ELECTRIC MOTORS FOR HAZARDOUS AREAS MUST MEET THE ELECTRICAL SAFETY AND OTHER REQUIREMENTS FOR INDUSTRIAL EQUIPMENT

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Abstract – Electric motors when installed in Class I, Division 1 / Zone 1 or Class I Division 2 / Zone 2 locations, are not only meeting the specific design requirements of applicable industry standards of hazardous locations but also of non-hazardous locations to establish basic safety guidelines. These may include some requirements of reliability, performance, and other requirements as established by the applicable industry standards for non-hazardous locations. When those motors are approved by applicable NRTLs (Nationally Recognized Testing Laboratories) or CBs (Certification Body), they assume that the electrical safety requirements are met voluntarily or be approved depending upon local country codes/regulations. In this paper, the authors would like to identify the key differences between the requirements of hazardous locations and non-hazardous locations for the benefit of end users and others as applicable.

Index Terms — Motors, safety, NRTL, CB, IEC, rotor, stator, SCC, Class, Zone, NEC, CE Code

I. INTRODUCTION

When electric motors are manufactured, they are assessed for meeting many requirements at the design stage apart from meeting customer requirements. These requirements may include reliability, performance, electrical safety, mechanical operational safety, environmental safety, and many more. Electrical safety and mechanical safety are the prime concern for an electric motor to operate safely in any industry where it is installed, irrespective of specific process such as mining, hazardous location of oil and gas industry, pulp, and paper etc. We consider the basic requirements to be met for industrial equipment in non-hazardous locations, which are sometimes referred to as ordinary locations, safe locations, or unclassified locations. The electrical safety requirements, along with other requirements, are explained further in the paper.

There are many other requirements to be met besides the general industrial requirements for motors operating in hazardous locations. The mitigation of the risk of explosion in a hazardous location is based on an assessment of the design against the fire triangle as explained in IEEE Std 1349 [1] standard. An explosion can take place when a mixture of all three elements is present. Those elements are an oxidizer (air with oxygen), flammable / explosible materials, and an ignition source. Many protection techniques have been developed to control these aspects in electric motors. Motors during operation could produce hot surfaces or produce arcs and sparks. Either of these could become the ignition source for an explosion. To mitigate this risk, motors are either inherently designed to limit hot surfaces and arcs / sparks by design, or by an enclosure-based technique. Enclosure-based techniques such as an explosionproof enclosure or a purged and pressurized enclosure can be applied. The authors will not cover or discuss these protection methods in this paper since many papers in the past have discussed on this topic [2]. We will limit the discussion to electrical safety along with other requirements.

Motor construction is discussed for the major components of motor to explain how safety is maintained at the design stage. To standardize on electrical safety and other requirements, various mandatory and voluntary standards have been developed to detail minimum requirements for motors. Electrical safety is generally mandated through regulations in most countries. Other safety related requirements are addressed through industry standards or by following sound engineering practices developed by manufacturers. The applicable various industry standards are discussed further under the sections on codes/regulations and standards. The selection of the right motor for the location or installation site is also important in terms of power supply, starting method, and enclosure selection to suit the environment, etc. Installation practices, with respect to local codes and standards, along with the maintenance of motors as specified by manufacturer must be followed.

Basic electrical safety concerns must be addressed when motors are installed in an industrial location to run a specific process safely. When a motor fails to operate for its intended purpose, it may create safety hazards for personnel operating the processes. When equipment is developed, many safety aspects along with many other requirements are considered at the design stage. The following safety topics are discussed in this paper for electric motors operating in any industry:

- Electrical Safety
- Mechanical safety
- Environment safety
- Performance / operational safety

II. SAFETY ADDRESSED AT CONSTRUCTION

The construction details of motors operating in an explosive atmosphere as explained in this paper must also meet the requirements of general industrial locations as well. Safety can be considered at three levels of motor operation:

- at continuous steady state load operation
- during malfunction or premature failure of equipment
- during catastrophic failure of equipment.

Catastrophic failure is beyond the scope of design of the motor; therefore, the paper will limit discussion to first two levels of motor operation and their safety concerns.

A typical view of a large, medium, or high voltage, weather protected (WP) induction motor is provided below in Fig. 1.

Fig. 1 Typical WP Induction Motor

A typical construction of low voltage, cast iron totally enclosed fan cooled (TEFC) motor is shown in Fig. 2 below.

Fig. 2 TEFC Cast Iron Frame Motor

Safety related concerns are addressed further in the details at component level.

A. Electrical Safety:

Electrical safety is further broken down at the component level:

1) *Low Voltage Stator Winding:* Low voltage motors as shown in Fig. 2 are typically operated with polyphase electric ratings of 230 V / 460 V / 575 V. These motors have random wound windings as shown in Fig. 3.

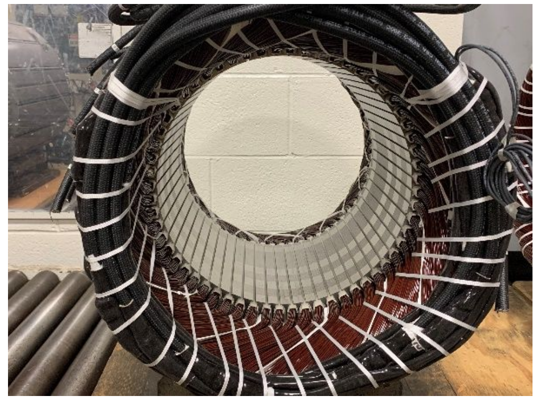

Fig. 3 Random Wound Stator

In general, they are insulated using either Class 130 (B) or Class 155 (F) insulation as explained in NEMA MG-1 [3]. Each class of insulation specifies the maximum temperature that is allowed during continuous operation at rated load, Class 155 (F) can handle higher temperature than Class 130 (B). It is a rule of thumb that if a motor operates 10 K higher than allowed by that specific class of insulation then its life reduces to half and therefore correct selection of motor is necessary for reliable operation of the motor. In this case, select a motor with a higher rated output rather than a motor with a 1.15 Service Factor (SF).

Proper electrical spacings are very important for the safety of personnel since breakdown of an insulation material is inversely proportional to the distance between live part and ground as explained in the equation below.

$$E = V/d \tag{1}$$

Where:

E	electrical stress
V	voltage across the metal plate or conductor
d	distance between the plates or conductor

2) *Medium or High Voltage Stator Winding:* Medium voltage or high voltage motors shown in Fig. 1 are typically operated with ratings from 2.4 kV to maximum 13.2 kV. These motors typically have a form wound stator winding as shown in Fig 4.

Fig. 4 Form wound stator with ETD

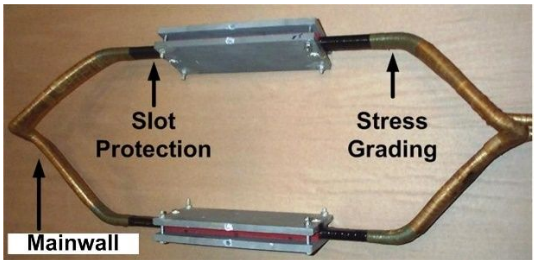

Fig. 5 Grading / Slot Protection Tapes

Special bracing and blocking of end windings as shown in Fig. 4 is specifically designed to handle the short circuit torque be developed in motor and to minimize vibration at the overhang of end winding which could contribute to winding failure if not supported. The windings are designed to handle higher surge voltages at the interturn of coils. Special turn insulation is incorporated for motor winding to handle higher voltage peak surges from the switching frequencies developed from an adjustable speed drive (ASD).

To minimize corona and partial discharge (PD) activities, special stress grading and grounding tape are applied in the slot and over the main wall winding as shown in Fig. 5. Creepage and clearances distances between two phases and ground are maintained depending upon rated voltage of motor. Larger distances are maintained with respect to ground in order to pass dielectric withstand tests to provide for the safety of personnel. If embedded temperature detectors (ETD) are provided in between two coils in a stator slot as shown in Fig.4, they must withstand dielectric tests to provide for the safety of personnel managing monitoring devices.

3) *Accessories: Accessories such as anti-condensation heaters:* Large fabricated frame motors, or motors operating in harsh or humid environment, are typically equipped with anti-condensation heaters as shown in Fig. 6. They are installed with proper electrical spacings, confirmed by a dielectric withstand test.

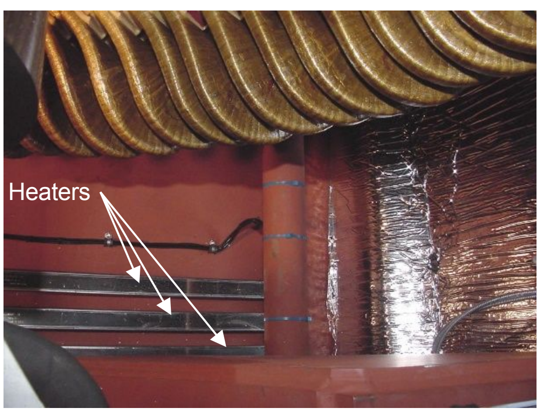

Fig. 6 Anti-Condensation Heaters Installed Inside the Frame

4) *Terminal Enclosure:* Terminal enclosure or box of medium and high voltage motors using busbars is shown in Fig. 7. The terminal enclosure can also include lightning arresters, surge capacitors, current transformers, etc.


Fig. 7 Terminal Enclosure

Correct clearances and creepage distances are important for the safety of personnel. The NEMA MG-1 [3] and other industry standards provide minimum electrical distances to be maintained between live parts and phases.

B. Mechanical Safety

Mechanical safety is assessed at each component as discussed below:

1) *Enclosure Safety*: The enclosure of the motor is typically made out of cast iron, as shown in Fig. 2, or uses a fabricated frame, as shown in Fig. 1, to hold all rotating parts inside the frame including all other associated components such as bearings and terminal boxes. Proper mechanical strength of the frame and rigidity are important. The strength can be calculated and validated by tests such as impact tests or pressure tests. Special cast iron properties are required for low ambient temperatures to provide the necessary strength. The enclosure is also designed to withstand allowed resonances at operating speeds due to vibration or in some cases to provide a lower resonating sound level leading to a lower sound pressure level.

2) *Bearing Selection*: Safe operation of a motor during the intended life span, depends on correct bearing system selection. Selection of the right anti-friction or sleeve bearings is important to be able to run the motor continuously while handling the intended load at the intended speed. Vertically oriented motors have special thrust bearings designed to support that vertical thrust. Proper lubrication to meet the intended environmental conditions must also be considered.

3) *Material Selection:* Safe operation of a motor depends on the proper material selection for the motor including enclosure material as addressed in 1) above, rotor or stator laminations, rotor copper bars, end ring or shorting ring material, etc.

4) *Rotating Shaft*: Shaft material selection to withstand the intended operating load at the intended speed is also important. A critical speed study is often performed to confirm safe operation with the intended load. Special applications such as high-speed compressor, reciprocating compressor etc. may require a special study. The shaft is also designed to handle peak torques developed during a short circuit of motor with extra safety margins.

C. Protection from Adverse Environmental Conditions

Safe operation of motor depends upon the proper selection of the enclosure for the intended environment. Motors can be installed indoors or outdoors and must be selected to suit the intended environmental conditions. Indoor locations are generally cleaner with respect to airborne dust, moisture, extreme ambient temperatures, etc. Therefore, open types of enclosures are often selected for indoor installations. Outdoor locations could have more extreme environmental conditions compared to those mentioned above, and a totally enclosed enclosure is often a better selection. Some weather-protected enclosures, such as WP II (Weather protected), are used for outdoors. In some cases, motors can be operated in harsh lower ambient temperature conditions such as minus 30 °C and below. In such cases, selection of the enclosure material is important.

D. Performance safety / Operational Safety

Safe motor operation is dependent on the performance of the motor in meeting the intended mechanical loading of the driven load. The performance of motor, as a minimum, includes the following unless other special conditions warrant:

- Operating at rated load or a service factor load
- Accelerating load to the rated speed without exceeding thermal limits of components specifically rotor bars/windings
- Limiting the number of allowed starts
- Ventilating adequately to not exceed the maximum temperature for the insulation class
- Limiting the allowable critical speeds/vibrations of rotating components
- Limiting the noise level across the operating speed range
- Operating from an Adjustable Speed Drive (ASD) within the speed range / load specified
- Withstanding a specified dielectric breakdown test to further confirm proper electrical insulation

Once the fully assembled motor is available, all of the above performance and operational limits are typically validated by test.

III. ASSESSMENT / VALIDATION

A. Assessment

An assessment is typically performed at the design stage before the motor is released for manufacturing. This assessment may include all aspects of the motor as discussed above. For mass production motors, the prototype of that particular design is assessed. A large custom motor is assessed for every design.

The assessment typically addresses the following areas:

- Verification of conformity to the motor specification supplied by the end user
- Verification of performance
- Verification of special requirements such as shaft critical speed study, sound level requirement, etc.
- Verification of compliance with specified industry standards such as IEEE Std 841 [4], API Std 546 [5], API Std 541 [6], API Std 547 [30], etc.
- Verification of electrical requirements such as insulation system, temperature rise at various specified ratings, winding selection, terminal box connections, approved accessories supplied with motor and many more
- Verification of electrical safety standards such as UL 1004-1 [7] for US or CSA C22.2 No. 100 [8] for Canada

B. Validation

Validation of a design is typically performed in two stages. The first is, in process during manufacturing, and second is, after completing the final assembly of a motor. In process validation is to meet customer requirements specified in the contract and other manufacturer’s requirement. Most of the validation at final assembly are to meet regulatory requirements mandated by the applicable codes and standards.

In process validations may include:

- Surge test of windings as specified in API 541 [6], API 546 [5], IEEE Std 841 [4], API Std 547 [30], etc.
- Coil dissection / VPI penetration test as specified in API standards
- Verification of correct Phase winding connections once motor is wound
- Winding resistance measurement on each phase to validate balanced windings
- Reduced voltage dielectric test on wet windings to avoid ground fault after varnishing or VPI (vacuum pressure impregnation)
- Water spray or water sealed test after VPI as specified by API or NEMA industry standards
- Rotor dynamic or rotor balancing test at full or partial speed depending upon the design or any manufacturing limitations
- Rotor winding impedance test to confirm correct connection of each pole of a synchronous motor rotor along with measuring resistance of each pole
- Exciter winding tests for a synchronous motor
- Power factor tip-up test of winding
- PD test of winding
- Welding checks of a fabricated frame
- Unwound core integrity or core loss test, if specified

Depending on the intended location, final Assembly tests to meet either UL 1004-1 [7] for US or CSA C22.2 No. 100 [8] for Canada.

The tests at final assembly are either type tests on a prototype or routine tests on serial production. Most of the tests identified below are safety related tests as specified in mandatory standards such as UL 1004-1 [7] for USA, or C22.2 No. 100 [8] for Canada. Test procedures are standardized in IEEE Std 112 [9] and IEEE Std 115 [10], as applicable. API standards may specify extra tests. A typical final assembly set up is shown Fig. 8 below.

Fig. 8 Test Setup at Final Assembly

Typical final assembly inspection and testing may include:

- Visual check to validate design as specified on the approved drawing by end user or by designer
- Impact test of cast frame or fabricated frame
- Temperature rise test to validate rating of motor and its insulation class
- Acceleration test to validate speed-torque performance and inrush current
- Locked rotor torque test to validate locked rotor torque and current
- Break-down torque test to validate maximum developed torque
- Noise test or sound power test
- Direction of rotation of motor test
- Ingress Protection (IP) test
- Winding resistance check for each phase
- Polarization Index (PI) test of winding
- Vibration test to validate allowed vibration along with critical speed validation
- Over-speed test of rotor
- PD tests
- After performing all above tests, the final validation test is a dielectric breakdown test of the stator winding and, in case of synchronous motor, of the rotor
- Safety and warning markings check as applicable

IV. CODES / REGULATIONS / STANDARDS

A. Regulatory Requirements – US

In the workplace, electrical safety is regulated by the Occupational Safety and Health Administration (OSHA) under the federal Department of Labor (DOL). The fundamental requirement is from Section 1910.303(a) from 29CFR (Title 29 of the Code of Federal Regulations) [11] is that all electrical equipment be "approved" as defined by Section 1910.399.

Approved:

(1) If it is accepted, or certified, or listed, or labeled, or otherwise determined to be safe by a nationally recognized testing laboratory (NRTL) recognized pursuant to Section 1910.7;

(2) With respect to an installation or equipment of a kind that no nationally recognized testing laboratory accepts, certifies, lists, labels, or determines to be safe, if it is inspected or tested by another Federal agency, or by a State, municipal, or other local authority responsible for enforcing occupational safety provisions of the National Electrical Code, and found in compliance with the provisions of the National Electrical Code as applied in this subpart.

(3) With respect to custom-made equipment or related installations that are designed, fabricated for, and intended for use by a particular customer, if it is determined to be safe for its intended use by its manufacturer on the basis of test data which the employer keeps and makes available for inspection to the Assistant Secretary and his authorized representatives.

Most motors used in the petrochemical industries fall into either (1) or (3). Smaller motors are generally available with an NRTL Listing with the electrical safety compliance documented as part of the Listing. Most larger motors fall into the "custom" category of (3) with the electrical safety examination and test data conducted by the motor manufacturer and provided to the end user.

B. Regulatory Requirements – Canada:

In Canada electrical safety is regulated by the Provinces and Territories. All electrical equipment is required to be Approved, generally by a Certification Body (CB) recognized by the Standards Council of Canada (SCC). If the electrical product is not certified by a CB, it will be required to be subjected to a Field Evaluation, generally in accordance with SPE-1000 [12].

C. Installation documents – US:

National Electrical Code (NEC), NFPA 70 [13]

For Class I, Division 1 or Zone 1 applications, an NRTL Listing will generally be required.

For Class I, Division 2 or Zone 2, there are special permissions in the NEC, Section 501.15(B) or 505.20(C) Exception 4, as applicable, to allow non-hazardous location motors to be assessed by the end user for their suitability in that location. Guidance is provided in IEEE 1349 [1] and UL 1836 [14].

D. Installation documents – Canada

Canadian Electrical Code (CE Code), CSA C22.1 [15]

For Class I, Division 1 or Zone 1 applications, a Certification from an SCC accredited CB will be required.

For Class I, Division 2 or Zone 2, there are special permissions in the CE Code, Section 18-150e) and J18-150 e), as applicable, to allow non-hazardous location motors to be assessed by the end user for their suitability in that location. Guidance is provided in IEEE Std 1349 [1] and UL 1836 [12].

E. Product Safety Standards:

These are generally focused on the following aspects:

- Mechanical construction
- Grounding / bonding
- Field wiring connections
- Electrical spacings
- Insulation system
- Rating confirmation
- Temperature rise
- Environmental protection

1) *US Standards:*

a) *Non-Hazardous Locations:*

- UL 1004-1, *Rotating Electrical Machines – General Requirements* [7]
- UL 1004-8, *Inverter Duty Motors* [16]
- UL 1004-9, *Form Wound and Medium Voltage Rotating Electrical Machines* [17]

b) *Class I, Division 1 Hazardous (Classified) Locations*

- UL 674, *Electric Motors and Generators for Use in Hazardous (Classified) Locations (Explosionproof)* [18]
- NFPA 496, *Purged and Pressurized Enclosures for Electrical Equipment* [19]

c) *Class I, Division 2 or Zone 2 Hazardous (Classified) Locations (If NRTL Listing for the location is required by the end user):*

- UL 1836, *Outline of Investigation for Electric Motors and Generators for Use in Class I, Division 2, Class I, Zone 2, Class II, Division 2 and Zone 22 Hazardous (Classified) Locations* [12]
- UL 60079-0, *Explosive Atmospheres – Part 0: Equipment – General Requirements* [20]
- UL60079-7, *Explosive atmospheres – Part 7: Equipment protection by increased safety "e"* [21]

d) Zone 1 Hazardous (Classified) Locations:

- UL 60079-0, *Explosive Atmospheres – Part 0: Equipment – General Requirements* [20]
- UL60079-1, *Explosive Atmospheres – Part 1: Equipment Protection by Flameproof Enclosures "d"* [22]
- UL60079-2, *Explosive Atmospheres – Part 2: Equipment Protection by Pressurized Enclosure "p"* [23]
- UL60079-7, *Explosive atmospheres – Part 7: Equipment protection by increased safety "e"* [21]

2) *Canadian Standards:*

a) *Non-Hazardous Locations:*

- C22.2 No. 100, *Motors and Generators* [8]

b) *Class I, Division 1 Hazardous Locations:*

- CSA C22.2 No. 145, *Electric Motors and Generators for Use in Hazardous (Classified) Locations (Explosion-proof) [24]*
- NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment [19]*

c) *Zone 1 Hazardous Locations:*

- CSA C22.2 No. 60079-0, *Explosive Atmospheres – Part 0: Equipment – General Requirements* [25]
- CSA C22.2 No. 60079-1, *Explosive Atmospheres – Part 1: Equipment Protection by Flameproof Enclosures "d"* [26]
- CSA C22.2 No. 60079-2, E*xplosive Atmospheres – Part 2: Equipment Protection by Pressurized Enclosure "p"* [27]
- CSA C22.2 No. 60079-7, *Explosive atmospheres – Part 7: Equipment protection by increased safety "e"* [28]

d) *Class I, Division 2 or Zone 2 Hazardous Locations (If Certification for the location is required by the end user)*

- UL 1836, Outline *of Investigation for Electric Motors and Generators for Use in Class I, Division 2, Class I, Zone 2, Class II, Division 2 and Zone 22 Hazardous (Classified) Locations [14]*
- CSA C22.2 No. 60079-0, *Explosive Atmospheres – Part 0: Equipment – General Requirements* [25]
- CSA C22.2 No. 60079-7, *Explosive atmospheres – Part 7: Equipment protection by increased safety "e"* [28]

F. Industry Standards: These are generally focused on application issues beyond the basic electrical safety requirements.

- IEEE Std 303, *Recommended Practice for Auxiliary Devices for Rotating Electrical Machines in Class I, Division 2 and Zone 2 Locations* [29]
- IEEE Std 841, *Premium-Efficiency, Severe-Duty, Totally Enclosed Squirrel Cage Induction Motors from 0.75 kW to 370 kW (1 hp to 500 hp)* [4]
- IEEE Std 1349, *Guide for the Application of Electric Machines in Zone 2 and Class I, Division 2 Hazardous (Classified) Locations* [1]
- API Std 541, *Form-wound Squirrel Cage Induction Motors—375 kW (500 Horsepower) and Larger* [6]
- API Std 546, *Brushless Synchronous Machines - 500 kVA and Larger* [5]

- API Std 547, *General Purpose Form-wound Squirrel Cage Induction Motors-185 kW (250 hp) through 2240 kW (3000 hp)* [30]

V. END USERS PROSPECTIVE

The safety of electrical motors starts at the conception of a motor application, and continues to the end of its life, irrespective of whether it is in a hazardous area or not. This section will discuss items to consider during procurement, installation, and maintenance. Almost every item is executed regardless of the location of the installation in a petrochemical facility. A typical photo of a motor in a petrochemical refinery is provided below in Fig. 9.

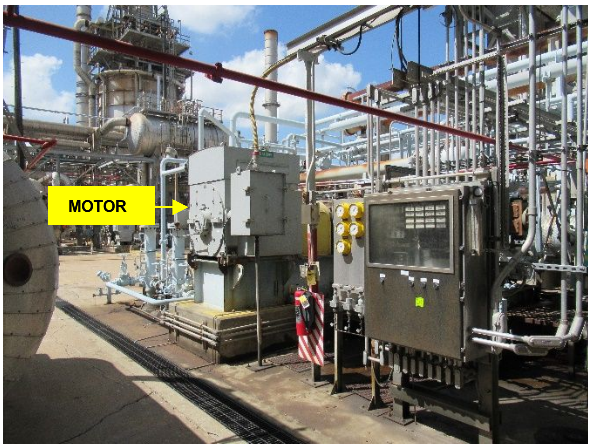

Fig. 9 Typical Refinery Installations

A. *Procurement*

Once it is determined that a motor needs to be procured, the applicable IEEE Std 841 [4], API Std 541 [6], API Std 546 [5], or API Std 547 [30] data sheets should be filled out and sent to the vendor. Two important items to specify on the data sheets, in particular to safety for the installation is if the motor will be located in a hazardous or non-hazardous location, and the temperature class (T-code) required. In hazardous locations, it may be necessary to oversize the motor to achieve the necessary temperature limitation.

B. *Installation Safety*

A major part of motor safety depends on how it is installed. This takes place in several pieces through design, relay protection settings, testing, and inspection.

1) *Design:* Properly bond the motor case to the grounding grid, and motors that have two-piece enclosures should be supplied with bonding jumpers to prevent sparking. It is often practical to install viewing windows on the motor terminal box to allow for infrared (IR) inspections during motor operation. For high priority motors, consider the installation of an "on-line testing package" that reads signals from the CTs and PTs. Power the anti-condensation heaters from a separate power source so they can be energized while the motor is locked out, but make sure to put a sign on the Motor and on the Motor Control Center (MCC) door that two sources of power are present. If there are any problems with voltage drop, a captive transformer, soft starter, or ASD may be a solution. Lastly, a "management of change" procedure should be followed through to have all aspects of the design examined by more than just the electrical team.

2) *Protection Relay Settings:* Relays are installed to protect the motor and minimize damage. There are many settings to program including, locked rotor, overload, motor differential, Embedded Temperature Detectors (ETD) alarms, and temperature differential alarms. In addition, relays are programmed to prevent too many motor starts per hour. This is typically two starts in succession (coasting to rest between starts) with the motor initially at the ambient temperature or one start with the motor initially at a temperature not exceeding its rated load operating temperature (NEMA MG1 [3]). Certain motor-operated valves (MOV) used in emergency isolation and shutdown should not have overload protection, nor should separate overcurrent protection be provided for their control power transformers or control circuit conductors. The hazardous location certification for some MOVs may require that any thermal protection not be bypassed in order to maintain the hazardous location rating, particularly the temperature class, of the MOV. The user will often make a risk assessment and decide that defeating the thermal protection results in a less significant consequence than not being able to operate the valve in an emergency shutdown situation.

3) *Testing:* There are many tests to be performed on the motor before it is put in service. At a minimum, the typical tests consist of measuring the insulation resistance of the windings, hipot testing of larger motors, and calculating the polarization index (PI) and comparing to the factory test value to use as a baseline. PI is a calculated value which indicates the relative condition of the motor winding insulation. This value is calculated by dividing the insulation resistance megohm reading obtained after 10 minutes by the reading after 1 minute. A typical value is about 2.0. In no case should a PI be less than 1.0 (NETA MTS [31]).

4) *Inspection:* Lastly, many items require somewhat simple checks or verification. These include validating bearings have proper lubrication, that the shaft can be turned by hand or barred to ensure it is free to rotate, inspect and test any surge protection devices, verify anti-condensation heater operation, and verify any air filters are installed. In addition, bump the uncoupled motor to determine the rotation. Then run it for a period of time to check for unusual conditions such as vibration, noise and excessive winding or bearing temperature rise. Measure the running current and compare it to the nameplate full-load. Motor starts for testing should be kept to a minimum. Do not exceed the nameplate starting duty of the motor.

C. *Maintenance Safety*

Motor safety does not end once it is in operation. There are many things to do throughout its life to properly maintain it, especially for critical motors as typically shown in the Fig. 10 below.

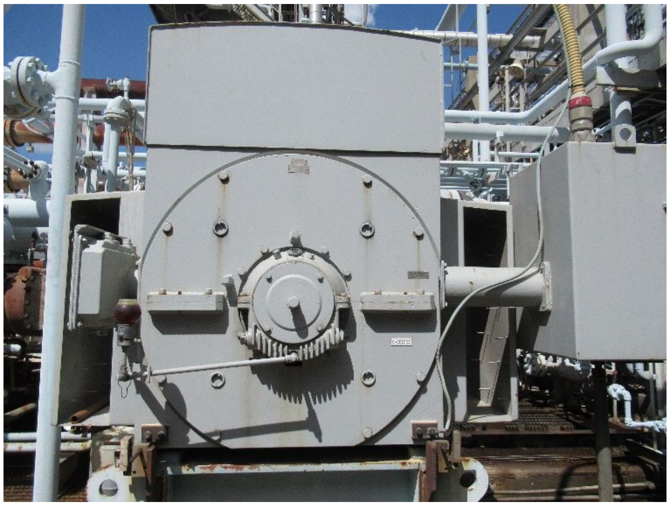

Fig.10 Critical motor operation

A critical motor is a motor that is very important to a production unit, for production, safety, and/or environmental purposes. This type of motor warrants additional preventative maintenance (PM) and monitoring over other motors in a plant. Large motors are generally considered to be rated at 1000 hp or above.

1) *Motor Starter and Controls:* Inspect, test, lubricate, and adjust the contactor, perform an IR scan of all control section components, test and calibrate protective relays, test and inspect annunciation alarming, function test trips and alarm points by simulating actual conditions and verifying circuitry is intact to cause the relay to actually trip the machine and perform a circuit breaker trip test.

2) *Relays:* Every three years download the native settings file and motor operating statistics, review all new event records, and review the sequence of events for the past month. Every six years perform meter accuracy checks, verify ETD measurements, and perform a function test of all active elements such as pickup, time, and alarms.

3) *Motor Cables*: Perform partial discharge testing of shielded cables rated above 5 kV and perform insulation resistance testing for cables rated 5 kV and below.

4) *Captive Transformers:* Test per site's typical transformer tests.

5) *Motor Terminal Box:* Test and inspect anti-condensation heaters, surge capacitors, surge arrestors, current transformers, and visually check motor lead connections, insulation, insulators, ground connections, and bus supports.

6) *Bearings:* Have a motor lubrication program to either grease bearings, change oil, or conduct appropriate PM on the lubrication system, as appropriate. This program should have sufficient detail to avoid over-greasing motors which can reduce the bearing life.

7) *Filtered Air System:* If there is one; test and inspect the blower motor, clean and inspect the filter housing, and clean and replace the filter elements.

8) *Temperature:* For winding and bearing temperature trends and alarms, design the winding temperature devices to be monitored online.

9) *Partial Discharge Detection:* Can be online or periodic.

10) *Vibration analysis:* online is preferred but can be periodic.

11) *IR Scanning:* Perform IR scanning of motor junction boxes and connections.

12) *Additional PM's:* Conduct phase-to-phase resistance test and phase-to-phase induction test on stator windings, rotor influence test, capacitance test, temperature compensated insulation resistance test, dielectric absorption, and PI tests.

13) *Field Inspection:* Perform every five years if it is not feasible to send the motor to a repair shop for reconditioning. This should include dropping the end bells and visually checking windings, rotor, end rings, and air gap. Inspect the machine for moisture, dirt, oil ingestion, loose material and a check of overall external motor condition.

14) *Shop Inspection:* If you can send it out to a shop, do all of the above field inspections at the shop, plus replace antifriction bearings, steam clean, heat to drive out moisture, dip in a Class F insulation system, no load electrical testing, and anything else as recommended by the motor repair shop.

15) *Insulation Resistance Test:* Perform this test before starting a motor that has been shut down for 24-48 hours, or 4 hours if raining. Low voltage motors should typically measure at 100 megohms or higher, and medium or high voltage motors should measure 500 megohms or higher depending on the nominal voltage (NETA MTS [31]).

VI. CONCLUSION

Safety concerns can arise during normal operation, at a premature failure, or with a catastrophic failure of a motor. This paper has shown how those safety concerns can be taken care at design stage by selecting right material or component, unforeseen failure study, environment safety, operational related considerations and many more. These concerns are over and above the safety being addressed for motors operating in a hazardous area.

A manufacturer considers all aspects of safety in designing the motor and not all of those aspects may be covered by industry standards. However, industry standards are developed to specify minimum requirements to be followed and to be validated before shipping. UL 1004-1 [7] for US and CSA C22.2 No. 100 [8] are the industry standards to validate motors and generators for non-hazardous locations.

Unless it is a custom design with the electrical safety assessed by the manufacturer, it is mandated that it be approved by a NRTL (in the US) or CB (in Canada) for electrical safety. For Class I, Division 1; or for Zone 1; it is also mandated that it be approved by a NRTL or CB body for that location. For Class I, Division 2; or Zone 2, there are allowances for the user to make a determination of suitability for that hazardous location.

The end user's involvement with the motor does not stop once the motor is in service but is an ongoing process throughout the life of the motor, no matter of its location. The manufacturer needs to build a safe motor, but the end user needs to do the proper maintenance to help ensure the safety of the motor, which can also affect the safety of the people, and processes around it.

VII. REFERENCES

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[8] CSA C22.2 No. 100, *Motors and Generators*

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[11] 29CFR, *Title 29, US Code of Federal Regulations*

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VIII. VITAE

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