



IEEE Guide for the Application of Electric Machines in Zone 2 and Class I, Division 2 Hazardous (Classified) Locations

IEEE Industry Applications Society

Developed by the
Petroleum and Chemical Industry Committee

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STANDARDS

IEEE Guide for the Application of Electric Machines in Zone 2 and Class I, Division 2 Hazardous (Classified) Locations

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Petroleum and Chemical Industry Committee
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IEEE Industry Applications Society

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Abstract: Three-phase and single-phase ac synchronous and induction electric machines in ratings 0.18 kW (1/4 hp) and larger are covered in this guide. Primary emphasis is on the use of open or nonexplosionproof or nonflameproof enclosed machines in Zone 2 and Class I, Division 2 locations as covered in the *NEC*[®] (NFPA 70-2020) and *CE Code*[®] (CSA C22.1-2021) as applicable. Surface temperature test methods and sine wave and non-sine wave applications are covered. Precautions against excessive surface temperatures and sparking are included. To help mitigate hot surface temperatures and sparking, this document provides guidance for selecting, operating, and maintaining machines in Zone 2 and Class I, Division 2 locations. This guide does not cover ac wound rotor machines and dc electric machines. Machines installed in locations other than Zone 2 and Class I, Division 2 as covered in NFPA 70-2020 or CSA C22.1-2021 are not covered in this guide. This document is not a specification and is not intended to be used as a specification for purchasing electric machines. The voltage breaks in this document are 1000 V and less, and over 1000 V.

Keywords: adjustable speed drive; autoignition temperature; Class I, Division 2; classified locations; electric machine; enclosure sparking; generator; hazardous locations; IEEE 1349[™]; induction motor; label test; motor; motor enclosure; motor temperature; multisection motor; paint test; rotor; rotor sparking; rotor temperature; space heater test; synchronous motor; T Code; temperature code, Zone 2

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Introduction

This introduction is not part of IEEE Std 1349-2021, IEEE Guide for the Application of Electric Machines in Zone 2 and Class I, Division 2 Hazardous (Classified) Locations.

This standard was originally published in 2001 and revised in 2011 by the Motors in Hazardous Locations Working Group Committee. In 2018 this Working Group scope was expanded and the name was changed. This edition was revised by the Machines in Hazardous Locations Working Group Committee of the IEEE Petroleum and Chemical Industry Committee.

This guide was developed to assist individuals, organizations, and suppliers with the application of machines in Zone 2 and Class I, Division 2 locations, where flammable gases and vapors may occasionally be present. Primary emphasis is on the use of open or nonexplosionproof enclosed or nonflameproof enclosed motors and precautions against excessive surface temperatures and sparking of rotor bars and enclosure joints.

This guide is divided into several clauses, as follows:

- Clause 1 provides the scope of this guide.
- Clause 2 lists references to other standards that are inclusive when applying this guide.
- Clause 3 provides definitions, abbreviations, and acronyms that are either not found in other standards, or have been modified for use with this guide.
- Clause 4 describes the phenomenon of a motor as a possible ignition source.
- Clause 5 provides guidance for Common applications of motors in Zone 2 and Class I, Division 2 locations.
- Clause 6 provides guidance for Uncommon applications of motors in Zone 2 and Class I, Division 2 locations and 6.3 discusses nonsinusoidal or adjustable speed operation.
- Clause 7 discusses the operating and maintenance considerations that help mitigate hot surface temperatures and sparking, specifically focusing on motors located in Zone 2 or Class I, Division 2 locations.
- Clause 8 describes preferred test methods for determining internal motor surface temperatures for the purpose of applying motors in Zone 2 and Class I, Division 2 locations, including rotor temperature test methods and space heater temperature test method.

Ten annexes are included: Annex A bibliography, Annex B regulations and standards for motors used in areas where flammable gases or vapors may be present, Annex C AIT (autoignition temperature) and group designations for Class I materials, Annex D motor enclosure types and protection techniques, Annex E motor information tables to check a motor data sheet, Annex F multisection motor inspection procedure, Annex G motor sparking considerations and procedures for determining discharge energy due to common-mode voltage, Annex H surface temperature study results and considerations, Annex I motor surface temperature test methods and limitations, and Annex J event history.

First Edition: “*Guide for the Application of Motors in Class I, Division 2 Hazardous (Classified) Locations*”. In the early 1990’s, a paper presented at the PCIC Conference addressed motors in hazardous locations. A Study Group / Working Group was formed to primarily address existing codes and standards, such as the *National Electrical Code (NEC)* cautionary notes for general-purpose motor applications in Division 2 areas. The Working Group conducted motor rotor temperature tests and manufacturers conducted independent tests and confidentially shared their data with the Working Group. Significant motor temperature information is contained in the Guide including maximum recommended Division 2 exposed surface temperatures at full load. This Guide documented industry experience and established practices for the application of general-purpose motors in Division 2 locations and provides guidance for applying motors in these locations. Applications were designated as Common Applications or Uncommon Applications. This Guide included the first rotor temperature test method. Manufacturers, users, and other industry experts worked about 8 years to develop this consensus standard. It was approved by the IEEE-SA Standards Board in 2001.

Second Edition: “*Guide for the Application of Motors in Class I, Division 2 or Class I, Zone 2 Hazardous (Classified) Locations*”. The 2011 edition of the Guide expanded the scope to include Class I, Zone 2 locations. Manufacturers conducted independent motor and Adjustable Speed Drive (ASD) tests and confidentially shared their data with the Working Group. The motor temperature test data tables were expanded and ASD applications temperature test data tables were added. New applications were designated as Common ASD Applications or Uncommon ASD Applications. The maximum recommended exposed surface temperatures at full load were updated. A procedure for determining discharge energy due to common-mode voltage was included in Annex G.3. Information was updated throughout the standard to include the latest technologies.

Third Edition: This edition of the Guide expanded the scope to include the Canadian Electrical Code and both generators and motors are included. Manufacturers conducted independent machine and ASD tests and confidentially shared their data with the Working Group. Machine temperature test data was expanded for fixed speed and ASD applications along with companion ASD Test Configuration drawings. The maximum recommended exposed surface temperatures at full load were updated and expanded to include permanent magnet motors. The procedure for determining discharge energy due to common-mode voltage was significantly expanded in Annex G.3 and an IEEE 1349 Discharge Energy Calculator spreadsheet was made available for download and use. This Guide includes the first space heater temperature test method in Clause 8. Information was updated throughout the standard to include the latest technologies.

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IEEE Guide for the Application of Electric Machines in Zone 2 and Class I, Division 2 Hazardous (Classified) Locations

1. Overview

1.1 Scope

Three-phase and single-phase ac synchronous and induction electric machines in ratings 0.18 kW (1/4 hp) and larger are covered in this guide. Primary emphasis is on the use of open or nonexplosionproof or nonflameproof enclosed machines in Zone 2 and Class I, Division 2 locations as covered in *National Electrical Code*[®] (*NEC*[®]) (NFPA 70-2020)³ and Canadian Electrical Code[®] (CE Code[®]) (CSA C22.1-2021 Safety Standard for Electrical Installations) as applicable.⁴ Surface temperature test methods and sine wave and non-sine wave applications are covered. Precautions against excessive surface temperatures and sparking are included. To help mitigate hot surface temperatures and sparking, this document provides guidance for selecting, operating, and maintaining machines in Zone 2 and Class I, Division 2 locations. This guide does not cover ac wound rotor machines and dc electric machines. Machines installed in locations other than Zone 2 and Class I, Division 2 as covered in NFPA 70-2020 or CSA C22.1-2021 are not covered in this guide. This document is not a specification and is not intended to be used as a specification for purchasing electric machines.

The voltage breaks in this document are 1000 V and less, and over 1000 V.

³ NFPA 70[®], *National Electrical Code*[®], and *NEC*[®] are registered trademarks of the National Fire Protection Association, Quincy, MA.

⁴ Information on references can be found in Clause 2.

1.2 Purpose

Existing codes and standards contain cautionary notes for open or nonexplosionproof or nonflameproof enclosed machines in Zone 2 and Class I, Division 2 locations as covered in the *NEC* and the CE Code. This guide documents industry experience and established practices and provides guidance for applying machines in these locations.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{5, 6}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

In this document, the word *shall* is used to indicate a mandatory requirement. The word *should* is used to indicate a recommendation. The word *may* is used to indicate a permissible action. The word *can* is used for statements of possibility and capability.

1.4 Background

As early as 1905, the *National Electrical Code*® (*NEC*®) recognized that a suitable enclosure would be required when an electric motor was installed in the vicinity of combustible materials (National Electric Code, 1905 [B78]).⁷ In the early 1920s, the *NEC* began to designate and recognize flammable and combustible materials by the current Class system. With this system, an electric motor located within a Class I location was required to have an explosionproof enclosure.

In 1931, Classes were introduced to the *NEC*; in 1935, Groups A, B, C, and D were added; and in 1947, Divisions 1 and 2 were added. By allowing a Division 2 location to be individually evaluated on the basis of the amount of material that may escape during abnormal operating conditions, adequacy of ventilation, total area involved, and the history of the type of installation, the *NEC* allowed open-type, nonexplosionproof electric motors to be installed in Division 2 locations. During this same period, electric motor manufacturers also developed the totally enclosed, fan cooled (TEFC) motor. By 1947, the *NEC* permitted open-type and TEFC motors “without brushes, switching mechanisms or integral resistance devices” for installation in Division 2 locations.⁸ From that time until the mid-1980s, hundreds of thousands of open-type and TEFC motors, ranging in size from fractional horsepower to over 10 000 hp, had been installed in Class I, Division 2 locations.

⁵ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁶ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

⁷ The numbers in brackets correspond to those of the bibliography in Annex A.

⁸ Reproduced with permission of NFPA from NFPA 70®, *National Electrical Code*®, 2020 edition. Copyright © 2019, National Fire Protection Association, Quincy, MA. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety. For a full copy of NFPA 70, please go to nfpa.org.

This guide addresses two Informational Notes for Division applications: Fine Print Note (FPN) No. 1 was added to the *NEC* in 1984 to Section 501 and currently is in Section 501.125(B) Informational Note No. 1 as follows: “It is important to consider the temperature of internal and external surfaces that may be exposed to the flammable atmosphere.”⁹ FPN No. 2 was added to the *NEC* in 1993 to Section 501 and currently is in Section 501.125(B) Informational Note No. 2 as follows: “It is important to consider the risk of ignition due to currents arcing across discontinuities and overheating of parts in multisection enclosures of large motors and generators. Such motors and generators may need equipotential bonding jumpers across joints in the enclosure and from enclosure to ground. Where the presence of ignitable gases or vapors is suspected, clean-air purging may be needed immediately prior to and during start-up periods.”¹⁰

In 1996, Zones were added to the *NEC*. This guide addresses two Informational Notes: Section 505.20(C), Informational Note No. 1 and Informational Note No. 2, which were added to the *NEC* in 1999 for Zone applications as follows: Section 505.20(C), Informational Note No. 1, which includes a statement that: “It is important to consider the temperature of internal and external surfaces that may be exposed to the flammable atmosphere.”¹¹ Section 505.20(C), Informational Note No. 2, which includes a statement that: “It is important to consider the risk of ignition due to currents arcing across discontinuities and overheating of parts in multisection enclosures of large motors and generators. Such motors and generators may need equipotential bonding jumpers across joints in the enclosure and from enclosure to ground. Where the presence of ignitable gases or vapors is suspected, clean air purging may be needed immediately prior to and during start-up periods.”¹²

Since the mid-1980s, at least nine events involving motors were documented (See Annex J). The extent of these events ranged from internal explosions causing enclosure failure to visible sparking across enclosure panels. In all cases, where the information is known, the motor sizes were over 5 MW or the motor voltage ratings were over 6.0 kV.

Starting in the early 1990s a number of independent engineering groups conducted tests on open-type and TEFC motors in flammable atmospheres. To date, most testing has involved manually filling a motor enclosure with a flammable mixture and measuring the resulting atmospheric and motor characteristics during motor starting, motor running, and motor overload conditions. Additional testing is expected to continue to identify further those elements that contribute to the successful installation of motors in Zone 2 and Class I, Division 2 locations.

In 2017, an additional requirement related to sliding contact shaft bonding devices was added to Section 501.125(B) of the *NEC*. In 2020, Class I was removed from Article 505. Class I was originally included to the Zone 0, Zone 1, and Zone 2 locations and references as an identifier for flammable gases, vapors, or liquids and to differentiate from Class II and Class III locations. Zone 0, Zone 1, and Zone 2 only apply to flammable gases, liquids, or vapors, and therefore, Class I is redundant and was deleted. Rules for the hazardous locations have existed in both the CE Code and *NEC* since the 1920s. In the 1930s, the CE Code and *NEC* developed the “Class” system for designating hazardous locations. Despite many changes over time, and some differences in wiring methods, the two codes remained quite similar. The 2015 Edition of the CE Code removed “Class” from the Section 18, which had been used by both the CE Code and *NEC* for decades. The 23rd edition of the CE Code adopted the IEC version of the Zone system. Class I, which was changed in 1998 to include Zones, became simply Zones 0, 1, and 2. Since then, all new construction must use the new system for area classification. The legacy “Class” and “Division” system relocated to Appendix J. The CE Code does allow for continued use of Class/Division equipment in the Zone System.

Both the CE Code and *NEC* put rules in place to accept Division equipment in Zone locations and Zone equipment in Division locations. The CE Code adoption process was much different from that of the *NEC*. The CE Code changed the Section 18 Rules that dealt with Class I locations to “Zones” and moved the

⁹ See Footnote 8.

¹⁰ See Footnote 8.

¹¹ See Footnote 8.

¹² See Footnote 8.

“Division” Rules to Appendix J. While existing facilities were permitted to continue using the “Division” system, it was mandatory that all new construction used the “Zone” system. The *NEC* added Article 505 and allowed users the option to use either the “Division” or the “Zone” system. The result is that the “Zone” system for Explosive Gas Atmospheres is used far more in Canada than it is in the USA. See CAN/CSA C22.2 No. 145-2011 [B21].

1.5 Industry experience

By far the world’s largest user of open-type and TEFC motors in Zone 2 and Class I, Division 2 locations is the petrochemical industry. Electric motors are used to drive centrifugal and positive displacement pumps, compressors, mixers, fans, conveyors, and blowers. The typical motor utilized has been an open-type or TEFC, squirrel cage induction motor designed to operate at a fixed speed and started across the line with full rated voltage.

The petrochemical industry has experienced an excellent history utilizing these open-type and TEFC motors in Class I, Division 2 and Zone 2 hazardous locations; see Haynes and Messec [B43], Padden, Bried, and Dymond [B88], and Padden, Lockley, Mistry, and Wood [B89]. For more than 70 years, the only known incidents are motor sizes over 5 MW or motor voltage ratings over 6.0 kV; see Bartels and Bradford [B10] and BEAMA Ltd. [B93]. (Refer to Annex J.)

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

API 541, Form-Wound Squirrel-Cage Induction Motors—375 kW (500 Horsepower) and Larger.¹³

API 546, Brushless Synchronous Machines—500 kVA and Larger.

API 547, General-Purpose Form-Wound Squirrel Cage Induction Motors—250 Horsepower and Larger.

CAN/CSA C22.1-2021, Canadian Electrical Code® (CE Code®) Safety Standard for Electrical Installations.¹⁴

IEEE Std 303™, IEEE Recommended Practice for Auxiliary Devices for Rotating Electrical Machines in Class I, Division 2 and Zone 2 Locations.^{15, 16}

IEEE Std 841™, IEEE Standard for Petroleum and Chemical Industry—Premium-Efficiency, Severe Duty, Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp).

IEEE Std 1068™, IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical, and Process Industries.

NEMA MG 1, Motors and Generators.¹⁷

NFPA 70-2020, *National Electrical Code*® (*NEC*®).^{18, 19}

¹³ API publications are available from the American Petroleum Institute (<https://www.api.org/>).

¹⁴ CSA publications are available from the Canadian Standards Association (<https://www.csa.ca/>).

¹⁵ IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹⁶ The IEEE standards or products referred to in Clause 2 are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

¹⁷ NEMA publications are available from the National Electrical Manufacturers Association (<https://www.nema.org/>).

¹⁸ *National Electrical Code* and *NEC* are both registered trademarks of the National Fire Protection Association, Inc.

¹⁹ The *NEC* is published by the National Fire Protection Association (<http://www.nfpa.org/>). Copies are also available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.²⁰

abnormal operating condition: As applied to motors, including, but not limited to, starting, locked rotor, voltage unbalance, overload, and short-circuit. As applied to equipment in classified locations, equipment failure is considered to be an abnormal operating condition.

adjustable speed drive (ASD): An electric drive designed to provide easily operable means for speed adjustment of the motor, within a specified speed range.

ambient temperature: Ambient temperature is the temperature of the surrounding cooling medium, such as gas or liquid, which comes into contact with the heated parts of the apparatus. (See NEMA MG 1.)

approved: Acceptable to the authority having jurisdiction (AHJ).²¹

autoignition temperature (AIT): The minimum temperature required to initiate or cause self-sustained combustion of a solid, liquid, or gas independently of the heating or heated element.²² For the Canadian Electrical Code, the Minimum Ignition Temperature is normally the AIT.

Class B rise: Based on a maximum 40 °C ambient, a motor stator temperature rise at 1.0 service factor of 80 °C (measured by resistance) or 80 °C, 85 °C, or 90 °C (measured by embedded detectors) in accordance with NEMA MG 1, depending on the motor size, motor type, enclosure type, and voltage rating. The rise at 1.0 service factor corresponds to Class B type of insulation system in the NEMA MG 1 temperature rise tables.

Class I, Division 2: A location 1) in which volatile flammable gases, flammable liquid-produced vapors, or combustible liquid-produced vapors are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems or in case of abnormal operation of equipment, or 2) in which ignitable concentrations of flammable gases, flammable liquid-produced vapors, or combustible liquid-produced vapors are normally prevented by positive mechanical ventilation and which might become hazardous through failure or abnormal operation of the ventilating equipment, or 3) that is adjacent to a Class I, Division 1 location, and to which ignitable concentrations of flammable gases, flammable liquid-produced vapors, or combustible liquid-produced vapors above their flash points might occasionally be communicated unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air and effective safeguards against ventilation failure are provided. [See Section 500.5(B)(2) of the 2020 *NEC*.]²³

²⁰ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

²¹ See Footnote 8.

²² Reproduced with permission of NFPA from NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, 2017 edition. Copyright © 2016, National Fire Protection Association, Quincy, MA. This reprinted material is not the complete and official position of the NFPA on the reference subject, which is represented only by the standard in its entirety. For a full copy of NFPA 497, please go to nfpa.org.

²³ See Footnote 8.

Common application: A Common application in Zone 2 or Class I, Division 2 location is where a synchronous or low-slip (typically less than 3%) induction motor is operating at rated or below full-load steady-state conditions and within the defined parameters.

NOTE—The defined parameters for Common applications are provided in 5.1.²⁴

Common ASD application: A Common ASD application in Zone 2 or Class I, Division 2 location is where a synchronous or low-slip (typically less than 3%) induction motor is operating within the defined parameters.

NOTE—The defined parameters for Common ASD applications are provided in 6.3.2.

common-mode filter (CMF): Also referred to as “common-mode choke.” In the context of adjustable speed drives (ASDs), CMF is a passive device installed between the ASD output and motor input that appears as a lossy series inductive element, adding inductance with respect to ground (not between phases). The CMF attenuates common-mode current to ground, reduces peak voltage to ground at the motor, reduces CMV reflection, reduces dv/dt to ground at the motor, and does not alter positive-sequence voltage or current.

common-mode voltage (CMV): In the context of adjustable speed drives (ASDs), CMV is the displacement of the neutral point (and each phase voltage) of the ASD output from ground due to the switching of the solid state devices in the drive. It is an alternating voltage whose magnitude and frequency components are dependent on the drive topology. All present drive topologies create CMV to some extent. CMV can also be created at the motor if phase circuit conductors, unsymmetrical with respect to the equipment grounding conductor(s) or grounded sheaths or raceways, are used between the ASD output and the motor.

comparable converter: A converter where the losses in the motor supplied by the converter are not higher than the losses that would have occurred if the motor were used with the specific converter that was used during the type test.

NOTE—This converter is similar with respect to the output voltage, output current, and switching frequency specifications so the machine limiting temperatures, for maximum surface temperature and material thermal stability, are not exceeded.

continuous duty: Operation at a substantially constant load for an indefinitely long time. This is also known as continuous rating in NEMA MG 1.

corona: A type of localized discharge resulting from transient gaseous ionization on an insulation system when the voltage stress exceeds a critical value. The ionization is usually localized over a portion of the distance between the electrodes of the system. (Corona activity can result in surface discharges and surface tracking on motor windings.) Corona is visible partial discharges in gases adjacent to a conductor. (See IEEE Std 1434™ [B58].)

electric discharge machining (EDM): Micro arcing in a bearing that typically removes metal.

electric machine: Electric machine or machine is a rotating electric motor or generator.

explosionproof equipment: Equipment enclosed in a case that is capable of withstanding an explosion of a specified gas or vapor that may occur within it and of preventing the ignition of a specified gas or vapor surrounding the enclosure by sparks, flashes, or explosion of the gas or vapor within, and that operates at such an external temperature that a surrounding flammable atmosphere will not be ignited thereby.²⁵

²⁴ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

²⁵ See Footnote 8.

exposed surface: A surface that is internal to an enclosure or an external surface of an enclosure that could be exposed to the surrounding flammable atmosphere, without the benefit of an enclosure that would contain an explosion or exclude the hazardous gas. (An exposed internal surface may be the rotor, stator, or space heater surfaces of open and totally enclosed fan cooled (TEFC) motors. An exposed external surface is the exterior surface, which could be exposed to the surrounding flammable atmosphere such as the exterior surface of explosionproof, pressurized, or force ventilated enclosures.)

general-purpose enclosure: An enclosure used for usual service applications where special types of enclosures are not required.

identified: (as applied to equipment). Recognizable as suitable for the specific purpose, function, use, environment, application, and so forth, where described in a particular Code requirement.²⁶

NOTE—Some examples of ways to determine suitability of equipment for a specific purpose, environment, or application include investigations by a qualified testing laboratory (listing and labeling), an inspection agency, or other organizations concerned with product evaluation.²⁷

IC Code: The IC Code designates the method of electrical machine cooling as described in NEMA MG 1, Part 6.

IP Code: The IP Code designates the degree of protection provided by the enclosure of a rotating machine as described in NEMA MG 1, Part 5.

listed: Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.²⁸

NOTE—The means for identifying listed equipment may vary for each organization evaluating products.²⁹

maximum experimental safe gap (MESG): The maximum clearance between two parallel metal surfaces that has been found, under specified test conditions, to prevent an explosion in a test chamber from being propagated to a secondary chamber containing the same gas or vapor at the same concentration.³⁰

minimum ignition energy (MIE): The minimum energy required from a capacitive spark discharge to ignite the most easily ignitable mixture of a gas or vapor.³¹

multisection motor: A motor whose construction utilizes a component block approach in the assembly of the enclosure, that is, the enclosure has a number of bolted joints which could connect together the stator frame, the ventilation hood, the motor base, the bearing supports, and enclosure covers.

NEMA frame: This refers to the NEMA MG 1 system of a standardized frame designation for ac machines including 449 frame size and smaller. NEMA MG 1, Part 4 provides critical mounting dimensions for each frame size.

nonincendive: Under normal operating conditions, accessories or devices that are not capable of igniting the specified flammable gases or vapors due to sparking or thermal means.

²⁶See Footnote 8.

²⁷See Footnote 8.

²⁸See Footnote 8.

²⁹See Footnote 8.

³⁰See Footnote 22.

³¹See Footnote 22.

normal operating condition: As applied to motors, a normal operating condition is operating at rated full-load steady state conditions.³² Locked-rotor, starting, single-phasing, and operating above base nameplate kilowatt or horsepower are not normal operating conditions.

overload: Loading in excess of normal rating of equipment. For a motor, it is considered overloaded when operated above its base current or nameplate kilowatt or horsepower.

partial discharge: A localized electric discharge resulting from ionization in an insulation system when the voltage stress exceeds the critical value. This discharge partially bridges the insulation in the voids internal to the motor winding insulation.

per unit torque: Per unit torque is the test value of load torque divided by the motor rated torque at nameplate rated conditions, such as rated voltage and rated frequency.

NOTE—As applied in Annex H.

prestart ventilation: The process of applying purging, but not the pressurization aspects of NFPA 496 [B83] or UL 60079-2 [B102] or CSA 60079-2 [B24], prior to starting a motor to reduce the concentration of any flammable gas or vapor that may initially be present.

service factor: A multiplier that, when applied to the rated power, indicates a permissible power loading that may be carried under the conditions specified for the service factor.

spark: A sudden and irreversible transition from a stable corona discharge to a stable arc discharge. It is a luminous electrical discharge of short duration between two electrodes in an insulating medium. It is generally brighter and carries more current than corona, and its color is mainly determined by the type of insulating medium. It generates radio noise of wider frequency spectrum (extending into hundreds of megahertz) and wider magnitude range than corona. A spark is not classified as corona. Sparking can also include static discharge, sparking due to mechanical contact, and capacitive discharges (i.e., across bearing oil film and separating switch contacts).

Uncommon application: An Uncommon application in Zone 2 or Class I, Division 2 locations is where the motor is operating or applied outside the defined parameters for Common applications.

NOTE—Operating or applied outside those defined parameters for Common application given in 5.1.

Uncommon ASD application: An Uncommon ASD application in Zone 2 or Class I, Division 2 locations is where the motor is operating or applied outside the defined parameters for Common ASD applications.

NOTE—Operating or applied outside those defined parameters for Common ASD applications given in 6.3.2.

Zone 2: A location 1) in which ignitable concentrations of flammable gases or vapors are not likely to occur in normal operation and, if they do occur, will exist only for a short period; or, 2) in which volatile flammable liquids, flammable gases, or flammable vapors are handled, processed, or used but in which the liquids, gases, or vapors normally are confined within closed containers or closed systems from which they can escape, only as a result of accidental rupture or breakdown of the containers or system, or as a result of the abnormal operation of the equipment with which the liquids or gases are handled, processed, or used; or, 3) in which ignitable concentrations of flammable gases or vapors normally are prevented by positive mechanical ventilation but which may become hazardous as a result of failure or abnormal operation of the ventilation equipment; or, 4) that is adjacent to a Zone 1 location, from which ignitable concentrations of flammable gases or vapors could be communicated, unless such communication is prevented by adequate positive pressure ventilation from a source of clean air and effective safeguards against ventilation failure are provided. [See Section 505.5(B)(3) of the 2020 *NEC*.]³³

³² See Footnote 8.

³³ See Footnote 8.

3.2 Acronyms and abbreviations

AFD	adjustable frequency drive (ASD is the IEEE preferred term)
AHJ	authority having jurisdiction
AIT	autoignition temperature
API	American Petroleum Institute
ASD	adjustable speed drive
ASTM	American Society for Testing and Materials
CE Code	Canadian Electrical Code
CENELEC	European Committee for Electrotechnical Standardization
CMF	common-mode filter
CMV	common-mode voltage
CMVR	common-mode voltage ratio
CSA	Canadian Standards Association International
DE	drive end
DPFV	dripproof forced ventilated
EDM	electric discharge machining
F	farad
FLC	full-load current
FLT	full-load torque
FPN	fine print note (formerly used in the <i>NEC</i>)
IC	IC Code
IEC	International Electrotechnical Commission
IGBT	insulated gate bipolar transistor
IP	IP Code
J	joule
LCI	load commutated inverter
LFL	lower flammable limit
LRC	locked rotor current
MESG	maximum experimental safe gap
MIE	minimum ignition energy
MOV	metal oxide varistor
NDE	non-drive end
<i>NEC</i>	<i>National Electrical Code</i>
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association

NRTL	nationally recognized testing laboratory
ODP	open dripproof
OEM	original equipment manufacturer
PDM	pulse duration modulation
PWM	pulse-width modulation
RP	recommended practice
RPM	revolutions per minute
RTD	resistance temperature detector
SCR	silicon controlled rectifier
SF	service factor
SHE	selective harmonic elimination
T Code	Temperature Class or Identification Number per 2020 <i>NEC</i> Table 500.8(C)
TEAAC	totally enclosed air-to-air cooled
TEFC	totally enclosed fan cooled
TEFV	totally enclosed force-ventilated
TENV	totally enclosed nonventilated
TEPV	totally enclosed pipe-ventilated
TEWAC	totally enclosed water-to-air cooled
TFE	tetrafluoroethylene
UFL	upper flammable limit
UL	Underwriters Laboratories Inc.
VFD	variable frequency drive (ASD is the IEEE preferred term)
VSD	variable speed drive (ASD is the IEEE preferred term)
VSI	voltage source inverter
WPI	weather protected Type I
WPII	weather protected Type II

4. Phenomenon of a motor as a possible ignition source

4.1 Ignition overview

The phenomenon of a motor being a possible ignition source in a Zone 2 or Class I, Division 2 location is discussed in this clause. One of the steps in selecting the proper motor for a location is determining the area classification where the motor will be located; this document(s) identifies possible fuel sources and their characteristics as related to area classification. As a consequence of facility improvements, a particular facility's area classification may have changed from when the facility first went into service, therefore, it may be necessary to update certain equipment requirements for the new area classification.

NOTE—As an example, significant improvements have been made over the years in equipment integrity, which has resulted in an improved general safety record of petrochemical process plants. This is due to the following:

- Improved equipment and containment measures.
- Reduction in accidental and escaping emissions.
- Improved understanding of the processes and their control requirements.
- Advances in use of computerized control techniques.
- Improvements in reclamation of volatile fluids (e.g., orifices that were normally open to the atmosphere during tank filling operations may now be closed vent systems).
- Improvements to sample lines in relation to their attachment points and/or their placement position in relation to drains.
- Improvements to drainage systems (e.g., open drains have been converted to closed drains or modified to prevent hydrocarbon accumulation).

Refer to API RP 500 [B6], API RP 505 [B7], NFPA 497 [B84], 2020 *NEC*, and the 2021 CE Code for guidance when determining area classifications and equipment requirements.

For motor applications, there are basically two potential types of ignition sources: hot surface temperatures and sparking. Mitigating hot surfaces and sparking conditions or containing sparking in approved enclosures are paramount to preventing ignition events caused by motors or their accessories. Sparking is discussed in Annex G. Surface temperatures are discussed in Annex H. The phenomenon of a motor causing an ignition is discussed in 4.1 through 4.4.

For a fire or explosion to occur, three things are needed: oxygen (air), a source of fuel, and an ignition source (heat or spark), which are discussed in 4.2. The characteristics of the fuel are critical to determining potential ignition sources. One of the critical characteristics of flammable gases and vapors is the autoignition temperature (AIT). The group designation of flammable gases and vapors is also important for the design of enclosures. These characteristics are described in 4.3.

External surfaces can come into contact with gas releases, so external surface temperatures should be considered potential ignition sources. If the gas can enter the motor enclosure, then internal surface temperatures may need to be considered as potential ignition sources. Motor enclosure gas ingress is discussed in 4.4.

Under normal operating conditions (excluding starting and accelerating), the exposed surface temperatures should be within acceptable limits, specifically, does not exceed the AIT of the potential flammable gases or vapors; and there should not be any sparking devices, except inside enclosures approved to contain such events. Experience has shown that the probability of the three ignition components (air, fuel, and ignition source) being present simultaneously and an ignition occurring is very small. (See API 2216-2003 [B3], Bredthauer et al. [B16], Buschart et al. [B18], and Hamer et al. [B39].)

4.2 Ignition components

Ignition is the process or means of igniting a fuel mixture, and igniting causes a fuel mixture to burn, also known as causing combustion. Combustion is simply a rapid oxidation reaction that is accompanied by the emission of energy in the forms of heat and light. It normally takes place in air, which is composed of approximately 21% oxygen. In order for combustion to occur, a Class I material, such as gasoline, would be present and there would be enough oxygen to sustain combustion as well as enough heat to raise the Class I material to its ignition temperature; see API 2216-2003 [B3]. This is often represented as a fire triangle, as shown in Figure 1.



Figure 1—Fire triangle

4.3 Gas AIT and group designation

The AIT of a flammable gas or vapor is important in determining the acceptability of equipment that operates at relatively high exposed surface temperatures (above 100 °C). Explosionproof equipment is designed with an external surface temperature that does not exceed the AIT, but the internal temperature can be above the AIT. Explosionproof enclosures contain an internal explosion and prevent the hot explosive gases from igniting the surrounding flammable atmosphere by cooling the gases as they exit the enclosure. The surface temperature of all exposed internal and external components of general-purpose enclosures or nonexplosionproof or nonflameproof motor enclosures should not exceed the AIT of potential flammable sources so that the surface does not become a potential ignition source.

In the late 1990s, the tests conducted by the IEEE P1349 Working Group confirmed that materials ignited in operating motors at higher temperatures than published AIT values. The Working Group test results are summarized in H.2.1.

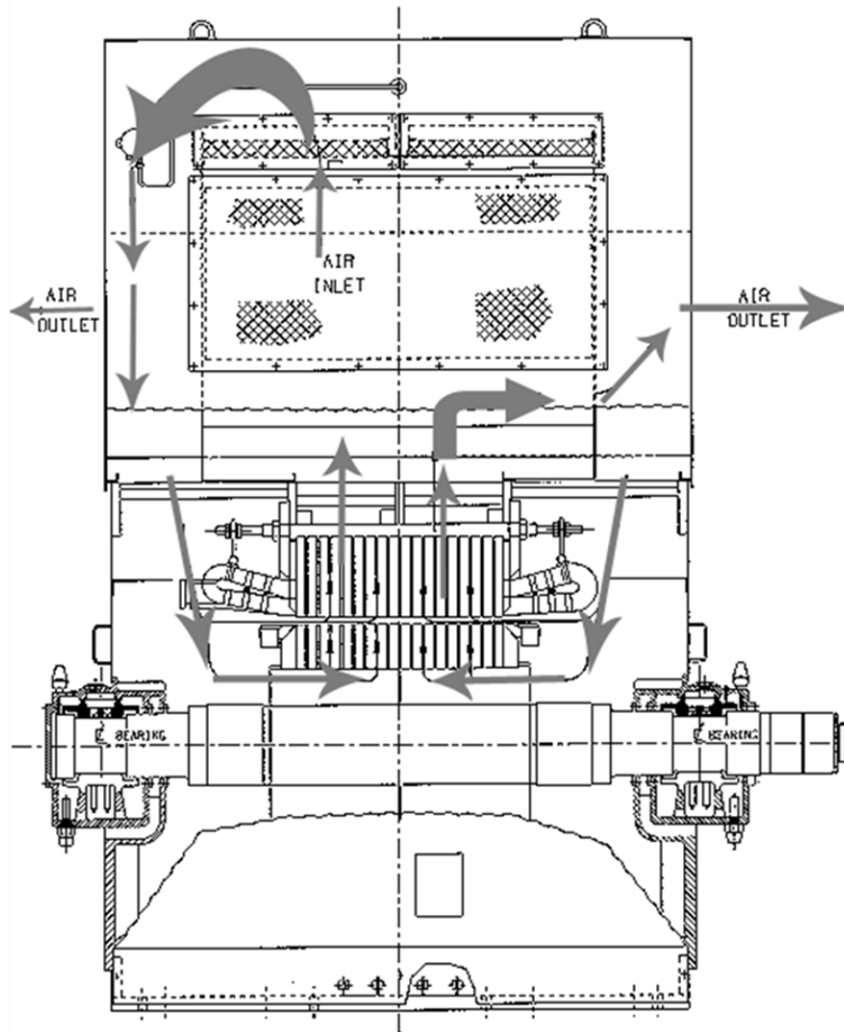
The group designation reflects that different gases and vapors cause varying maximum explosive pressures when ignited and is characterized by different maximum experimental safe gaps (MESGs). Enclosures designed to contain/cool an explosion have group designations and are applied within their listed, labeled, and/or tested group(s) for which they were approved.

For additional information, Annex C describes the AIT characteristics of flammable gases and vapors. The AITs of components are in NFPA 497 [B84] and ANSI/ISA TR 12.13.01-1999 (R2005) [B2]. The AIT of mixtures can be determined by testing using the methods described in Annex C. Gas mixture flammability (UFL and LFL) and Gas Group classification can sometimes be approximated using Le Chateleier's method described in the Bozek and Rowe paper [B15]. See NFPA 497 [B84] also for information on Le Chateleier's method. Group designations are defined in the 2020 *NEC* and single components are in NFPA 497 [B84].

4.4 Gas ingress

Gases and vapors infiltrate most types of motor enclosures with the exception of forced ventilated or pressurized (i.e. inert gas-filled) motors when the protection system is working properly. The rate at which the gas exchange occurs is a function of many factors.

Open-type motors have a rapid exchange because the gas can readily enter the motor through the ventilation openings. For the open dripproof (ODP) and similar enclosures, any gas release surrounding the motor is taken directly into the motor along with the cooling air. The gas is rapidly mixed with the cooling air and diluted. In the motor air gap, a laminar-to-turbulent flow exists. Close to the rotor surface, there is a narrow band of air only a few molecules thick that moves with the rotor and tends to act as a thermal barrier between the rotor surface and the gas in the air gap annulus. While the rotor is spinning, this thin band prevents the gas from igniting even if the rotor surface temperature is higher than the published AIT, similar to experiences described in API 2216-2003 [B3]. As the motor speed approaches zero, this thermal barrier influence diminishes. Therefore, the worst case for open motors occurs just after the hot motor stops. See Figure 2 for an illustration of the free exchange of outside atmosphere to the inside of the motor enclosure.



Source: Courtesy of General Electric.

Figure 2—Large motor with a top hat showing the free exchange of outside atmosphere

For TEFC motors, gas in the surrounding atmosphere enters the motor enclosure whenever the interior pressure is negative. This happens when the motor is subjected to a drop in operating temperature, for example when there is a drop in load, a shutdown, or other event causing a drop in operating temperature. The worst case for high gas concentrations inside the TEFC motor is whenever the gas release occurs while the motor is cooling down at shutdown. Tests done on totally enclosed motors have shown gas/air exchange rates from a few minutes to several hours. For totally enclosed motors many factors such as fits, clearances, gaskets, temperature differentials, and locations are factors that affect the rate of gas exchange.

In 1994, an IEEE paper by Buschart et al. [B18] presented some considerations regarding the application of totally enclosed motors in Class I, Division 2 locations. This paper showed that gas ingress was possible into totally enclosed motors based on testing. Conditions affecting gas ingress were presented. The paper also discussed motor internal temperatures and the relationships to AITs of potentially hazardous materials that might enter the motor (See 4.3). Normal and abnormal operating conditions that affect motor internal temperatures were discussed.

5. Common applications

5.1 Common application conditions

Clause 5 provides guidance for Common applications of motors in Zone 2 and Class I, Division 2 locations. The typical rotor operating temperatures shown in Table 1 for motors at full load have been shown by experience not to be an ignition source for motors applied in Zone 2 or Class I, Division 2 locations. The temperatures shown in Table 1 (See also the conditions stated in the footnotes) should permit application of standard, off-the-shelf motors meeting the Common application conditions of 5.1 when used with equipment handling materials having AITs at or above 200 °C. Motor manufacturers and users should discuss applications, and sound engineering judgment should be used.

Table 1—Motor operating temperatures for common application conditions^a

Size	Enclosure types	Rotor cooling type ^b	Typical rotor operating temperatures at full load ^c (°C)	Maximum recommended exposed surface temperature at full load (°C)
Single phase—Induction				
Up to 1.5 kW (2 hp), With arcing device	Explosionproof UL 674 listed [B99]	All	—	Per UL listing and T Code label ^d
Three phase—NEMA frame sizes - Induction				
Up to 335 kW (450 hp)	ODP	Nonducted ventilation	115–150 ^e	200
Up to 300 kW (400 hp)	TEFC	Nonducted or axial duct ventilation	105–160	200
Three phase—above NEMA frame sizes - Induction				
100 kW to 300 kW (125 hp to 400 hp)	TEFC	Nonducted or axial duct ventilation	120–175	200
Above 300 kW (400 hp)			120–195	200
Above 300 kW (400 hp)	WP II	Nonducted or axial duct ventilation	115–205	200
Three phase—above NEMA frame sizes - Synchronous				
Above 300 kW (400 hp)	WP II & ODP	Nonducted or axial duct ventilation	90–110	180
Above 300 kW (400 hp)	TEFV & TEWAC	Nonducted or axial duct ventilation	85–115	180
Three phase—above NEMA frame sizes - Induction & Synchronous				
Above 110 kW (150 hp)	All ^f	Axial duct <i>and</i> radial duct ventilation	90–135	180
Three phase—above NEMA frame sizes - Permanent Magnet				
Up to 100 kW (125 hp)	TEFC	Nonducted or axial duct ventilation	110–160	180

^a Table 1 is based on a small sampling of motors. Engineering judgment should be used and users should confer with the motor manufacturer. Temperatures are based on Class B rise at 1.0 SF, low-slip induction motors and synchronous motors, with a 40 °C ambient, rated voltage, and rated frequency.

^b See H.1.2 for a discussion of the rotor cooling types. See also Figure 2, which shows axial and radial ventilation ducts in the rotor.

^c Average rotor temperature of tested and calculated values within 1 standard deviation (rounded up to the nearest 5°). (See Table H.8, Table H.9, Table H.10, Table H.11, Table H.13a, Table H.13b, Table H.14, Table H.15, Table H.16, and Table H.18.)

^d Refer to Table H.7 and Annex I for more information on UL 674 surface temperature testing. For explosionproof motors, the group and T Code are on the motor nameplate. (Refer to the 2020 *NEC* and the 2021 *CE Code*.)

^e Typical range is primarily based on motor manufacturer's calculated rotor temperatures on NEMA Design B motors. (Refer to Table H.8.)

^f Radial rotor ventilation is currently not used for NEMA frame-sized TEFC enclosures and is rare for above NEMA frame-sized TEFC enclosures.

Motors should have exposed surface temperatures at or below the maximum Zone 2 or Class I, Division 2 exposed surface temperature in Table 1 when 1) built in accordance with NEMA MG 1, IEEE Std 841, API 547, API 546, and/or API 541, and 2) applied within the Common application conditions outlined in 5.1.

The majority of motors applied in Zone 2 or Class I, Division 2 locations conform to one or more of the above standards without special requirements. Most of the AITs shown in NFPA 497 [B84] and for example encountered in the petrochemical industry are at or above 200 °C. Some applications have products, gases, and vapors with AITs less than 200 °C, which are considered Uncommon applications. Few motor applications in Zone 2 or Class I, Division 2 locations should require special motor designs. For Zone 2 and Class I, Division 2 applications, this is only a guide; engineering judgment should be used, and users should confer with the motor manufacturers.

When applying a motor under conditions other than those in 5.1 in a Zone 2 or Class I, Division 2 locations, users should discuss the application with the motor manufacturer regarding the maximum exposed motor surface temperature. Hotter surface temperatures can occur under Uncommon application conditions, which are discussed in Clause 6.

This subclause defines the parameters for Common application conditions for motors in a Zone 2 and Class I, Division 2 location as follows:

- a) the maximum recommended Zone 2 or Class I, Division 2 exposed motor surface temperature should be as shown in Table 1 and does not exceed the AIT.
- b) Motors should have a maximum Class B rise at 1.0 service factor when tested with sine wave power at rated nameplate conditions. Refer to NEMA MG 1-2016, Parts 12.43, 12.44, 20.7, and 20.8.
- c) Motors should be operated at or below their base nameplate kilowatt or horsepower.
- d) The ambient temperature range should be –15 °C to 40 °C for grease-lubricated bearings, 0 °C to 40 °C for oil-lubricated bearings or 5 °C to 40 °C when water cooling is used. Refer to NEMA MG 1. Electric machines with Level of Protection AEx “ec” or Ex “ec” have a normal ambient temperature in service of –20 °C to 40 °C. Refer to UL 60079-0 [B100] and CAN/CSA 60079-0 [B22].
- e) The maximum altitude should not exceed 1000 m above sea level.
- f) The motors should have sine wave power and fixed speed operation.
- g) The motors should be designed for continuous duty operation.
- h) The number of starts should not exceed the motor’s design limitations.
- i) The load inertia should be within NEMA MG 1 requirements.
- j) Induction motor torque and speed characteristics at rated load should be low slip (e.g., NEMA Design A or B for NEMA frame size motors, typically less than 3%).
- k) The voltage or frequency variation should not exceed 10% of rated voltage or 5% of rated frequency or a combination of not more than ±10%, provided that the frequency variation does not exceed ±5% of rated frequency.
- l) The voltage unbalance at the motor terminals does not exceed 1% as defined in NEMA MG 1.
- m) The motor ventilation system should not be impeded by enclosure modifications or supplementary enclosures.

Motors that are applied in conditions other than the Common application conditions defined above require special consideration by the applications engineer and the motor manufacturer. Refer to Clause 6 for Uncommon applications.

5.2 Surface temperatures

As described in the *NEC* Section 501.125(B) Informational Note No. 1, and in the 2021 CE Code Subrule 18-150 2 e) i) “It is important to consider the temperature of internal and external surfaces that may be exposed to the flammable atmosphere.”³⁴ The typical and maximum temperatures given in Table 1 are based on motor tests and calculations conducted by companies participating in the development of this guide and the experiences of the P1349 Working Group participants. A summary of the tests conducted by the Working Group is in H.2.2. Sine wave fixed speed test and calculation data from motor and generator manufacturers are presented in H.2.3 with Figure H.3 showing an overview of 3-phase sine wave power test data tables (Table H.7 through Table H.19). Nonsinusoidal power or ASD fed motor test data from motor manufacturers are presented in H.2.4 with Figure H.4 showing an overview of LV ASD test data tables (Table H.20 through Table H.23) and with Figure H.5 showing an overview of MV ASD test data tables (Table H.24 through Table H.29). Other test data are in Hamer et al. [B39]. The sample group of motors tested is small compared to the number of motors in service.

5.3 Sparking

Sparking in motors is not expected under normal conditions and Common application conditions except from auxiliary devices, temperature/overload switches, centrifugal switches used in single-phase motors, and in some motors with higher voltages, particularly with high speeds.

NOTE—Additional information for sparking in motors showing various voltages and speeds, refer to UL 60079-0 [B100], CAN/CSA C22.2 No 60079-0 [B22], UL 60079-7 [B103], and CAN/CSA C22.2 No. 60079-7 [B25].

Because sparking and heating is a general concern for many auxiliary devices, a standard was created to address selection and incorporation of such devices. Refer to IEEE Std 303 for proper application of auxiliary devices in Zone 2 and Class I, Division 2 locations. For more information on sparking that can occur due to design, installation, and maintenance problems, refer to Annex G of this guide.

5.4 General equipment considerations

The following subclauses describe general equipment considerations that apply to motors applied in Zone 2 or Class I, Division 2 locations in Common applications.

5.4.1 Enclosures

Open or nonexplosionproof enclosed or nonflameproof enclosed motors are acceptable in Zone 2 or Class I, Division 2 locations for non-sparking devices as long as surface temperatures meet the requirements of the 2020 *NEC* and the 2021 CE Code. See *NEC* Sections 501.125(B) and 505.20(C) Exception 4 and the 2021 CE Code Subrule 18-150 2) e). Enclosures meeting the requirements of Class I, Division 1 locations can be used in Zone 2 or Class I, Division 2 locations provided that they are applied within the equipment listing or labeling requirements. For example, explosionproof motors or flameproof [Zone protection method “d”, ref. *NEC* 505.8(A)] are required to be applied within their “T Code” and group designation indicated on their nameplate.

The more commonly applied open-type and totally enclosed type motor enclosures applied in the petrochemical industry are described in Annex D. Other selections of open-type motors are described in NEMA MG 1-2016 Part 1.25, and totally enclosed type motors are described in NEMA MG 1-2016, Part 1.26. Within the enclosures options, the most commonly applied are the weather protected Type I (WPI or IP23), weather protected Type II (WPPI or IP24W), totally enclosed fan-cooled (TEFC or

³⁴ See Footnote 8.

IP44/54), explosionproof (TEFC-XP or IP44/54), totally enclosed water-to-air cooled (TEWAC or IP54), and totally enclosed air-to-air cooled (TEAAC or IP54). In some cases, these base enclosures are modified for forced ventilation. Refer to Annex D for further discussion on the selection of motor enclosures.

Open drip proof enclosures are generally not recommended for use in Zone 2 or Class I, Division 2 dirty environments because the contaminants add to the surface heating in the motors, and in higher voltage motors winding contamination can lead to corona and surface tracking as discussed in Dymond et al. [B35].

For Zone applications, *NEC* Section 505.8 and the 2021 CE Code Table 18 define several protection techniques applicable to motors, namely, flameproof (“d”), purged and pressurized (“px” or “py”), and increased safety (“eb”), all suitable for Zone 1 and Zone 2. The purged and pressurized (“pz”) and less stringent level of increased safety (“ec”) protection techniques are only suitable for Zone 2 use. These protection methods are further discussed in Annex D.

NOTE—For Zone 2 applications, Ex “ec” motor enclosures are IP 44 minimum, and terminal box enclosures are IP 54 minimum.

For locations where liquid or condensed vapors may accumulate within a motor enclosure, the motor should be equipped with breather-drainage fittings suitable for the location, as noted in 2020 *NEC* 501.15 (F)(2) and *NEC* 505.16(E)(2).

Internal arcs in motor terminal boxes and enclosures can generate high temperatures and destructive pressures. To avoid catastrophic damage and projectiles that may cause injury, the pressures are sometimes relieved by pressure relief blow out panels that open to reduce pressure and direct arc products away from areas where people may be present. Although these incidents generate sufficient temperature and energy to cause ignition, they are rare and are not considered normal condition. Therefore, no extra steps are required in a Zone 2 or Class I, Division 2 application. See Murfield et al. [B77].

5.4.2 Fans and ventilation systems

For motors over 1000 V, motors of the forced ventilated/air over designs (e.g., pipe ventilated or WP11 where the air is ducted from another cooling source) typically use blowers driven by TEFC or IP44/54 motors that are suitable for Zone 2 or Class I, Division 2 applications. In the event of ventilation failure, an alarm or an indicator may be appropriate for type Z purging per NFPA 496 [B83]. For air flow patterns and temperature information, refer to R. Mistry et al. [B75].

TEPV or TEFV or TEAAC or IP44/54 motors where cooling is required external to the motor, the fans, fan assembly and ventilation systems should be non-sparking construction. Motors and auxiliary devices operating such systems should be suitable for Zone 2 or Class I, Division 2 locations. Motors with internal fan systems, like WP11 or open type, should be designed non-sparking type construction.

Plastic fans should be fabricated of a non-sparking, semiconductive material to prevent sparking due to mechanical contact or static discharge. Other materials suitable for the environment commonly used are aluminum (with copper content of less than 0.2%), bronze, reinforced conductive plastic (to bleed off static charges), or epoxy-coated steel.

For motors over 1000 V and/or larger horsepower motors, fans are often made of epoxy coated (paint) metal, for example, bronze, steel, or aluminum. For metal fans, consideration should be given to non-sparking materials (i.e., aluminum), but the condition of a fan rubbing is not considered a normal condition. The cooling fan assembly and materials should be designed to prevent sparking as a result of mechanical contact or static discharge.

5.4.3 Accessories

Motor auxiliary devices should be non-sparking, nonincendive, hermetically sealed, or be installed inside an explosionproof enclosure.

Examples of sparking devices are temperature switches, vibration switches, shaft bonding brushes, zero-speed switches, certain types of motor winding temperature sensors (e.g., thermal bi-metallic switch elements), leak detector switches, relays, fuses, etc. These devices should be installed in enclosures suitable for the Class, Group, and Division or Zone; or the switch contacts should be hermetically sealed.

Examples of non-sparking devices are auxiliary fans, resistance temperature detectors, thermocouples, space heaters, current transformers, motor surge capacitors, gapless type arresters, noncontacting shaft vibration probes and their oscillator/demodulators (drivers), partial discharge sensors, and other devices that do not spark during normal operation.

These devices are typically installed in general-purpose enclosures, typically metallic, unless other environmental considerations suggest a different type enclosure. The 2021 CE Code Subrule 18-150 2) c) for Zone 2 locations permits equipment to be installed in Type 4, 4X, IP65 or higher enclosure where the equipment is non-sparking in normal operation, not used for heating purposes, and is not otherwise provided for in Subrule 18-150 2).

The more commonly applied accessories are discussed in 5.4.3.1 through 5.4.3.5. Additional information on other auxiliary devices is in IEEE Std 303.

5.4.3.1 Heaters

Moisture on motor windings can lead to premature aging and even motor winding failures (See Mistry et al. [B74]). To prevent moisture condensation when the motor is not in operation, space heater(s) can be installed to maintain the internal temperature of the motor approximately 5 °C above the ambient temperature. Refer to 5.5.3 for guidance on when to specify space heaters.

Large terminal boxes, especially those with accessories such as surge protection, may also be equipped with space heaters to prevent moisture condensation, thereby reducing contamination of insulator surfaces and corrosion. In addition, heaters submerged in the oil reservoir may be used for motors equipped with oil-lubricated bearings that are exposed to low ambient temperatures. The purpose of this oil heater is to maintain the oil temperature high enough to permit adequate lubrication of the bearing. Thermostats, suitable for the area classification, or other means should be installed to control the required oil temperature when the motor is not operating and the manufacturer should be consulted for the minimum oil temperature. Bearing oil heaters should not be energized in the absence of oil.

Refer to 8.3 for space heater test procedures used for determining space heater temperatures. See Table 2 for a summary of space heater temperature limits under normal operating conditions, marking, and code references.

Table 2—Space heater temperature under normal operating conditions

Zone 2 & Division 2		
Space heater tested and labeled with a T Code		
Space heater tested and labeled with a maximum temperature based on the ambient		
Applicable Code	Ambient ^c	Space Heater Temperature Limit
Zone 2 2021 CE Code Subrule 18-150 3) and Temperature Rule 18-054 ^b	40 °C	T Code temperature does not exceed the AIT
	40 °C	Maximum surface temperature ^a does not exceed the AIT
Division 2 2021 CE Code Subrule J18-150 3) and Temperature Rule J18-054 ^b	40 °C	T Code temperature does not exceed the AIT
	40 °C	Maximum surface temperature ^a does not exceed the AIT
Zone 2		
Space heater tested and labeled with a T Code		
Applicable Code	Ambient ^c	Space Heater Temperature Limit
2020 NEC Section 505.20 (C)	40 °C	T Code temperature does not exceed the AIT
Division 2		
Space heater marked with a maximum temperature based on the ambient		
Applicable Code	Ambient ^c	Space Heater Temperature Limit
2020 NEC Section 501.125 (B)	40 °C	Maximum surface temperature ^a does not exceed 80% of the AIT
Space heater identified for Class I, Division 2 (for example tested and labeled with a T Code)		
Applicable Code	Ambient ^c	Space Heater Temperature Limit
2020 NEC Section 501.125 (B)	40 °C	T Code temperature does not exceed the AIT

^a See 8.3.2 for space heater temperature test method.

^b For the CE Code, space heaters (anti-condensation heaters) shall not have any arcing devices in general-purpose enclosures. The CE Code does not permit the use of temperature-limiting controls to limit the maximum surface temperature of the heater (in case of failure of the limiter). See Figure 6.

^c For higher ambient temperatures, adjust the maximum surface temperature of the space heater. See 8.3.2.

2020 NEC Section 501.125(B) requires space heaters be identified for use in Class I, Division 2 location or the maximum exposed surface temperature (based on a 40 °C ambient) should not exceed 80% of the AIT when operated at rated voltage. (To correspond to an AIT of 200 °C, the maximum space heater surface temperature would be 160 °C.) 2020 NEC Section 505.20(C) requires space heaters be identified with a suitable temperature class (T Code) for use in the Zone 2 location.

The 2021 CE Code Subrules 18-150 3) for Zone 2 and J18-150 3) for Division 2 requires that anti-condensation heaters shall not have any arcing devices, shall not have any temperature-limiting controls, and that the maximum surface temperature under normal operating conditions shall not exceed the minimum ignition temperature (normally the AIT) by reference to the temperature Rules 18-054 for Zones and J18-054 for Divisions.

Heaters are usually resistance heating devices, either of the cartridge type, strip type, or the flexible strip type. Examples of commonly used space heater types are shown in the following figures:

- Figure 3, an example of a strip type space heater
- Figure 4, an example of a flexible strip type space heater
- Figure 5, an example of a wrap around flexible space heater installed on a motor
- Figure 6, an example of a thermostatically controlled tube-type space heater
- Figure 7, an example of a finned tube type space heater

Refer to R. Mistry et al. [B74] for information on space heaters and moisture in motors. All types can be used for winding or terminal box space heaters, but cartridge types are generally used for lube oil heaters. The flexible strip-type heater is typically mounted by wrapping it around the stator end windings. Flexible strip heaters wrapped around the end windings will reduce the clearance between adjacent coils, which could increase the chances for corona and discharges between coils and could reduce the end winding cooling resulting in higher winding temperature rise, particularly on motors over 1000 V. Care must be taken to ensure adequate clearances are maintained to prevent discharges between coils due to restricted

clearances. Precautions should be taken to avoid excessive temperatures on flexible strip-type space heaters, which are in direct contact with the stator winding. The total flexible strip heater temperature is the winding temperature plus the heater temperature rise. When used for heating motor windings, the cartridge-type or strip-type heater is mounted in a space adjacent to the winding. Therefore, it typically requires higher wattage ratings than the flexible strip heater because it first heats the air around it, which then heats the windings of the motor.

Stator winding space heater circuits should be designed so that the heater is energized only when the motor is not in operation. If the stator winding is hot when the space heater is energized, the temperature may be too high for the winding insulation or for the hazardous location. The manufacturer should inform the user if a cooldown time delay is needed prior to energizing flexible (winding wrap-around) heaters, instead of energizing immediately after the motor is de-energized. Surface heaters should be tested when several heaters are placed in close proximity because the physical space between adjacent heaters could affect the surface temperature significantly; therefore, a complete circuit energize test with a thermal test device is recommended to determine that surface temperature limits are met.



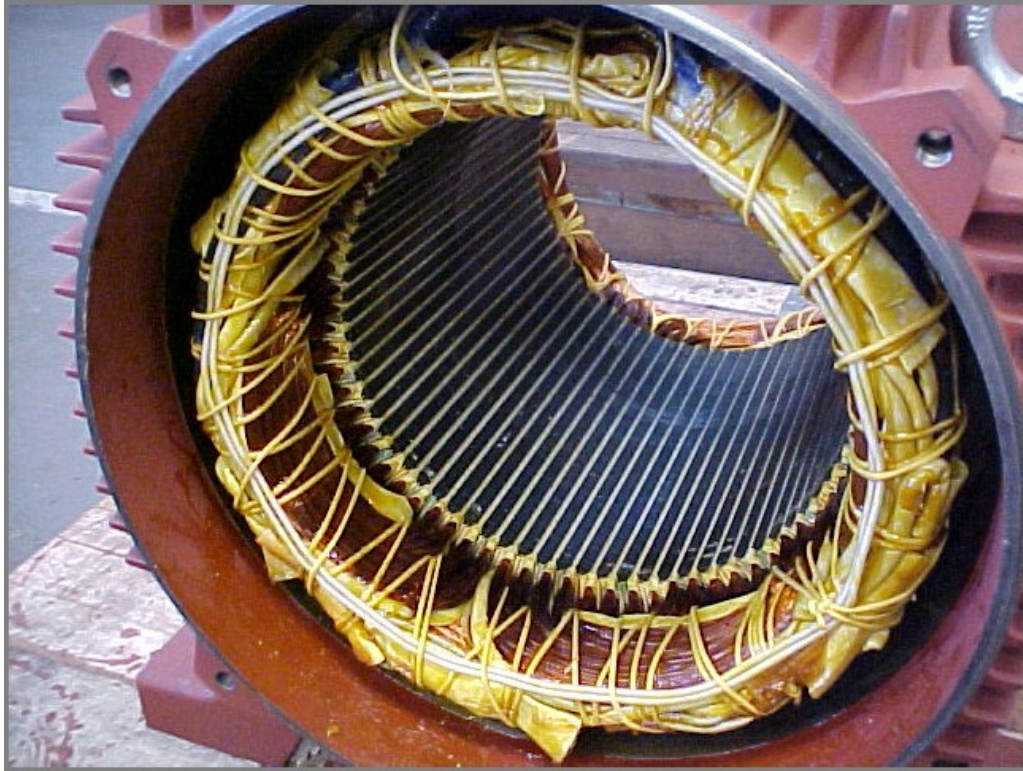
Source: Courtesy of Siemens

Figure 3—Example of a strip type space heater



Source: Courtesy of Siemens

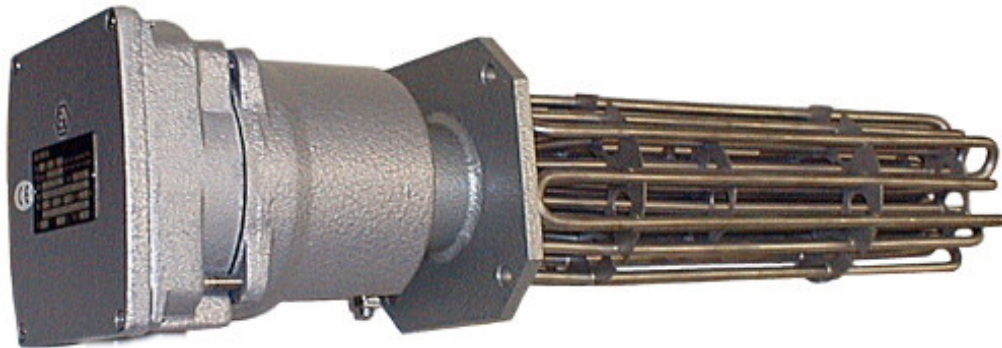
Figure 4—Example of a flexible strip type space heater



NOTE—Silicone insulated heater fastened onto the motor end-turns (white color in photograph).

Source: Courtesy of WEG Electric Corp.

Figure 5—Example of a wrap around flexible space heater installed on a motor

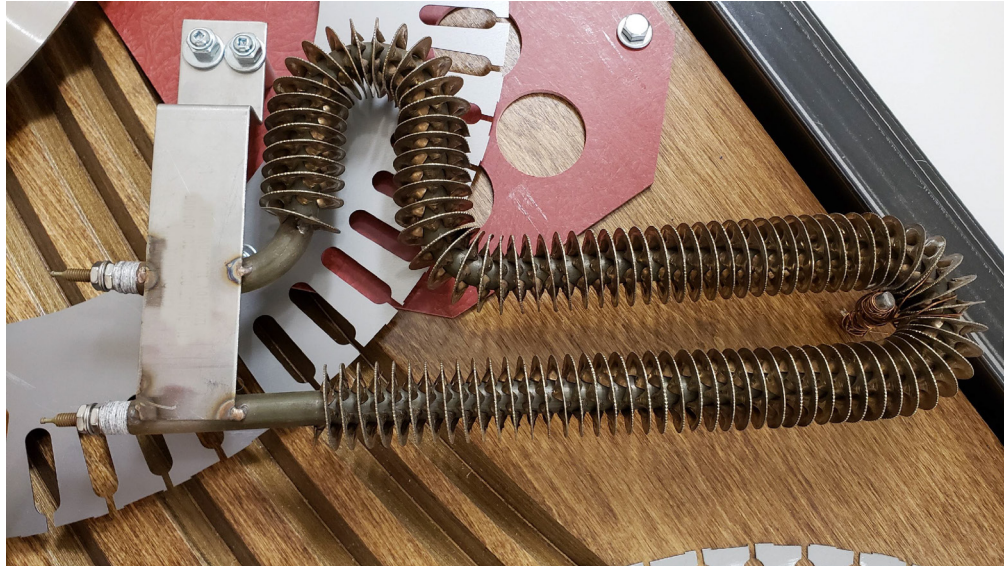


NOTE 1—The CE Code does not permit the use of temperature-limiting controls to limit the maximum surface temperature of the heater (in case of failure of the limiter).

NOTE 2—Temperature controls for space heaters need to be appropriate for the area classification.

Source: Courtesy of IPS

Figure 6—Example of a thermostatically controlled tube-type space heater



Source: Courtesy of Siemens

Figure 7—Example of a finned tube type space heater

5.4.3.2 Surge arresters and capacitors

Non-sparking surge arresters, such as metal-oxide varistor (MOV), sealed type, and specific duty surge protective capacitors can be installed in general-purpose enclosures. Surge protection types other than those described above require enclosures approved for Class I, Division 1 locations or Zone 1 locations. [See 2020 *NEC* Article 501.35(B) and 505.20(C) or the 2021 *CE Code* Subrules 18-150 2) a) and 18-150 2) c).]

NOTE 1—A MOV type surge arrester is currently known as a metal-oxide surge arrester (MOSA) in IEEE Std C62.11 [B66].

NOTE 2—For a motor application, using three single-phase specific duty surge capacitors instead of one three-phase specific duty surge capacitor avoids the potential for a phase-to-phase short-circuit fault within the capacitor. Surge arresters and surge capacitors are generally not recommended to be installed at the motor terminals for ASD applications. See IEEE Std 3004.8-2016 [B62].

5.4.3.3 Brakes

Brakes are typically mechanical friction devices used for the purpose of either holding a fixed load or producing torque to decelerate a load. When a mechanical friction brake is used to hold a static load, the heat generation is negligible.

5.4.3.4 Shaft bonding devices (brushes) and insulated bearings

Shaft voltage was historically only a concern for motors over 1000 V, but the shaft voltage may be a concern for motors 1000 V and below where adjustable speed drives (ASDs) are used. Motor manufacturers should be consulted regarding the applicability of shaft -bonding brushes. Shaft voltages can result in the flow of destructive currents through motor bearings, manifesting themselves through pitting of the bearings, scoring of the shafts, and eventual bearing failure. Bearing currents can be attributed to the following three different causes: electromagnetic asymmetries, capacitively coupled bearing voltages, and circulating currents created by operation with some ASDs. See Schiferl and Melfi [B95].

5.4.3.4.1 Shaft bonding devices applications and locations

The method of protecting bearings against bearing currents depends on the root cause of shaft voltages. This is application/design specific, and manufacturer and engineering input should be used. There may be both magnetically induced voltage as well as capacitively coupled voltage on the shaft (See Schiferl and Melfi [B95]). Methods to avoid bearing currents include adequately insulated bearings, shaft bonding devices and system/equipment selection, designs to reduce shaft voltages, and insulated couplings (See Schiferl and Melfi [B95]).

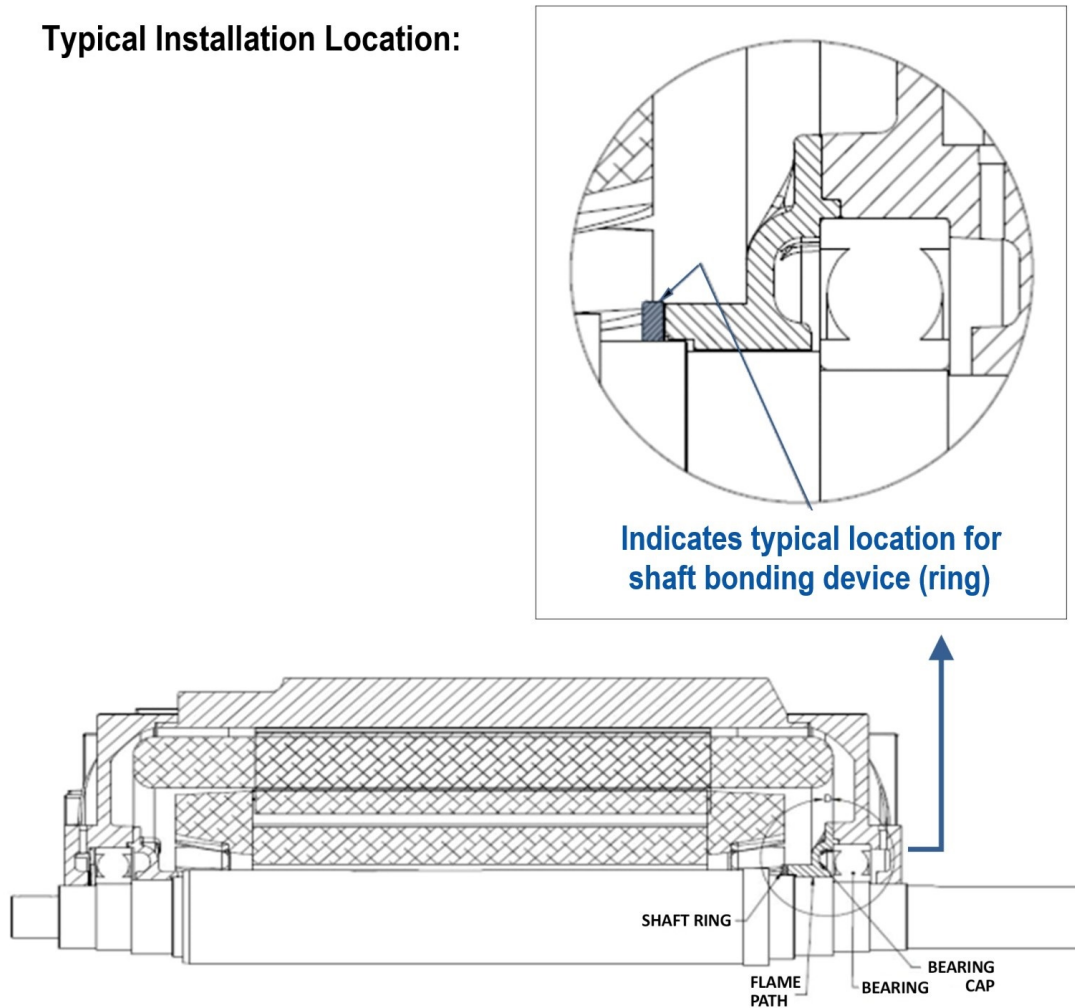
In many cases involving magnetically induced voltages, insulating the non-drive end bearing while bonding the drive end bearing to the frame is sufficient to prevent circulating currents in both the motor and the driven equipment. Because magnetically induced voltages are generated in the rotor, an end-to-end voltage is created between the drive end and non-drive end of the shaft. Therefore, the insulated non-drive end shaft and bearing will be at a higher voltage to the frame than the bonded end.

Capacitive coupled voltage is caused by common-mode voltage (CMV) in the ASD supplied waveform being transferred by capacitive coupling to the rotor. This voltage is the same along the length of the shaft. In cases where the capacitive voltage on the rotor could be sufficient to cause bearing damage, in addition to insulating the non-drive end bearing, a shaft bonding device to shunt this capacitive charge may be added either external to or inside the drive end bracket, to drain the charge from the rotor and bypass the bearings. Methods such as common-mode filters at the inverter, different inverter topology and special “drive supply cables” with three symmetrical ground conductors can be used to help minimize the CMV on the stator and rotor. See Abdelazim et al. [B1] and Schiferl and Melfi [B95].

Typical bearing current reduction applications include the following:

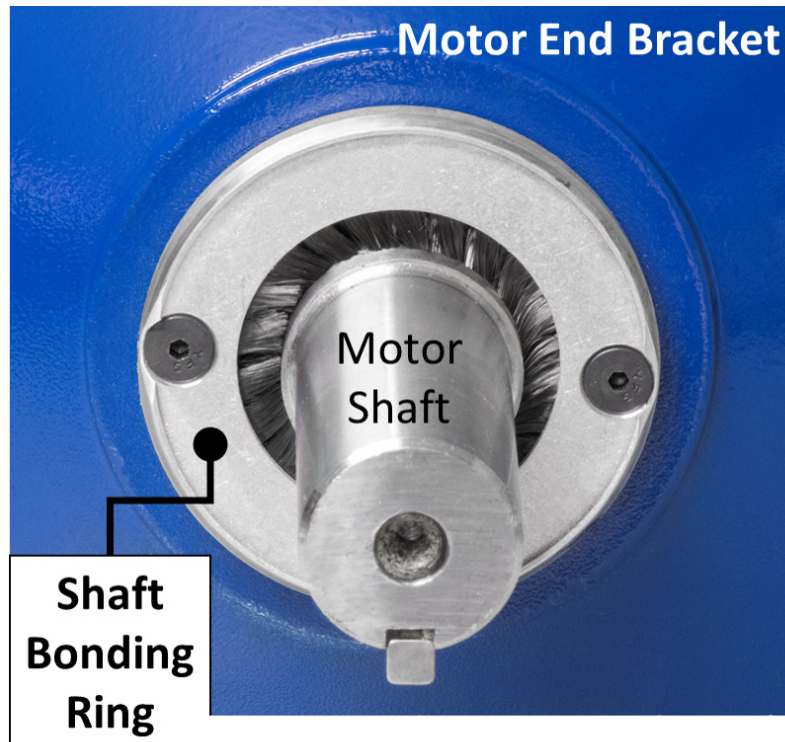
- a) For larger (over about 300 kW) fixed speed machines, in most cases, it is sufficient to insulate the non-drive end bearing and bypass any insulation on the drive end bearing with a jumper that can be lifted to check the overall insulation. In cases where a motor drives loads at each end, other measures such as insulated couplings and shaft bonding devices may be needed.
- b) For ASD supplied machines or where voltages are transferred from the coupled equipment, shaft bonding devices are sometimes required to dissipate the shaft voltages and avoid damaging current passing through the bearings. Insulated couplings may also be considered.
- c) It is possible to reduce the CMV reaching the stator windings, and therefore the rotor, by using ASD topologies that give lower CMV at their output by using filters or other CMV reduction methods at the inverter output and by using cables with three symmetrical ground conductors as discussed in 6.3.3 (See Abdelazim et al. [B1]).
- d) When both motor bearings are insulated, typically a drive end bearing should be bonded to the frame; otherwise the shaft voltage can be transferred to the driven equipment, and in this case, insulating the coupling should be considered.
- e) In some cases, install shaft bonding devices. Refer to Figure 8 for an illustration of the typical mounting of a bonding device installed inside the motor enclosure, and, refer to Figure 9 for an illustration of a typical bonding device (ring) installed outside the motor enclosure.

Typical Installation Location:



Source: Courtesy of AEGIS

Figure 8—Typical mounting of a bonding device installed inside the motor enclosure



Source: Courtesy of AEGIS

Figure 9—Typical bonding device (ring) installed outside the motor enclosure

Particular applications include the following:

- f) NEMA frame motors [typically 370 kW (500 hp) or less] with anti friction bearings in fixed speed sine wave applications seldom have sufficient end-to-end shaft voltage to require remedial measures. If insulated non-drive end bearings or shaft bonding devices are used, there typically will not be enough energy to cause ignition of any gas mixtures.
- g) For sine wave applications of larger fixed speed machines [typically over 370 kW (500 hp)], these machines will often have insulated non-drive end bearings to help prevent circulating currents. Although not often applied for these machines on sine wave power, shaft bonding devices may sometimes be applied near the drive end bearing for special applications.
- h) NEMA frame (e.g., IEEE Std 841) motors fed by ASDs often have ASD-induced CMV buildup on the shaft that can cause bearing damage. Methods to address this possibility include motor input CMV reduction methods, insulated bearings, and drive end shaft bonding devices. There have been no reported instances of gas ignition from arcing in these situations, and Annex G describes calculation methods for discharge energy.
- i) ASD supplied above NEMA frame motors typically have higher capacitances and stator CMV levels than NEMA frame motors so the need for insulated bearings and shaft bonding is greater, while available energies may also increase. Annex G discusses methods to estimate the risks for both induction and synchronous machines.
- j) Brushless exciters have stator and rotor windings with the stator being supplied by a relatively low power source, usually power electronics. Although the rotor usually has a higher induced ac voltage, it is insulated and under normal operation, there is no arcing expected.

- k) Magnetic bearings have similarities to lower power induction motors, with stator windings supplied by power electronics and no rotor windings. At present, magnetic bearings are relatively uncommon and there is limited available information on their performance. Therefore, each application should be reviewed with the manufacturer.

5.4.3.4.2 Shaft bonding devices in hazardous (classified) locations

Shaft bonding devices are considered as inherently sparking devices. If they are used in hazardous (classified) locations, the bonding devices should be:

- a) Determined to be nonincendive

NOTE 1—Guidance for determining if the discharge energy is nonincendive is in G.3.

or

- b) Contained in explosionproof or purged and pressurized (See NFPA 496 [B83]) housings or use other approved means to provide suitable guarding of the shaft bonding devices in accordance with 2020 *NEC* 501.125 (A), for Class I, Division 1 locations or are identified for use in Class I, Division 2 as per 501.125(B); or 2020 *NEC* 505.20 (C) for Zone 2 locations.

NOTE 2—The shaft bonding assembly may be in its own explosionproof or purged and pressurized enclosure or inside an explosionproof or purged and pressurized motor.

NOTE 3—When shaft bonding devices are used, they should be installed in a visible shaft/bearing location. If shaft bonding devices are installed inboard and not visible, a nameplate should be installed indicating the motor is provided with internally mounted shaft bonding device(s) and periodic visual wear inspections should be performed.

NOTE 4—For additional information on shaft bonding in hazardous locations, see Melfi et al. [B70].

5.4.3.5 Nameplate markings

No special nameplate markings of Class I, Division 2 are required for open or nonexplosionproof enclosed motors, such as squirrel-cage induction motors without brushes, switching mechanisms, or similar arc-producing devices. See the 2021 CE Code Subrule 18-150 2) e) and the 2020 *NEC* 501.125 (B): “In Class I, Division 2 locations, the installation of open or nonexplosionproof enclosed motors, such as squirrel-cage induction motors without brushes, switching mechanisms, or similar arc-producing devices that are not identified for use in a Class I, Division 2 location, shall be permitted.”³⁵ Likewise, as noted in *NEC* Article 505.20(C) Exception #4, “In Zone 2 locations, the installation of open or nonexplosionproof or nonflameproof enclosed motors, such as squirrel-cage induction motors without brushes, switching mechanisms, or similar arc-producing devices that are not identified for use in a Zone 2 location shall be permitted.”³⁶

Increased Safety “eb” Motors identified for Zone 1, as per 2020 *NEC* 505.22 and the 2021 CE Code Table 18 are permitted in Zone 2.

Motors can be marked in accordance with NEMA MG 1, IEEE Std 841, API 547, API 546, API 541, CAN/CSA C22.2 No. 100-2014 [B20], and/or the 2020 *NEC*. It is not necessary to put temperature class (T Code), maximum surface temperature, or “designed for Division 2 or Zone 2” on the nameplate. However, manufacturers may provide this additional nameplate information or similar based on the user’s

³⁵See Footnote 8.

³⁶See Footnote 8.

request. Users may choose to put additional information, such as these, on the nameplate because the users do not produce the nameplates, but they can specify additional markings if desired.

Motors listed by third party approval agencies are required to have nameplate markings in accordance with applicable testing standards. For example, the nameplate for an explosionproof single-phase motor listed by a Nationally Recognized Testing Laboratory should show the Class, Division, Group, and temperature class (T Code) and/or Zone, Group, and temperature class (T Code).

If the motor has a space heater, then the space heater should have a nameplate in accordance with the 2020 *NEC* and the 2021 CE Code Subrule 18-150.3) showing a T Code or a maximum surface temperature based on a 40 °C ambient (or higher). Refer to 5.4.3.1 and 8.3.2.

5.5 Application considerations for motors 1000 V and below

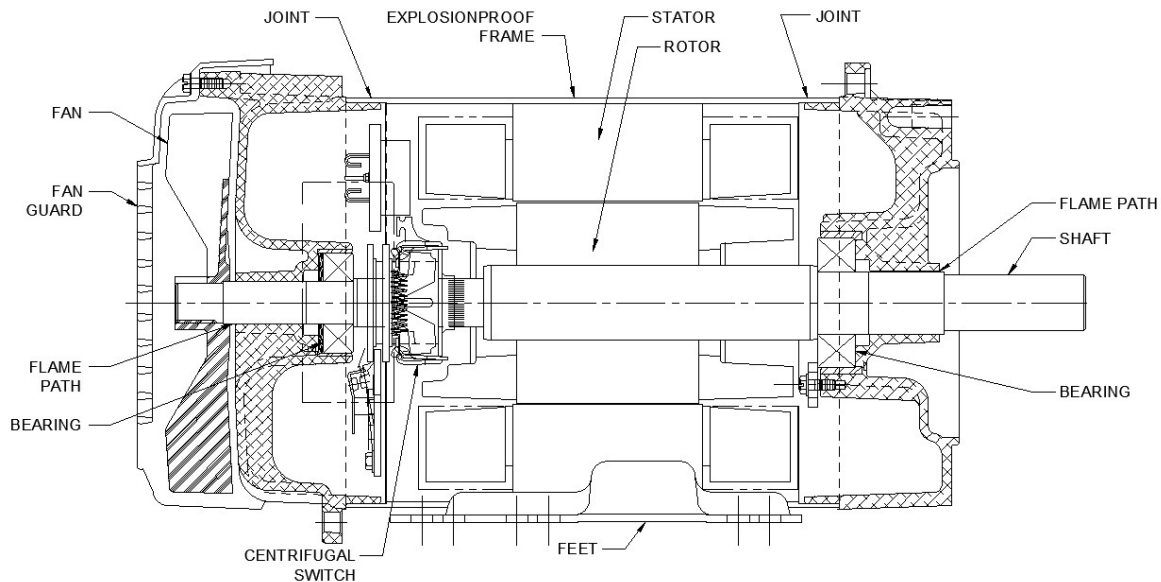
This subclause describes specific application considerations that apply to motors 1000 V and less. These considerations are in addition to the general considerations for motors applied in Zone 2 or Class I, Division 2 locations, discussed in 5.4 and the Common application considerations in 5.1.

NEMA Design A or B motors should be applied for use in Zone 2 or Class I, Division 2 locations where the torque requirements can be matched to load, such as for centrifugal pumps. Where the load torque characteristics require a Design C or D motor (e.g., a positive displacement pump), this application should be considered Uncommon and the motor manufacturer should be consulted regarding the surface temperature limits for the Zone 2 or Class I, Division 2 location.

There are two motor designs that are discussed: single-phase motors and three-phase motors.

5.5.1 Single-phase motors

Single-phase motors generally have a starting winding connected through a series capacitor by a centrifugal switch. The switch may be a sparking device. So, single-phase motors with sparking switches installed in Zone 2 or Class I, Division 2 locations should be explosionproof motors or incorporate suitable protection methods for the area classification. Single-phase motors with sparking switches are generally avoided in Zone 2 or Class I, Division 2 locations and three-phase motors are utilized where practicable. Refer to Figure 10 for an explosionproof single-phase motor. Some single-phase motors are designed with switches approved for Zone 2 or Class I, Division 2, and do not require explosionproof motor enclosures.



Source: Courtesy of Marathon Electric.

Figure 10—Explosionproof single-phase motor

5.5.2 Three-phase motors

Three-phase motors are generally used, from fractional horsepower and up, to allow the use of open or nonexplosionproof enclosed or nonflameproof enclosed motors where practicable. Three-phase motors do not spark during normal operation if they are designed, built, installed, and maintained properly.

5.5.3 Specification information

When operating conditions are within the Common application conditions listed in 5.1, the minimum information that should be provided to the motor manufacturer is in Table E.1 and Table E.2 in Annex E. Information is generally provided to the motor manufacturer in a data sheet. For those applications where the operating conditions are outside those defined by 5.1, applicable additional information in Table E.3, which is in addition to that in Table E.1 and Table E.2, should be provided to the motor manufacturer. These are discussed in Clause 6. Other information that may be needed by the motor manufacturer for a Zone 2 or Class I, Division 2 application is in Table E.4.

As an example, one item in Table E.1 is a space heater. When a space heater is required, the motor manufacturer should determine the space heater's maximum sheath temperature based on information provided. Refer to 8.3 for the space heater temperature test procedure and refer to 5.4.3.1 for additional information on application and types of space heaters. Refer to API RP 14F-2021 [B4], API 14FZ-2013 [B5], and API RP 540-1999 [B8] for guidance on when to specify space heaters. Refer to R. Mistry et al. for information on types and sizing of space heaters [B74].

5.6 Application considerations for machines over 1000 V

This subclause describes specific application considerations that apply to machines over 1000 V. These considerations are in addition to the general considerations for motors applied in Zone 2 or Class I, Division 2 locations, discussed in 5.4 and Common application considerations in 5.1.

Based on the machine design, application, and operation, consideration should be made to follow certain procedures to help mitigate the machine from sparking or being a heat source for potential ignition. The machine system design and operating methods should also reduce introduction of flammable mixtures to potential heat sources. Some of the motor design considerations for Zone 2 and Class I, Division 2 and applications are included in industry standards such as IEEE Std 841 for motors 370 kW (500 hp) and below, API 547 for motors 250 hp and larger, API 541 (induction) for 375 kW (500 hp) and larger, and API 546 (synchronous) for machines 500 kVA and above. In addition, for machines over 5 kV consider at least the following: enclosure selection and cooling method (5.4.1 and Annex D); pressurization, prestart purging, or prestart ventilation (6.12); gas detection and sniffing (6.12); insulation system (5.6.2.4); corona energy level (Annex G); gas characteristics and area classification (Clause 4 and Annex C); and soft-start and other starting methods.

When operating conditions are within the Common application conditions listed in 5.1, the minimum information that should be provided to the motor manufacturer is in Table E.1 and Table E.2 in Annex E. Information is generally provided to the motor manufacturer in a data sheet.

For those applications where the operating conditions are outside those defined by 5.1, applicable additional information in Table E.3, which is in addition to that in Table E.1 and Table E.2, should be provided to the motor manufacturer. These are discussed in Clause 6. Other information that may be needed by the motor manufacturer for a Zone 2 or Class I, Division 2 application is in Table E.4.

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5.6.1 Heat source considerations

Manufacturers sometimes use nonmetallic components as part of the motor to help minimize circulating currents. Use of nonmetallic material lowers the stray losses and circulating currents in enclosure housings. Current may be induced in steel bolts used to hold other components to nonmetallic parts where they are located within the magnetic field of the stator winding. This is particularly true during motor starting. If the bolts are made of a magnetic material, they may become hot. Use of nonmagnetic bolts, such as 300 series stainless steel, helps minimize circulating currents and hot components. Type 300 series stainless steel may be susceptible to galling and may have lower tensile strength and torque requirements, so the motor manufacturer should be consulted on the uses of this hardware type. Grounding of any ungrounded hardware is recommended, as there are recorded instances of intense sparking between ungrounded hardware and adjacent ground planes. (See Bartels and Brandford [B10], Bredthauer et al. [B16], Costello [B31], Merrill and Olsen [B71], and BEAMA Ltd. [B93].)

One of the main heat sources of motors is the rotor. Rotors with axial and radial ducts for cooling ventilation tend to have cooler temperatures than nonducted or axial duct only rotors. Refer to Annex H and Table 1. However, radial ducts in the rotor increase the possibility of rotor sparking during motor starting. In general, two-pole motors tend to have higher temperatures than slower motors, but many other factors also impact the overall temperature. Refer to H.1 for a detailed discussion of hot motor surfaces.

5.6.2 Sparking considerations

This subclause discusses sparking considerations that are discussed in more detail in Annex G.

5.6.2.1 Sparking across bearing lubrication

Some motor bearing systems are designed by the motor manufacturer to be insulated to protect the bearing from conducting shaft currents across the oil film. In some applications, only the drive end bearing is insulated. In some other applications, both bearings are insulated and a bonding jumper is installed on one bearing. Voltage induced on a motor shaft may result in a circulating current with a magnitude limited by the bearing impedance. This bearing impedance acts as a capacitor with the oil film acting as the dielectric in a capacitor that is charged by the shaft voltage. When the shaft voltage across the oil film capacitor reaches its dielectric breakdown voltage a discharge occurs which can cause pitting in the bearing. For fixed speed applications, experience shows that the amount of energy discharged across the oil film does not produce a spark that could cause ignition. It is recommended that the insulation and bonding should be discussed with the motor manufacturer and maintained to help prevent damage to the bearings. (See Costello [B31].) For ASD applications, refer to 6.3.1.3 and G.3 for CMV calculations showing the amount of energy discharge across the oil film.

5.6.2.2 Joints and clearances

Motor characteristics that would help minimize sparking across joints and clearances include at least the following:

- a) One-piece cast or welded fabricated frames, so there is no risk of sparking across frame joints.
- b) An adequate number of bolts to secure bearing brackets and end-covers to the frame. An adequate number of bolts should provide a path for current flow during starting.
- c) Machined surfaces between bearing bracket and frame mating surfaces provide good contact between frame and bracket.
- d) Adequate clearances between motor windings and structural parts to reduce sparks or discharges between the components.

Where needed for multi-section motors, equipotential bonding conductors should be installed to help prevent sparking between sections (See the *NEC*, Section 501.125(B), Informational Note No. 2 and Section 505.20(C), Informational Note No. 2). Bonds should be applied as specified by the motor manufacturer.

5.6.2.3 Rotors

Some manufacturers can offer motors with rotor designs that are less susceptible to sparking. Refer to Annex G for further discussion on rotor designs.

Some rotor design features that may reduce or eliminate sparking are as follows:

- a) Motors with cast rotors
- b) Motors with tight fitting rotor bars in the slots
- c) Motors with high conductivity end rings
- d) Motors with no skew (in either the rotor or stator slots) for motor ratings greater than 200 kW per pole
- e) Motors with no radial cooling ducts in the rotor

NOTE—Also refer to UL 60079-7 [B103] and CAN/CSA C22.2 No. 60079-7 [B25].

Manufacturers consider these features during the motor design. Also refer to 6.12 for further discussion of Uncommon Applications.

5.6.2.4 Insulation systems for machines at 6 kV and above

Insulation systems for high voltage machines at 6.0 kV and above may be designed to help minimize partial discharge and corona activities, which can escalate to sparking and failures. Designs may include selection and application of conducting and voltage grading tape on high voltage coils and providing adequate space between coils of the winding. The application of motors in hydrogen (Gas Group B for Divisions or Gas Group IIC for Zones) may require special attention or treatment. See Rautee et al. [B92], Stranges et al. [B96]. Also refer to 6.12 for further discussion of Uncommon Applications.

NOTE—Similar design considerations apply for MV motors used on ASD applications. See 6.3.3.

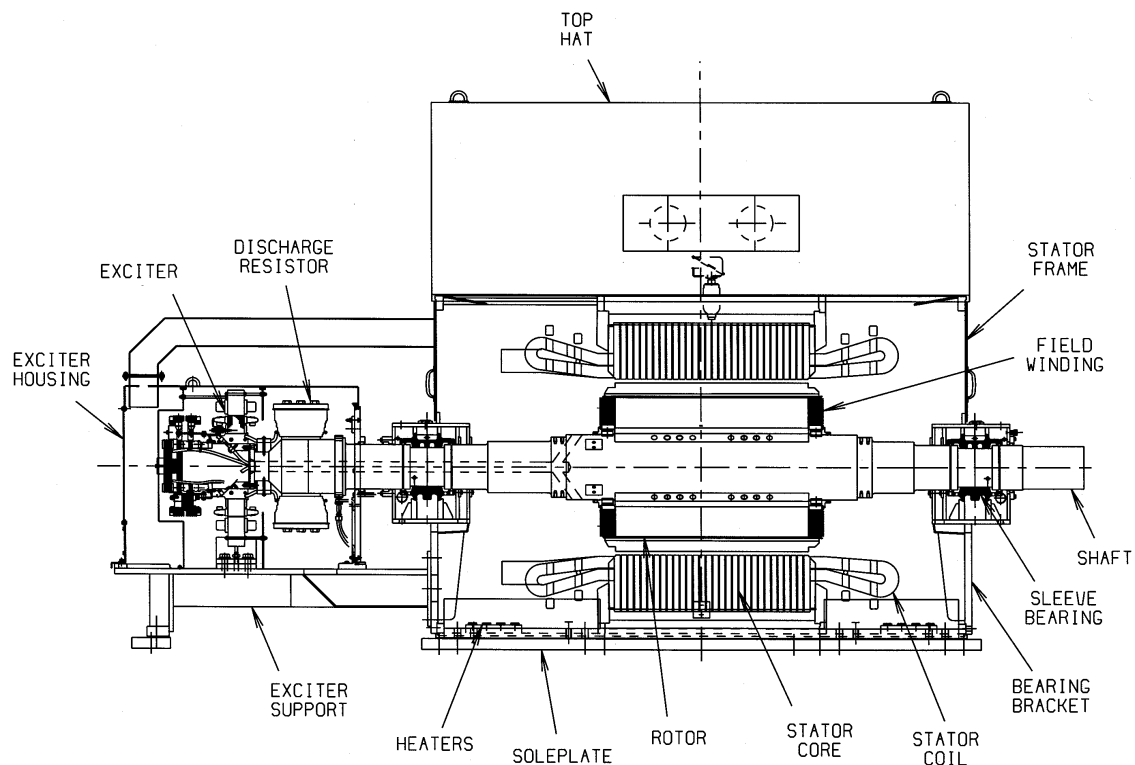
5.6.3 Separate lube oil systems

Lubricating systems of gas compressors or hydrocarbon pumps should be kept separate from a driving motor's lubricating system. This is necessary to preclude combustibles and flammables from entering the motor through the oil system. The electrical components of the lubricating system should meet the hazardous area classification. (Reference IEEE Std 242™-2001, 10.5.3.3.4 (c) [B57] and IEEE Std 3004.8™-2016, 8.5.4.5 c) [B62])

Common lube oil systems should be avoided because a pump or compressor process seal failure can allow flammable material to enter the lube oil system. This circulated lube oil containing flammable materials then enters the motor bearing housing. Flammable material can pass into the motor enclosure through the seals between the motor's bearing housing and the motor enclosure. Over time an explosive accumulation of flammable material can build up in the motor enclosure. This explosive material buildup could then be ignited by an internal ignition source. Although starting of a motor is not considered a normal operation, if the flammable material accumulated during a running condition, it might also be ignited during a future start. Refer to Annex J, Table J.1, items 3, 4, 6, 7, and 8. An alternative to total separation of the two lubricating systems is to install degassing equipment to continually remove gas from the lube oil system.

5.7 Application considerations for synchronous machines

This discussion highlights brushless exciter-type synchronous motors, which are the most suitable for Zone 2 and Class I, Division 2 locations. For information on the design of synchronous machines, refer to NEMA MG 1, API 546, IEEE Std C50.12™ [B64], and IEEE Std C50.13™ [B65]. Starting, stalling, and short-circuit conditions are abnormal conditions and are not considered. Brushless synchronous motors today use an exciter physically direct-connected to the motor shaft. The brushless exciter has a three-phase ac armature winding. The stationary field winding is on poles on the stator and is connected to an excitation supply source. The generated ac current is directly connected along the shaft to a rotating three-phase diode wheel, where the ac is rectified to dc before going to the motor's main field. This excitation system integrated with the motor helps minimize or eliminate the possibility of sparks during operation. An example of a brushless synchronous motor is shown in Figure 11.



Source: Courtesy of General Electric.

Figure 11—Typical cutaway of brushless synchronous motor

Brush-type exciter synchronous motors do not meet Zone 2 or Class I, Division 2 application requirements due to sparking between the brushes and the slip rings, unless a suitable enclosure is used. For division locations, the brush area enclosure should be either a Class I, Division 1 housing or appropriately purged and pressurized (reference NFPA 496 [B83]). For zone locations, the brush area enclosure should be either AEx “d” (reference UL-60079-1 [B101]) or Ex d for the 2021 CE Code (reference CAN/CSA C22.2 No. 60079-1 [B23]) or AEx “p” enclosure (reference UL-60079-2 [B102]) or Ex pz for the 2021 CE Code (reference CAN/CSA C22.2 No. 60079-2 [B24]). Some older motors of this type may still be in operation. The collector rings and brushes are shown in Figure 12.