the range increases the temperature of the windings. Operation at the high end of the range reduces the temperature of most motors. An exception is low speed induction motors which can experience a high increase in magnetizing current at the higher voltage.

**Motor running current:** Measured current values are nameplate rated amperes or less, although motors with service factor ratings can operate to service factor levels. The three phase currents are required to be balanced within a few percent. Current pulsations at slip frequency can be an indication of broken rotor bars. Baseline currents are recorded at full unit load. Winding temperature is proportional to the running current. Thus, increased running current causes rise of winding temperature i.e. rise in winding temperature from its normal operational value (above the ambient temperature) to the higher value. Excessive winding temperature rise causes electrical insulation degradation.

**Speed:** Motor speed is measured and compared to rated motor speed or baseline motor speed to verify that the motor is operating within its rating. For induction motors, motor speed reflects motor load. As motor load increases, its speed of rotation decreases slightly.

**Bearing temperature:** For large motors, bearing temperatures may be measured by RTD, thermocouple or bulb type thermometer. For motors not equipped with devices, bearing temperature is measured by a portable thermometer on the outside of the bearing housings. Before considering the measurement, it is proposed to wait five times the time constant. High bearing temperature may be related to vibration, lube oil performance, grease deterioration or bearing deterioration.

**Winding temperature:** Large critical motors are usually equipped with RTDs to measure insulation temperature. It is important to monitor and trend the winding temperature with base line temperature and allowable limits. Winding temperature may be related to supply voltage, running current, speed, cooling air temperature, lack of cooling air due to the blocked air discharge and inlet openings.

**Insulation resistance:** It measures the condition of insulation between conductor and ground. Low values indicate moisture, dirt or damaged insulation. Test voltage should be higher than rated voltage, e.g. 500 V or 1000 V DC test for a 480 V motor, and 5 kV to 10 kV DC for a 4000 V motor. This test is applicable to both operating motors and motors in storage.

**Polarization index:** This test provides additional information on condition of insulation between conductor and ground (for motors rated to 4000 V and higher). Polarization index is the ratio of the insulation resistance for a ten minute test and that of a one-minute test. A ratio of 2 or higher indicates suitability for service. This test is used to determine if a winding is wet.

**DC spot:** Another test on condition of insulation between conductor and ground. This test is effective for motors rated to 4000 V and higher. It is also recommended on motors rated 575 V and less to determine if it is safe to apply the surge comparison test. IEEE [5] step voltage method is recommended because it controls the charging current in a uniform manner to allow the test operator to stop the test if indication of impending failure develops during the test. Trained operator should perform the test because of safety considerations and because of the possibility of causing a winding failure.

**Vibration:** Monitoring of vibration levels of an operating motor over a period of time can provide valuable baseline information on motor condition. Changes in vibration indicate bearing deterioration, misalignment, damaged parts, electrical imbalance, and other conditions which are associated with the rotation of the machine.

**Oil analysis:** Analysis of bearing oil can provide evidence that oil has correct properties, or that deterioration of lubricating properties has taken place. Also, bearing babbitt particles may indicate development of bearing failure or cooler leak.

**Grease analysis:** Analysis of grease can provide evidence of deterioration of lubricating properties as shown by hardening, chemical breakdown or excessive amount of dirt.

**Winding resistance (including feeder cables):** Using a Kelvin bridge which is more accurate than a Wheatstone bridge, resistance measurement can detect high resistance connections before they develop into a connection or winding failure. This also will identify imbalances between phase windings.

**Ultrasound:** Changes in ultrasonic frequency from 24 kHz to 50 kHz in a bearing give warning of bearing deterioration long before such indicators as temperature and low vibration levels increase.

* 1. Motor diagnostic software

Different software is available in the market for motor diagnostics. Computers are used to automate the data collection process, digital processing of the results, analysis, comparison, and digital storage of the information. The trending of motor data is greatly enhanced by using computers and the analytical software available in these diagnostic packages and can serve as a useful tool for ageing and predictive maintenance in nuclear plants. Data may include voltage, running current, speed, bearing temperature, winding temperature, insulation resistance and vibration. Other parameters depend upon the manufacturers.

1. Mitigating ageing effects:

To mitigate the detected ageing effects of motors which are within the acceptance criteria specified in the relevant documents, the following actions may be taken, if appropriate:

* 1. Stator winding assembly

Ageing effects on stator winding assembly can be mitigated by the actions listed below:

* Motor cleaning;
* Maintaining ventilation clearance and unrestricted flow;
* Use of surge capacitors;
* Maintaining good operating practices to reduce number of start-ups;
* Monitoring and trending vibration;
* Monitoring and trending of ambient temperature, winding temperature, process fluid temperature, motor amperes, rpm, process fluid temperature cooling water temperature;
* Monitoring and trending insulation condition parameters;
* Consider upgrading to higher insulation class on next rewind;
* Performing periodic internal or bore scope inspection;
* Improving quality of station electric power.
  1. Rotor core assembly

Any detected ageing effect in rotor core assembly may be mitigated by trending of the following parameters to keep control and observe the rotor related issues:

* Periodic visual or borescope inspection;
* Periodic infrared thermography surveys and trending;
* Monitoring and trending vibration;
* Monitoring and trending motor amperes, rpm, winding temperature;
* Monitoring and trending bearing temperature;
* Precision alignment and balancing.
  1. Bearings

Bearings are the important part of the motor which give response in case of any mechanical issue of the motor. These responses arise in form of vibration and rising temperature of bearing. Another cause of bearing ageing/failure is insufficiency, poor quality, and loss of cooling system of lube oil. Following are the mitigating actions for any detected ageing issues which may cause degradation of the bearing:

* Periodic inspection and cleaning of bearings;
* Monitoring and trending vibration;
* Monitoring and trending bearing temperature;
* Good maintenance practices, procedures, and training for bearings and lube oil system;
* Periodic inspection of bearings and seals;
* Periodic replacement of bearing seals;
* Periodic maintenance of lube oil system including visual inspection, lube oil sampling and analysis, oil change, and oil filter change;
* Periodic maintenance of CCW supply to motor including visual inspection, flow rate and functional check, heat exchanger inspection, clean/change screens or filters.
  1. Motor frame, enclosure and mounting

Mitigating actions for motor frame, supports, terminal box and connections, and ground connections are important for safe operation of motor from mechanical point of view. These actions may include:

* Periodic visual inspection;
* Monitoring and trending vibration;
* Good maintenance, modification, installation, practices, procedures and training;
* Monitoring and trending stator winding temperature;
* Monitoring and trending bearing temperature;
* Good housekeeping practices.
  1. Integral monitoring sensors and heaters

Integral sensors are vibration, temperature and lube oil level related sensors which collect the data from motors and display or record for trending, where required. Availability and functionality of these components are very important. Mitigating actions include:

* Periodic channel calibration and functional tests;
* Repair or replace faulty RTD circuits;
* Repair or replace faulty vibration monitoring circuits and recorders;
* Repair or replace faulty monitoring circuits, indicators, and recorders;
* Periodic heater and thermostat calibration and functional tests.

1. Acceptance criteria:

Acceptance criteria for all motor tests, monitoring parameters and their limitations are defined by the manufacturers, plant designers, national/international codes and standards. The results of the tests and monitoring parameters trending are compared with previous results to identify a possible degradation trend and with the basic design/operational data for deviation measurement from initial conditions of the motor. If all results are within acceptance criteria but the trending shows degradation then mitigating actions mentioned above may be adopted accordingly.

1. Corrective actions:

Corrective actions are required when the acceptance criteria are not met. With reference to *“Detection of ageing effects”*, corrective actions may be taken to resolve the issues/ageing/degradation/failure if the detected parameters do not meet the acceptance criteria set by the plant for each individual motor.

These actions may include

* Preventive/corrective maintenance;
* Replacement or modifications as per plant procedures;
* Performance analysis to examine if the ageing affects the safety function criteria required by the Current Licence Basis;
* Reliability centred maintenance (RCM) may be followed by integrating preventive maintenance, predictive maintenance or corrective maintenance as per plant procedures in a balanced approach to avoid the motor ageing or failure. [2]

After any electrical test, vibration measurement or visual inspection, if a deviation or problem occurs which cause the motor parameters to cross the limits of acceptance criteria, then it becomes necessary to replace the motor components or replace the motor whichever is feasible. Components that may need refurbishment or replacement are as follows:

* Winding coils;
* Insulation (varnish, rebake, replace with higher class e.g. Class F);
* Space heaters;
* Bearing and restoration of fits and seals (antifriction bearings, sleeve bearings or journal bearing);
* Gaskets;
* Collector rings;
* Electrical connections in junction box.

Alignments/balancing of a rotor shaft is one of the important actions that can be considered to avoid vibration and other issues. Damaged or worn sleeve bearings can be re-babbitted. Journals can be lapped to assure trueness. End-bell to frame fits may need to be renewed as well as antifriction bearing to end-bell fits.

1. Operating experience feedback and feedback of research and development results:

This AMP addresses the industry-wide generic experience. Relevant plant-specific operating experience is considered in the development of the plant AMP to ensure the AMP is adequate for the plant. The plant implements a feedback process to periodically evaluate plant and industry-wide operating experience and research and development (R&D) results, and, as necessary, either modifies the plant AMP or takes additional actions (e.g. develop a new plant-specific AMP) to ensure the continued effectiveness of ageing management.

At the time when this AMP was produced, no relevant R&D was identified.

1. Quality management:

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national regulatory requirements, e.g. [6].

References

[1] UNITED STATES NUCLEAR REGULATORY COMMISSION, Aging Assessment of Large Electric Motors in Nuclear Power Plants, NUREG/CR-6336, USNRC, 1996

[2] ELECTRIC POWER RESEARCH INSTITUTE, Electric Motor Predictive and Preventive Maintenance Guide, EPRI, Palo Alto, CA: NP-7502

[3] INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS,IEEE Guide for Insulation Maintenance of Electrical Machines (35 kVA and above), IEEE Std. 56-2016

[4] INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS,IEEE Standard Test Procedure for Polyphase Induction Motors and Generators, IEEE Std. 112-2017

[5] INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS, IEEE Recommended Practice for Insulation Testing of AC Electric Machinery(2300 V and Above) with High Direct Voltage, IEEE Std. 95- 2002

[6] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Processing Plants, Office of the Federal Register, National Archives and Records Administration, USNRC, 2015