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

IEEE Industry Applications Society

Sponsored by the
Petroleum and Chemical Industry Committee

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Petroleum and Chemical Industry Committee
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Approved 20 December 2001

IEEE-SA Standards Board

Abstract: This guide was developed to assist individuals, organizations, and suppliers with the application of motors in Class I, Division 2 locations, where flammable gases and vapors may occasionally be present. Three-phase and single-phase ac synchronous and induction electric motors, fractional through very large sizes, are covered in this guide. Primary emphasis is on the use of general-purpose enclosures and precautions against excessive surface temperatures and sparking of rotor bars and enclosure joints. Results of motor surface temperature tests and calculations performed by Working Group Member companies are documented in the guide. Guidance is included for maintaining the life-cycle integrity of motors in Class I, Division 2 locations.

Existing codes and standards contain cautionary notes for general-purpose motor applications in Class I, Division 2 areas. Industry experience and established practices are documented for the application of general-purpose motors in Class I, Division 2 locations and guidance is given for applying motors in these locations. This guide is not a specification and is not intended for use as a specification for purchasing motors installed in Division 2 locations.

Keywords: autoignition temperature, Class I, Division 2, classified locations, enclosure sparking, hazardous locations, induction motor, motor, motor enclosure, motor temperature, multisection motor, paint test, rotor, rotor sparking, rotor temperature, synchronous motor, T Code, temperature code

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Introduction

[This introduction is not part of IEEE Std 1349-2001™, Guide for the Application of Electric Motors in Class I, Division 2 Hazardous (Classified) Locations.]

This guide was developed to assist individuals, organizations, and suppliers with the application of motors in Class I, Division 2 locations, where flammable gases and vapors may occasionally be present.

Participants

At the time this guide was completed, the Motors in Hazardous Locations Working Group had the following membership:

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The final conditions for approval of this guide were met on 20 December 2001. The guide was conditionally approved by the IEEE-SA Standards Board on 7 December 2001, with the following membership:

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Contents

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

1. Overview

This guide is divided into several clauses. 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 Class I, Division 2 locations. Consideration should be given to the maximum recommended Division 2 exposed motor surface temperatures described in 5.2 for Common applications. Clause 6 provides guidance for Uncommon applications of motors in Class I, Division 2 locations. Clause 7 discusses the operating and maintenance considerations that mitigate hot surface temperatures and sparking when the motors are located in a Division 2 location. Clause 8 describes acceptable test methods for determining internal and external motor surface temperatures for the purpose of applying motors in Class I, Division 2 locations.

Ten annexes are included: A) bibliography, B) major regulations and standards covering applications of motors in potentially flammable atmospheres, C) AITs and group designations for Class I materials, D) motor enclosure types, E) motor information tables to check a motor data sheet, F) multisection motor inspection procedure, G) motor sparking considerations, H) surface temperature considerations, I) surface temperature test methods, and J) event history.

1.1 Scope

Three-phase and single-phase ac synchronous and induction electric motors in sizes from fractional horsepower and larger are covered in this guide. Primary emphasis is on the use of general-purpose enclosures and precautions against excessive surface temperatures and sparking of rotor bars and enclosure joints. This guide provides guidance for maintaining the life-cycle integrity of motors in Class I, Division 2 locations.

This guide does not cover ac wound rotor motors and dc electric motors. Motors installed in locations other than Class I, Division 2 locations are not covered in this guide.

The voltage breaks in this document are a) 1000 V and less and b) over 1000 V.

1.2 Purpose

Existing codes and standards contain cautionary notes for general-purpose motor applications in Class I, Division 2 areas. This guide documents industry experience and established practices for the application of general-purpose motors in Class I, Division 2 locations and provides guidance for applying motors in these locations. This guide is not a specification and is not intended to be used as a specification for purchasing motors installed in Division 2 locations.

1.3 Background

As early as 1905, the *National Electrical Code*® (*NEC*®)[1] recognized that a suitable enclosure would be required when an electric motor was installed in the vicinity of combustible materials [B28].[2] In the early 1920s, the *NEC* began to designate and recognize flammable and combustible materials by the current Class system without Division subcategories. With this system, an electric motor located within a Class I location was required to have an explosion-proof 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, nonexplosion-proof 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. 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.

This guide addresses two Fine Print Notes (FPNs): Section 501-8(b) FPN No. 1 was added to the *NEC* in 1984 as follows: "It is important to consider the temperature of internal and external surfaces that may be exposed to the flammable atmosphere."[3] Section 501-8(b) FPN No. 2 was added to the *NEC* in 1993 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."[3]

Since the mid-1980s, at least five 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 5.5 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

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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 Class I, Division 2 locations.

1.4 Industry experience

By far the world's largest user of open-type and TEFC motors in Class I, Division 2 locations is the petrochemical industry. Electric motors are used to drive centrifugal and positive displacement pumps, compressors, mixers, fans, 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 hazardous locations; see Haynes and Messec [B22]. For more than 60 years, there have been no known incidents caused by sparking or excessive surface temperatures involving motor sizes up to 5 MW or motor voltage ratings up to 5.5 kV; see Bartels and Bradford [B7] and BEAMA Ltd. [B37]. (Refer to Annex J.)

2. References

This guide shall be used in conjunction with the following publications.

API 541-1995, Form-Wound Squirrel-Cage Induction Motors—250 Horsepower and Larger, Third Edition, April 1995.[4]

API 546-1997, Brushless Synchronous Machines—500 kVA and Larger, Second Edition, June 1997.

IEEE Std 303-1991™ (Reaff 1996), IEEE Recommended Practice for Auxiliary Devices for Motors in Class I, Groups A, B, C, and D, Division 2 Locations.[5]

IEEE Std 841-1994™, IEEE Standard for Petroleum and Chemical Industry—Severe Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 500 hp.

IEEE Std 1068-1996™, IEEE Recommended Practice for the Repair and Rewinding of Motors for the Petroleum and Chemical Industry.

NEMA MG-1-1998, Motors and Generators.[6]

NFPA 70-1999, *National Electrical Code®*, (*NEC®*).[7]

[4]API publications are available from the American Petroleum Institute, 1220 L Street NW, Washington, DC 20005-4070, USA (http://www.api.org/).
[5]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).
[6]NEMA publications are available from the Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80122, USA (http://global.ihs.com/).
[7]NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (http://www.nfpa.org/).

3. Definitions, abbreviations, and acronyms

3.1 Definitions

For the purposes of this guide, the following terms and definitions apply. IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition, should be referenced for terms not defined in this subclause [B23].

3.1.1 approved: Acceptable to the authority having jurisdiction.[8]

3.1.2 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.

3.1.3 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.[9]

3.1.4 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 RTD) in accordance with NEMA MG-1-1998,[10] 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-1-1998 temperature rise tables.

3.1.5 Class I, Division 2: A location 1) in which volatile flammable liquids or flammable gases and 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 gases or 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 gases or vapors 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) of the 1999 *NEC*].[8]

3.1.6 Common application: A Common motor application in Class I, Division 2 locations is where a synchronous or low-slip induction motor is operating at rated or below full-load steady-state conditions and within the parameters given in 5.1.

3.1.7 corona: A type of localized discharge resulting from transient gaseous ionization in 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.)

3.1.8 exposed surface: A surface that is internal to an enclosure or an external surface of an enclosure which 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

[8]See footnote 3.

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[10]Information on references can be found in Clause 2.

the rotor, stator, or space heater surfaces of open and 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 explosion-proof, pressurized, or force ventilated enclosures.)

3.1.9 explosion-proof apparatus: Apparatus 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.[11]

3.1.10 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.[12]

3.1.11 minimum igniting current (MIC) ratio: The ratio of the minimum current required from an inductive spark discharge to ignite the most easily ignitable mixture of a gas or vapor, divided by the minimum current required from an inductive spark discharge to ignite methane under the same test conditions.[12]

3.1.12 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.[12]

3.1.13 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.

3.1.14 normal operating condition: As applied to motors, a normal operating condition is operating at rated full-load steady state conditions.[11] Locked-rotor, single-phasing, and operating above base nameplate kilowatt or horsepower are not normal operating conditions.

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

3.1.16 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.

3.1.17 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.

3.1.18 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.

3.1.19 Uncommon application: An Uncommon motor application in Class I, Division 2 locations is where the motor is operating or applied outside the parameters given in 5.1.

[11]See Footnote 3.
[12]See Footnote 9.

3.2 Acronyms and abbreviations

AFD	adjustable frequency drive
AIT	autoignition temperature
API	American Petroleum Institute
ASD	adjustable speed drive
ASTM	American Society for Testing and Materials
CEC	Canadian Electrical Code
CENELEC	European Committee for Electrotechnical Standardization
CSA	Canadian Standards Association International
FLC	full-load current
FLT	full-load torque
FPN	Fine Print Note (used in the *National Electrical Code*®)
IEC	International Electrotechnical Commission
LEL	lower explosive limit
LRC	locked rotor current
MESG	maximum experimental safe gap
MIC	minimum igniting current
MIE	minimum ignition energy
MOV	metal oxide varistor
NEC	National Electrical Code
NEMA	National Electrical Manufacturing Association
NFPA	National Fire Protection Association
ODE	opposite drive end
ODP	open dripproof
OEM	original equipment manufacturer
PWM	pulse-width modulation
RP	recommended practice
RPM	revolutions per minute
RTD	resistance temperature detector
SCR	silicon controlled rectifier
SF	service factor
T Code	Temperature Code or Identification Number per 1999 *NEC* Table 500-5(d)
TEAAC	totally enclosed air-to-air cooled
TEFC	totally enclosed fan cooled
TENV	totally enclosed nonventilated
TEPV	totally enclosed pipe-ventilated
TEWAC	totally enclosed water-to-air cooled
TFE	tetrafluoroethylene
UL	Underwriters Laboratories Inc.
WPI	weather protected Type I
WPII	weather protected Type II

4. Phenomenon of a motor as a possible ignition source

The phenomenon of a motor being a possible ignition source in a Class I, Division 2 location is discussed in this clause.

NOTE—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.

As a consequence of one or more of the above improvements, a particular facility's area classification may have changed from when the facility first went into service. A common practice in petrochemical facilities is to specify that equipment be designed for a Class I, Division 2 location even when originally placed in an unclassified location to prepare for potential future facility modifications. Refer to API RP 500 [B3], NFPA 497-1997 [B32] and the 1999 *NEC* 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.

4.1 Ignition overview

For a fire or explosion to occur, three things are needed: oxygen, a source of fuel, and an ignition source, 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, the exposed surface temperatures should be within acceptable limits 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 being present simultaneously and an ignition occurring is very small. (See API 2216-1991 [B1], Bredthauer et al. [B11], Buschart et al. [B12], and Hamer et al. [B19].)

4.2 Ignition components

Ignition is the process or means of igniting a fuel mixture, and igniting causes a fuel mixture to burn or cause 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 2216-1991 [B1]. This can be 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). Explosion-proof equipment is designed with an external surface temperature below the AIT, but the internal temperature can be above the AIT. The explosion-proof 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 equipment should also be below the AIT of potential flammable sources so that the surface does not become a potential ignition source.

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.

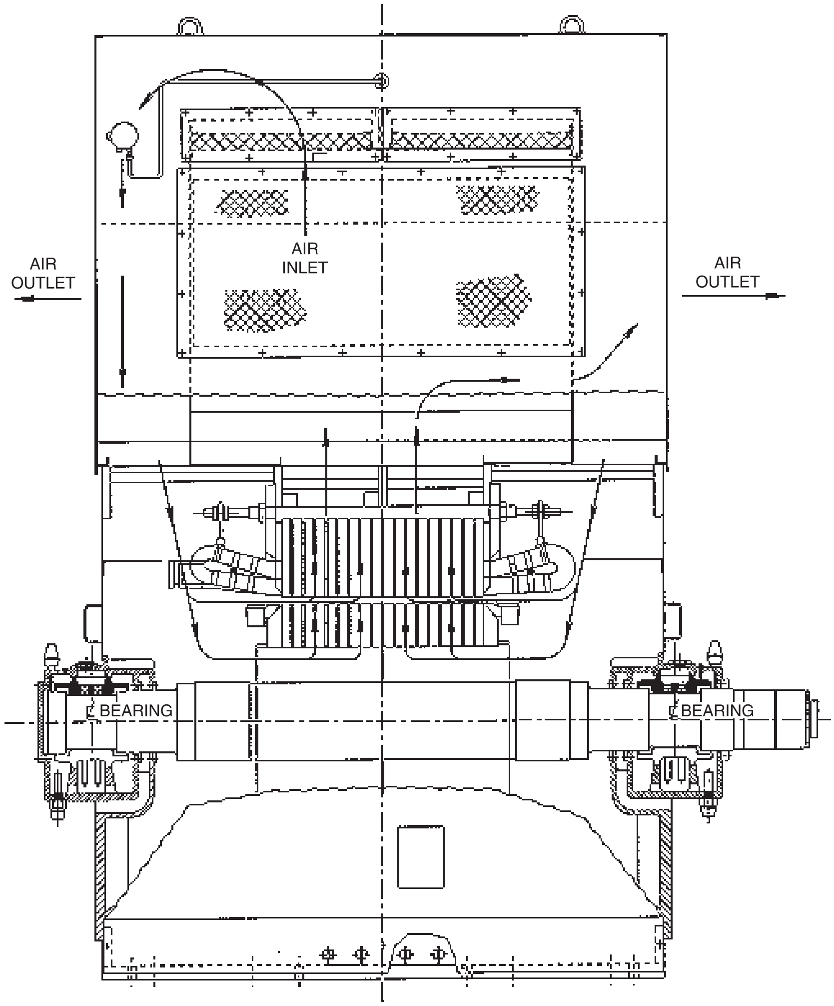
The group designation reflects that different gases and vapors cause varying maximum explosive pressures when ignited and is characterized by different maximum experimental safe gaps (MESGs). Enclosures designed to contain/cool an explosion have group designations and are applied within their listed, 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 and shows the group designation as defined in the 1999 *NEC*.

4.4 Gas ingress

Gases and vapors infiltrate most types of motor enclosures with the exception of forced ventilated or 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 reaching ignition even if the rotor surface temperature is higher than the published AIT. 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, i.e., drop in load, shutdown, etc. 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. [B12] presented some considerations regarding the application of totally enclosed motors in Class I, Division 2 locations. This paper presented support for gas ingress 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

Clause 5 provides guidance for Common applications of motors in 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 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 above 200 °C. Manufacturers and users should discuss applications, and engineering judgment should be used.

Motors should have exposed surface temperatures at or below the maximum Division 2 exposed surface temperature in Table 1 when: 1) built in accordance with NEMA MG-1-1998, IEEE Std 841-1994™, API 546-1997, and/or API 541-1995, and 2) applied within the Common application conditions outlined in 5.1. The majority of motors applied in Division 2 locations conform to one or more of the above standards without special requirements. Most of the AITs shown in NFPA 497-1997 [B32] and encountered in the petrochemical industry are 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 Division 2 locations should require special motor designs. For Division 2 applications, this is 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 Class I, Division 2 location, 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.

5.1 Common application conditions

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

a) The maximum recommended Division 2 exposed motor surface temperature should be as shown in Table 1 and should be less than the AIT.
b) Motors should have a maximum Class B rise at 1.0 service factor when tested with sinewave power at rated nameplate conditions. Refer to NEMA MG-1-1998, 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 or, when water-cooling is used, the ambient temperature range should be 5 °C to 40 °C.
e) The maximum altitude should not exceed 1000 m above sea level.
f) The motors should have sinewave 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 requirements.
i) The load inertia should be within NEMA MG-1-1998 requirements.
j) The motor torque characteristic at rated load should be low slip (i.e., NEMA Design A or B)
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%.
l) The voltage unbalance should be within 1%.

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

5.2 Surface temperatures

As described in the 1999 *NEC* Section 501-8(b) FPN No. 1, "It is important to consider the temperature of internal and external surfaces that may be exposed to the flammable atmosphere."[13] 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 Working Group participants. A summary of the tests conducted by the Working Group is in H.2.2. Some of the test and calculation data from manufacturers are presented in H.2.3 in Table H.7, Table H.8, Table H.9, Table H.10, Table H.11, Table H.12, Table H.13, and Table H.14. Other test data are in Hamer et al. [B19]. The sample group of motors tested is small compared to the number of motors in service.

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 Division 2 exposed surface temperature at full load (°C)
Single phase				
Up to 1.5 kW (2 hp), With arcing device	Explosion-proof UL 674 listed	All	—	Per UL listing and T Code label[d]
Three phase—NEMA frame sizes				
Up to 340 kW (450 hp)	ODP	Nonducted ventilation	110–130[e]	200
Up to 300 kW (400 hp)	TEFC	Nonducted or axial duct ventilation	120–170	200
Three phase—above NEMA frame sizes				
150 to 300 kW (200 to 400 hp)	TEFC	Nonducted or axial duct ventilation	115–185	200
Above 300 kW (400 hp)			105–190	200
Above 300 kW (400 hp)	WPII	Nonducted or axial duct ventilation	120–200	200
Above 110 kW (150 hp)	All[f]	Axial duct <u>and</u> radial duct ventilation	90–105	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 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 or down to the nearest 5°). (See Table H.8, Table H.9, Table H.10, Table H.11, Table H.12, Table H.13, and Table H.14.)
[d]Refer to Table H.7 and Annex I for more information on UL 674 surface temperature testing. For explosion-proof motors, the group and T Code are on the motor nameplate. (Refer to the 1999 *NEC*.)
[e]Typical range is based on motor manufacturer's calculated rotor temperatures on NEMA Design B motors. (Refer to Table H.8.)
[f]Radial ventilation is currently not used for NEMA frame-sized TEFC enclosures and is rare for above NEMA frame-sized TEFC enclosures.

[13]See Footnote 3.

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. Sparking that can occur is discussed in Annex G.

5.4 General equipment considerations

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

5.4.1 Enclosures

General-purpose enclosures are acceptable in Division 2 locations for nonsparking devices as long as surface temperatures meet the requirements of the 1999 *NEC*. Enclosures meeting the requirements of Class I, Division 1 locations can be used in Division 2 locations provided that they are applied within the equipment listing or labeling requirements. For example, explosion-proof motors are 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, Part 1.25-1998, and totally enclosed type motors are described in NEMA-MG-1, Part 1.26-1998. Within the enclosures options, the most commonly applied are the weather protected Type I (WPI), weather protected Type II (WPII), totally enclosed fan-cooled (TEFC), explosion-proof (TEFC-XP), totally enclosed water-to-air cooled (TEWAC), and totally enclosed air-to-air cooled (TEAAC). 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 used in 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. [B17].

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 WPII where the air is ducted from another cooling source) typically use blowers driven by TEFC motors that are suitable for Division 2 applications. In the event of ventilation failure, interlocks may be appropriate for type Z purging per NFPA 496-1998 [B31].

Plastic fans should be fabricated of a conductive or semiconductive material to avoid continuous static sparking hazards. For motors over 1000 V and/or larger horsepower motors, fans are often made of metal, e.g., bronze, steel, or aluminum. For metal fans, consideration should be given to nonsparking materials (i.e., aluminum), but the condition of a fan rubbing is not considered a normal condition. As such, nonsparking metal fans are desirable, but are not considered a requirement for Division 2 locations.

5.4.3 Accessories

Motor auxiliary devices should be of the nonsparking type, nonincendive, hermetically sealed, or be installed in an explosion-proof enclosure.

Examples of sparking devices are temperature switches, vibration switches, shaft grounding brushes, zero-speed switches, certain types of motor winding temperature sensors, leak detector switches, etc. These devices should be installed in enclosures suitable for the Class, Group, and Division.

Examples of nonsparking devices are resistance temperature detectors, space heaters, current transformers, motor surge capacitors, gapless type arresters, noncontacting shaft vibration probes and their oscillator/demodulators (drivers), and other devices that do not spark during normal operation. These devices are typically installed in general-purpose enclosures unless other environmental considerations suggest a different type enclosure.

The more commonly applied accessories are discussed below. Additional information on other auxiliary devices is in IEEE Std 303-1991™.

5.4.3.1 Space heaters

Moisture on motor windings can lead to premature aging and even motor winding failures. 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. 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.

Precautions should be taken to assure that the space heater maximum surface temperature does not exceed 80% of the AIT of the flammable mixture that may be present in Class I, Division 2 locations. The space heater should comply with the requirements of the 1999 *NEC* Section 501-8(b) which states: "The exposed surface of space heaters used to prevent condensation of moisture during shutdown periods shall not exceed 80 percent of the ignition temperature in degrees Celsius of the gas or vapor involved when operated at rated voltage, and the maximum surface temperature (based on a 40 °C ambient) shall be permanently marked on a visible nameplate mounted on the motor. Otherwise, space heaters shall be approved for Class I, Division 2 locations."[14] (To correspond to an AIT of 200 °C, the maximum space heater surface temperature would be 160 °C.)

Space heaters are usually resistance heating devices, either of the cartridge type or the flexible strip type. Both types can be used for winding or terminal box space heaters, but cartridge types are generally used for lube oil heaters.

When used for heating motor windings, the cartridge-type heater is mounted in a space adjacent to the winding. Therefore, it typically requires higher wattage than the flexible strip heater because it first heats the air around it, which then heats the windings of the motor.

The flexible strip-type space heater is typically mounted by wrapping it around the stator winding end turns. Precautions should be taken to avoid excessive temperatures on strip-type space heaters, which are in direct contact with the stator winding. The total space heater temperature is the winding temperature plus the heater temperature rise.

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.

[14]See Footnote 3.

5.4.3.2 Surge arresters and capacitors

Nonsparking surge arresters, such as metal oxide varistor (MOV), sealed type, and specific duty surge protective capacitors can be installed in general-purpose type enclosures. Surge protection types other than those described above require enclosures approved for Class I, Division 1 locations. [1999 *NEC* 501-17(b).]

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 may be negligible. However, when used to decelerate a load, the mechanical friction brake converts rotational energy into thermal energy and the surface temperatures produced can be considerable. In such applications, precautions should be taken to assure the maximum brake temperature does not exceed the AIT of the flammable mixture.

5.4.3.4 Shaft grounding brushes

Shaft voltages were historically only a concern for motors over 1000 V, but the shaft voltages may be a concern for motors 1000 V and below where adjustable speed drives (ASDs) are used. Manufacturers should be consulted regarding the applicability of shaft grounding 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 ASDs.

The method of protecting bearings against bearing currents depends on the root cause of shaft voltages. This is application/design specific. In some cases, insulating one bearing is sufficient, but in other cases both bearings should be insulated. In extreme cases, a combination of insulated bearings and shaft grounding brushes should be used. These extreme cases typically occur when motors are operated on ASDs.

Because shaft-grounding brushes are inherently sparking devices, if used in classified areas, they should be contained in explosion-proof or purged housings or use other approved means to provide suitable guarding of the sparking brushes in accordance with 1999 *NEC* 501-8(b). That is not to say that the motor itself should be explosion-proof, but rather the shaft grounding assembly itself.

5.4.3.5 Nameplate markings

No special nameplate markings are required as noted in the 1999 *NEC*, Article 501-8(b): "In Class I, Division 2 locations, the installation of open or nonexplosion-proof 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."[15]

General-purpose motors can be marked in accordance with NEMA MG-1-1998, IEEE Std 841-1994™, API 546-1997, API 541-1995, and/or the 1999 *NEC*. It is not necessary to put temperature codes, maximum surface temperature, or "designed for Division 2" on the nameplate. However, users may choose to put additional information, such as these, on the nameplate because the users do not produce the nameplates, but 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 explosion-proof single-phase motor listed by a Nationally Recognized Testing Laboratory should show the Class, Division, Group, and Temperature Code classification.

[15]See Footnote 3.

If the motor has a space heater, then the space heater should have a nameplate in accordance with the 1999 *NEC* showing a T Code or a maximum temperature based on a 40 °C ambient.

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 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 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 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 capacitor start with a centrifugal switch. The switch may be a sparking device. So, single-phase motors with sparking switches installed in Division 2 locations use explosion-proof enclosures. Single-phase motors with sparking switches are generally avoided in Division 2 locations and three-phase motors are utilized where practicable. Refer to Figure 3 for an explosion-proof single-phase motor. Some single-phase motors are designed with switches approved for Class I, Division 2, and do not require explosion-proof motor enclosures.

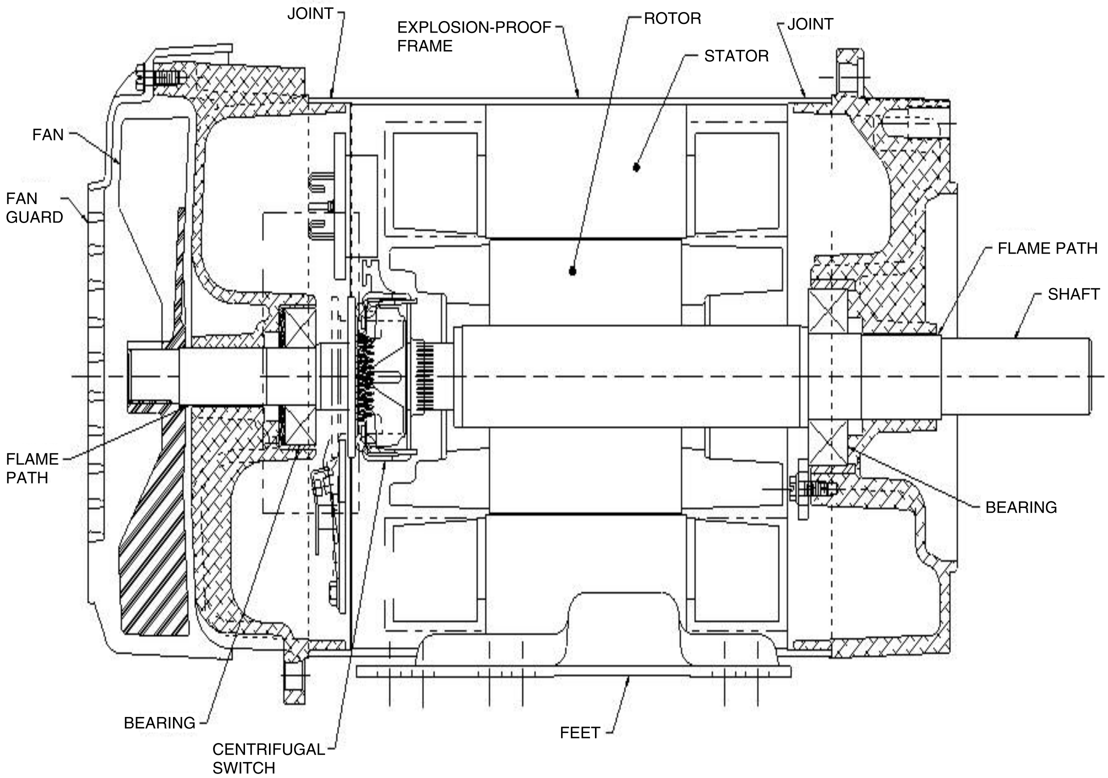
5.5.2 Three-phase motors

Three-phase motors are generally used from fractional horsepower and up to allow the use of general-purpose enclosures where practicable. Three-phase motors 1000 V and less do not spark during normal operation if they are designed, built, installed, and maintained properly. For fan-cooled motors, the external fans are usually plastic in the NEMA-frame sizes. Plastic fans should be fabricated of a nonsparking material to avoid continuous static sparking hazards.

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 manufacturer is in Table E.1 and Table E.2 in Annex E. Information is generally provided to the 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, 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 manufacturer for a Division 2 application is in Table E.4.

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. For example, where the AIT is 200 °C, a space heater should have a maximum sheath temperature of 160 °C to comply with this requirement. Once the space heater maximum sheath temperature has been specified, the motor manufacturer provides a nameplate marking for the motor declaring the space heater sheath temperature that has been supplied. Refer to 5.4.3.1 for additional information on space heaters. Refer to API RP 14F-1999 [B2] and API RP 540-1999 [B4] for guidance on when to specify space heaters.



Source: Courtesy of Marathon Electric.

Figure 3—Explosion-proof single-phase motor

5.6 Application considerations for motors above 1000 V

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

Based on the motor design, application, and operation, consideration should be made to follow certain procedures to mitigate the motor from sparking or being a heat source for potential ignition. The motor system design and operating methods should also reduce introduction of flammable mixtures to potential heat sources. Some of the motor design considerations for Division 2 applications are included in industry standards such as IEEE Std 841-1994™ for motors 500 hp and below and API 541-1995 (induction) and API 546-1997 (synchronous) for motors 250 hp and above.

When operating conditions are within the Common application conditions listed in 5.1, the minimum information that should be provided to the manufacturer is in Table E.1 and Table E.2 in Annex E. Information is generally provided to the 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, 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 manufacturer for a Division 2 application is in Table E.4.

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200 °C, a space heater should have a maximum sheath temperature of 160 °C to comply with this requirement. Once the space heater maximum sheath temperature has been specified, the motor manufacturer provides a nameplate marking for the motor declaring the space heater sheath temperature that has been supplied. Refer to 5.4.3.1 for additional information on space heaters. Refer to API RP 14F-1999 [B2] and API RP 540-1999 [B4] for guidance on when to specify space heaters.

5.6.1 Heat source considerations

Manufacturers sometimes use nonmetallic components as part of the motor to 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, minimizes 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 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 [B7], Bredthauer et al. [B11], Costello [B14], Merrill and Olsen [B27], and BEAMA Ltd. [B37].)

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

5.6.2.1 Bearings

Some motor bearing systems are designed by the manufacturer to be insulated to protect the bearing from developing shaft currents across the oil film. In some applications, one bearing is insulated. In some applications, both bearings are insulated and a grounding jumper is installed on one bearing. The insulation and grounding should be discussed with the manufacturer and maintained to prevent damage to the bearings. (See Costello [B14].)

5.6.2.2 Joints

Motor characteristics that would minimize sparking across joints are as follows:

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 ensure good contact between frame and bracket.
d) Adequate clearances between motor windings and structural parts.

Where needed, equipotential bonding conductors should be installed to prevent sparking between sections in multisection motors. Bonds should be applied as specified by the 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

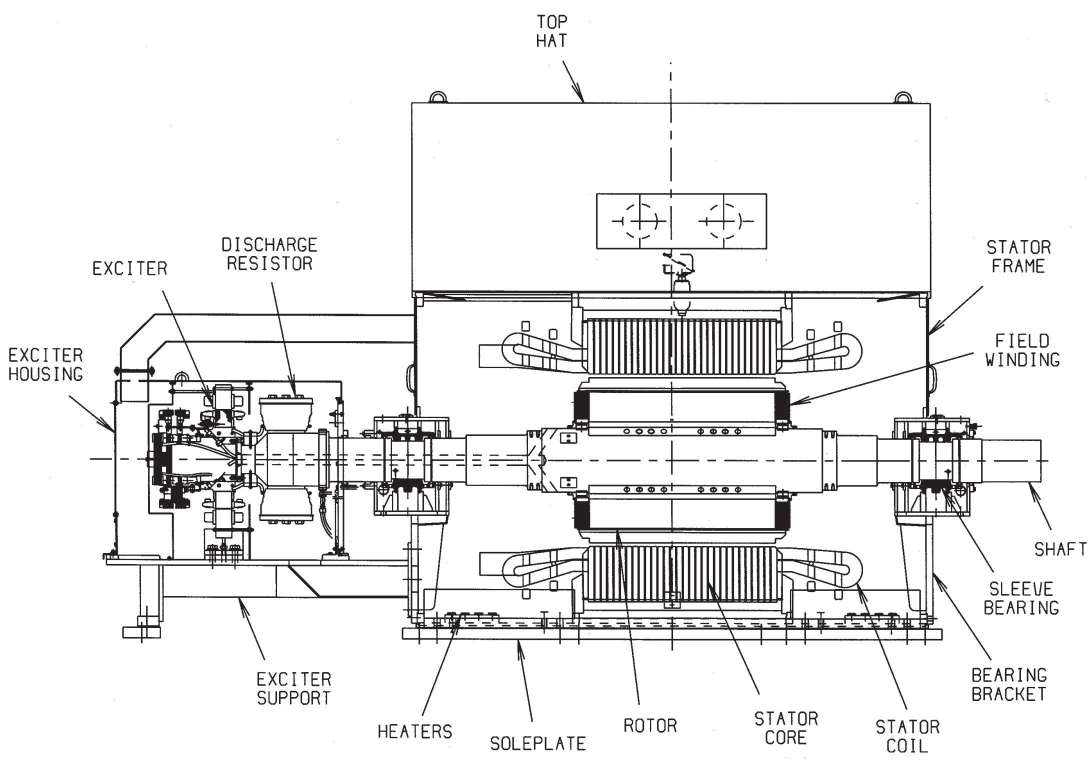
Manufacturers consider these features during the motor design.

5.6.3 Separate lube oil systems

Separate lube oil systems should be installed for the motor and the pump or compressor where a leak in the pump's or compressor's seals could introduce flammable mixtures into a common lube oil system serving the motor. For example, hydrocarbon compressors should have a separate lube oil system to minimize migration of gas via any common compressor-motor lube-seal oil system. An alternative to total separation of the two systems is to install degassing equipment to ensure that the lube oil is totally gas free at all times.

5.7 Application considerations for synchronous motors

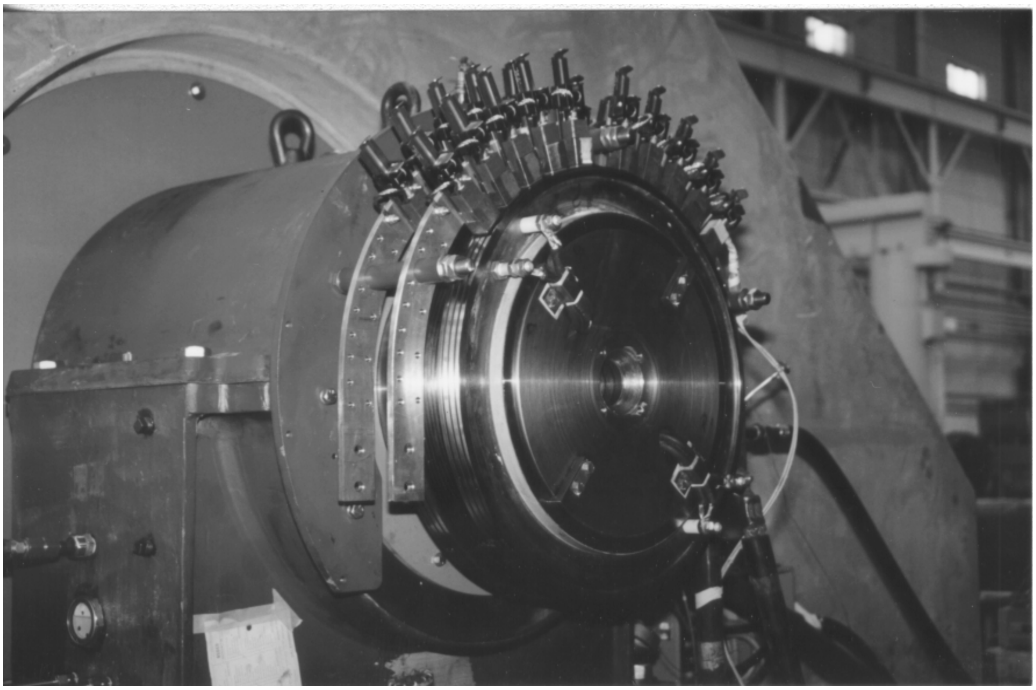
This discussion highlights brushless exciter-type synchronous motors, which are the most suitable for Class I, Division 2 locations. An example is shown in Figure 4.



Source: Courtesy of General Electric.

Figure 4—Typical cutaway of a brushless synchronous motor

Brush-type exciter synchronous motors do not meet Class I, Division 2 application requirements due to sparking, unless the brush area is either enclosed in a Division 1 housing, or appropriately purged. Some older motors of this type may still be in operation. The collector rings and brushes are shown in Figure 5.



Source: Courtesy of General Electric.

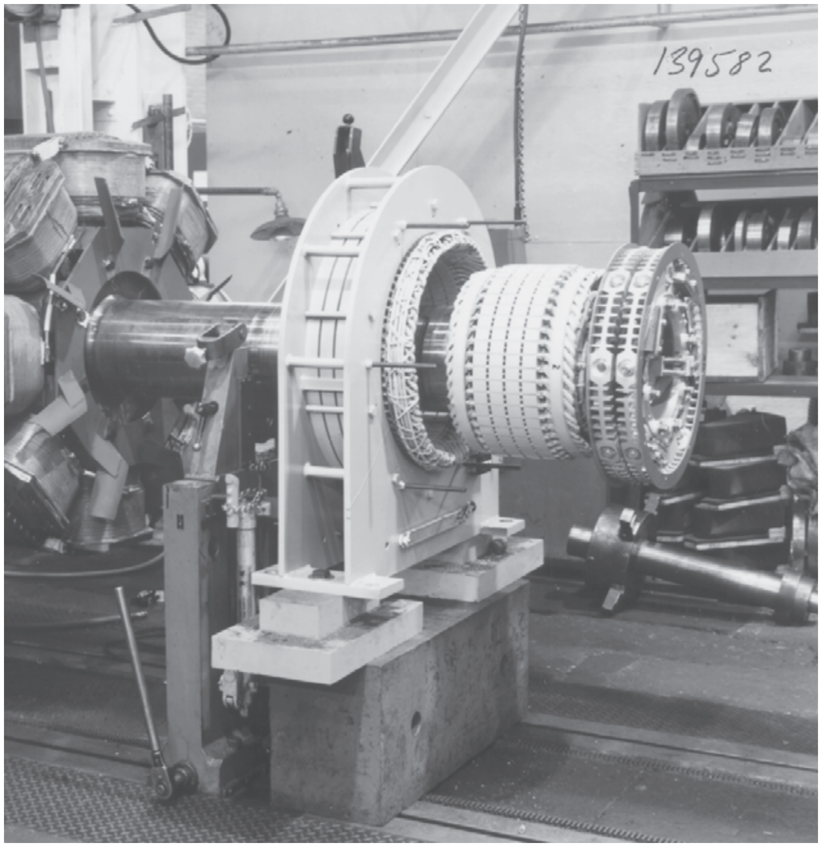
Figure 5—Collector rings and brushes on a synchronous motor

5.7.1 Brushless synchronous motor components

The amortisseur winding is a subassembly of the rotor and consists of cage bars and end rings, located in the pole faces. This temporary duty winding is used to start the motor in the same manner as a squirrel cage induction motor. The exciter is basically a low-voltage generator consisting of a stationary field and a rotating armature. A brushless type exciter is specified today for most Division 2 applications and is shown in Figure 6. Some manufacturers offer brushless exciters with redundant rotating diode assemblies that are fused. The fuses should be of nonindicating, filled, current-limiting type to meet the Division 2 requirements of the 1999 *NEC*.

A discharge/starting resistor is connected into the rotor circuit during starting to reduce the voltages induced into the rotor circuit to a low level and to increase motor starting torque near pull-in speed. On brushless excitation systems, the discharge resistor is mounted on the rotor and is typically in the rotor circuit from standstill to synchronous speed. The resistor should be sized to absorb the energy induced into the rotor circuit during the acceleration period. The temperature of the discharge resistor is limited by the insulation system employed in its construction and the connections to less than 180 °C. Most discharge resistors have a maximum temperature during operation under 150 °C.

The field windings are located on the rotor pole pieces. They serve to develop the rotor magnetic field, which interacts with the stator field to bring the rotor up to speed and maintain synchronization. When appropriately designed and controlled, the field can also allow the motor to operate with a leading power factor.



Source: Courtesy of General Electric.

Figure 6—Brushless exciter mounted on shaft of synchronous motor

5.7.2 External excitation control panel

One function of the external excitation control panel is to monitor the acceleration and de-energize the system if the starting time exceeds the capability of the amortisseur winding. Under normal operating conditions, the devices do not spark and the excitation control panel is located in the motor control center. Therefore, the internal surface temperatures during running are of the same concern as those of a squirrel cage motor. Starting, stalling, and short-circuit conditions are abnormal conditions and are not considered.

The typical breakdown of the semiconductor devices, which includes diodes, silicon controlled rectifiers (SCRs), and synchronization control circuitry components, occurs near the 125 °C junction (80 °C case) temperature. Therefore, the temperature of these devices is generally not a concern for most Division 2 applications.

6. Uncommon application considerations

This clause provides guidance for Uncommon applications of motors in Class I, Division 2 locations. For purposes of applying motors in Class I, Division 2 locations, any operating condition outside of the Common application conditions defined in 5.1 are considered Uncommon application conditions.

For example, temperature increases associated with unusual conditions, such as voltage unbalance, which may be allowed to persist long term, should be considered an Uncommon application. Motors that operate under Uncommon conditions may require special designs to adequately perform the intended service. In NEMA MG-1-1998 and IEEE Std 841-1994™, some "unusual service conditions" are listed that are considered Uncommon conditions.

6.1 High or low ambient temperature

Ambient temperatures above 40 °C may require adjustments to be made to the motor temperature rise specified. Refer to NEMA MG-1-1998, Parts 12.43.3, 20.83, or 21.10.3. In general, the temperature rise at 40 °C ambient, Class B rise at 1.0 SF, should be reduced by the number of degrees the ambient exceeds 40 °C. Motors with heat exchangers, such as TEWAC, may have other considerations. For all motors, ambient temperatures below −15 °C require special consideration. Explosion-proof equipment may not be suitable for use at temperatures lower than −25 °C unless approved for low ambient service.

6.2 High altitudes

Altitudes above 1000 m can cause increased heating due to lower airflow across the motor for cooling, resulting from lower air density. Refer to NEMA MG-1-1998, Parts 14.4, 20.8.4, or 21.10.4. The NEMA derating is basically as follows: the allowed temperature rise at sea level, Class B rise at 1.0 SF, should be reduced by 1% for each 100 m in excess of 1000 m. To compensate for the "lighter" air, manufacturers may increase the material in the motor, which may result in a larger frame and/or increase the fan size, which generally increases the dBA sound level and lowers the motor efficiency.

Also, adequate electrical clearances should be provided to prevent flashovers and corona activity due to the lower air density. Greater electrical clearances may be needed at higher elevations.

6.3 Nonsinusoidal power or adjustable speed operations

ASDs and adjustable frequency drives (AFDs) are becoming increasingly popular and larger in size. Units in the 5000 to 10 000 hp ranges are no longer uncommon. Proper application of ASDs normally requires informed considerations of many issues including the motor, drive, cable, wire length, isolation transformers, line filters, etc. All of these concerns are important and communication between the suppliers and user should not be ignored for overall system optimization and minimum downtime. (See Barolucci and Finke [B6], Bell et al. [B8], Bonnett [B9], Doughty et al. [B16], Epperly et al. [B18], Hanna and Luscombe [B20], Hanna and Prabhu [B21], and Saunders et al. [B38].)

6.3.1 Affect of adjustable speed drives

A motor operated on an ASD may exhibit increased temperature as compared to a motor operated on sinewave power due to the affects of the harmonic frequencies produced by the drive. This is predominantly a result of increased I^2R losses in the stator and the rotor. The rotor is especially susceptible to the effects of harmonics. The high slip speed between the rotor rotational frequency and the harmonic frequencies causes relatively large magnitudes of harmonic currents to be induced in the rotor, causing increased I^2R losses and heating. The degree to which the motor losses are increased depends on the harmonic characteristics of the drive and the design of the motor.

Motors that are cooled by shaft mounted fans may also experience increased temperature due to reduced cooling at low operating speeds. This is normally not a problem with loads such as centrifugal loads (i.e., centrifugal pumps, compressors, and fans) because the power requirements reduce rapidly with decreases in speed. Referring to the affinity laws for centrifugal loads, power changes by the cube of the speed. However, for constant torque loads (i.e., positive displacement pumps and reciprocating compressors) where full-load current can be required at low operating speeds, the temperature increase can be significant at low operating speeds.

6.3.2 Adjustable speed drive applications

To mitigate high surface temperature concerns for ASD applications, the following should be considered where applicable.

- Consider drive type and technology such as high pulse input, active front-end, and multilevel pulse-width modulation (PWM) output.
- Factory test the motor and ASD together under the proposed loading conditions. Some testing, labeling, and/or approvals may be needed for some jurisdictions. (See B.4.2.)
- Install filters at the drive and/or at the motor terminals, such as impedance matching circuits at the motor terminals when long length cables are between a PWM drive and the motor. (These devices can also reduce voltage spikes. The surface temperature of the impedance matching devices should be checked if they are located in the Division 2 location.)
- Use cables designed for use with ASDs. Review cable types and grounding method with the motor and drive manufacturers. (Also see Barolucci and Finke [B6].)
- Install thermistors in motors 1000 V and below to shut down the motor due to high stator temperature.
- Install RTDs in motors over 1000 V to shut down the motor due to high stator temperature.
- Limit the turn down range, slowest operating speed.
- Use a larger frame motor.
- On larger motors, use an auxiliary fan.
- Use an explosion-proof motor.

To mitigate effects of voltage spikes in motors over 1000 V for ASD applications, the following methods should be considered.

- Specify stator winding insulation systems designed to withstand a peak voltage of 2.04 times rated voltage with a rise time of 1.0 μs. (Similar to NEMA MG-1-1998, 31.4.4.2.)

To mitigate affects of voltage spikes in motors 1000 V and below for ASD applications, the following methods should be considered.

- Specify stator winding insulation systems designed to withstand a peak voltage of 3.1 times rated voltage with a rise time of 0.1 μs. (Similar to NEMA MG-1-1998, 31.4.4.2.)
- Use short lead lengths from the drive to the motor.

To mitigate bearing sparking in ASD applications, users should discuss options with the manufacturer. (Also see Bell et al. [B8] and Epperly et al. [B18].)

To minimize the ASD effects on motor temperature, the motor and ASD should be supplied as an integrated system, making sure that they are compatible for the application. The user and the manufacturer should work together to keep the motor exposed surface temperatures below the AIT over the expected operating range.

6.3.3 Referenced specifications for adjustable speed drives applications

For definite-purpose inverter-fed polyphase motors, NEMA MG-1-1998: Part 31 should be referenced for motors rated less than 5000 hp and voltages less than 7200 V. Consider referencing IEEE Std 841-1994™ for motors 1000 V and less. Consider referencing API 541-1995 for induction motor applications above 1000 V and 250 hp and larger. Consider referencing API 546-1997 for synchronous motor applications 500 kVA and larger.

6.4 Duty cycle other than continuous

Motors with duty cycles other than continuous duty can cause excessive heating and may require special designs from the motor manufacturer. Some include jogging, reversing, or plugging duty cycles or intermittent duty cycles such as the duty cycle associated with the start motor for a gas turbine or the motors for hydraulic cylinders and power rams with integral motor/pumps.

6.5 Excessive starts

Starting is not a normal operating condition. From NEMA MG-1-1998, motors shall be capable of two starts in succession (coasting to rest between starts) with the motor initially at the ambient temperature or one start with the motor initially at a temperature not exceeding its rated load operating temperature. This starting capability is provided without injurious heating if the motor voltage, frequency, starting method, load torque, and load Wk^2 (the moment of inertia where W is the weight of all rotating parts in pounds and k is the radius of gyration of rotating parts in feet) are those for which the motor was designed, including allowable tolerances.

The effects of multiple successive starting may be short-term higher operating temperatures, especially in the rotor. The rotor temperature during starting depends on the motor design and the type of load being accelerated, but may reach 300 °C rise in some applications. This higher temperature returns to normal within a short period after reaching normal operating speed and load.

When the starting duty exceeds that allowed by NEMA MG-1-1998, excessive heating can result. Starting requirements beyond the above limitations should be referred to the manufacturer. Some specifications, such as API 541-1995 and API 546-1997, require the motor to be designed for a number of successive starts in excess of NEMA requirements. Also, in many applications, especially NEMA frame motors driving centrifugal pumps, the load inertia is less than the standard value given in NEMA MG-1-1998 and additional successive starts can be made without excessive temperature rise. In this case, the allowed number of successive starts should be determined in consultation with the manufacturer.

6.6 High inertia load

When the inertia load exceeds NEMA MG-1-1998 requirements, the motor acceleration time is expected to be longer, which in turn generates additional heating. Even though starting is not considered a normal condition, the high inertia load can cause additional heating in the bearings, windings, and rotor, which should be addressed by the user and manufacturer.

Care should be used when substituting motors of equal size in high inertia service. The rotor gains heat equal to the kinetic energy being stored in the rotating train (motor rotor plus driven machine). So, if a motor is coupled to a high inertia load, it should be designed to dissipate the heat to avoid high-temperature gains during start.

6.7 NEMA Design C or D motors

The manufacturer should be consulted for applications of NEMA Design C or D motors to determine the motor's surface temperatures for the specific application. These motors are generally applied to constant torque loads (e.g., reciprocating pumps) and/or loads that can have longer acceleration times or cyclical loads. To achieve the torque characteristic of a NEMA D motor, the rotor resistance is increased, which in turn increases the induction motor slip and heating in the rotor. Consideration should be given to the material AIT to compare with the manufacturer's information on motor surface temperature.

NOTE—Oil-well pumping unit motors may be NEMA C or D; however, the area classification should be determined to see if Division 2 applies. See API RP 500-1997 [B3].

6.8 Voltage and frequency variation

Voltage and/or frequency variation can cause increased heating losses, which can result in higher surface temperatures than shown in Table 1. For example, a low voltage causes a proportional increase in current to deliver the required output horsepower demanded by the load. This increased current increases I^2R losses, and thus produces a higher temperature rise.

For another example, if a low frequency occurs while maintaining rated voltage and load, the core losses increase and could cause a temperature increase. However, low frequency does not always cause excessive heating. On variable torque applications, the relationship between the speed and load is a cubed function. Also, the flux density increases and the slip loss decreases. As a result, the motor may actually run cooler, depending on the amount of change in frequency. As guidance, NEMA MG-1-1998 allows a $\pm 10\%$ voltage variation, a $\pm 5\%$ frequency variation, or a combined voltage and frequency variation of $\pm 10\%$. This allowed variation is based on the assumptions that load does not exceed the nameplate rating (1.0 SF).

At conditions other than rated voltage, the performance characteristics of the motor change as noted in IEEE Std 141-1993 (*IEEE Red Book*) [B26]. For example, the stator temperature rise could increase 10% to 15% at 90% rated voltage, depending on the design and loading of the motor. Outside of that range, the manufacturer should be consulted.

Motors operating on unbalanced power systems have higher rotor and stator temperatures because of the additional losses caused by the unbalance. The rotor is more susceptible to additional heating than is the stator when the voltages are unbalanced due to the relatively high magnitude of negative sequence voltages and currents that are produced by the unbalance and induced into the rotor. NEMA MG-1-1998, 14.36 and 20.24, gives typical derating data for smaller and larger motors, respectively.

6.9 Overload

A motor is considered overloaded when operated above its base nameplate kilowatt or horsepower. For example, a 10 hp motor with a 1.15 SF should not be operated continuously above 10 hp in a Division 2 location. Any operation above 10 hp is considered an overload condition.

6.9.1 Overload heating

An overload increases the motor operating temperature rise approximately in proportion to the square of the current increase. For example, a motor that normally operates with an 80 °C stator temperature rise at rated load has approximately a 106 °C rise at 115% of rated load $[(1.15)^2 \times 80\,^\circ\mathrm{C} = 106\,^\circ\mathrm{C}]$. While modest overloads are usually not sufficient to encroach on the AIT of most classified locations, in some cases the AIT limit could be violated and this possibility should be considered. Also, the higher operating temperature reduces the life expectancy of the motor. (As an approximation, each 10 °C increase in temperature reduces the insulation life by 50%.)

6.9.2 Operating above base nameplate, but within the service factor

Most of today's NEMA frame-size petrochemical severe duty motors are manufactured with a 1.15 SF. This means the motor has been designed to stay within design limits of the insulation and other physical and mechanical systems when operated at no more than 1.15 times nameplate horsepower.

However, operating above base nameplate kilowatt or horsepower increases the internal and external surface temperatures and shortens the insulation life and lessens motor reliability. Although 1.15 SF operation remains within design limits of the motor, it is considered an Uncommon application condition and the temperatures given in Table 1 could be exceeded.

For TEFC motors operated at 1.15 SF, the typical range was 140 °C to 220 °C based on a 40 °C ambient. One motor exceeded 240 °C based on a 40 °C ambient. Refer to Table H.12. Continuous (nontransient) operation above a 1.0 SF is not a recommended continuous operating condition for a Division 2 location. Service factor operation has been considered reserved for intermittent overloads resulting from typically transient and not steady-state operations.

6.9.3 Overload relay settings impact

The motor should be selected to avoid overload conditions. The overload protection requirements are in the 1999 *NEC*, Sections 430-32 and 430-125 (motors over 600 V nominal). Refer to Padden and Pillai [B36] for information on overload types and selection. Overload conditions affect the typical operating rotor temperatures shown in Table 1. See Table H.12 for operating temperatures at 1.15 SF in TEFC motors.

6.10 Atmospheres with an AIT at or less than those of Table 1

The application should be considered Uncommon if the area is classified as Class I, Division 2, with an AIT at or less than the maximum recommended Division 2 exposed surface temperature in Table 1. The motor manufacturer should be consulted to apply a motor for these conditions.

For these applications, a motor with a general-purpose enclosure may be designed for a maximum surface temperature that is less than the AIT of the flammable gases and vapors that may be present. For smaller motors, a current practice is to use explosion-proof motors with a T Code below the AIT. For larger motors, a current practice is to consider purged and pressurized enclosures.

6.11 Motor exposed surface temperature above Table 1 values or above Class B rise

Motors with exposed surface temperatures above the Table 1 values should be considered an Uncommon application. Also motors with temperature rises above Class B at a 1.0 SF are considered Uncommon applications (such as a Class F rise at 1.0 SF).

The manufacturer should be consulted to determine motor temperatures for the specific application and/or the application's actual AIT should be reviewed for potential problems. Many applications in the petrochemical industry have AITs above 200 °C, and the user may be able to utilize motors with higher surface temperatures without introducing a potentially hazardous condition.

Each manufacturer has specific details on their enclosures and temperature profiles of their motor product line. Therefore, it is beneficial for the user or original equipment manufacturer (OEM) to work closely with the motor manufacturer when faced with Uncommon application conditions to optimize the design and minimize the cost. For each manufacturer, each rating and enclosure has a unique temperature rise, and the manufacturer may have built in allowances that this guide cannot take into consideration. Although other performance conditions are affected by Uncommon application conditions, this guide is focused on heat rise since this is of primary concern in regard to Division 2 applications. The user and OEM need to take into further consideration the efficiency of the motor because the by-product of a less efficient motor is more heat dissipation or, in other words, generally higher temperature rise.

6.12 Other considerations

6.12.1 Pressurization, prepurging, or periodic purging

Pressurization, prestart purging, or periodic purging are not required, but may be considered to minimize further the possibility of gas being present within a motor. These options should be considered for special applications such as where sparking may occur during starting, such as in a higher voltage motor, or where accumulation of gas may occur in a motor after a flammable vapor release, or where the motor internal temperature exceeds the AIT.

For those special applications, *pressurization* is made possible by constructing the motor to retain a slight positive pressure within its enclosures and coolers, without requiring vast quantities of pressurizing air. Pressurization air should be drawn from a nonhazardous area. Pressurization using an inert gas may be an acceptable alternative. Where standby motors may be required to start automatically, there may be a requirement for instant start on demand. In such cases the time required to purge the motor may not be tolerable and, as a consequence, such motors may need to be continuously pressurized in readiness for any such start requirement. (See NFPA 496-1998 [B31].)

For those special applications, *prestart purging* prior to any start may be a solution for some motors, particularly those under manual control. Purge air should be drawn from a nonhazardous area. Purging with an inert gas may be used, although this is unlikely to be cost effective. Purging is continued until the interior is gas free or below its lower explosive limit (LEL).

For those special applications, automatic prepurging, together with additional *periodic purging*, may be considered for some applications.

For those special applications, *periodic purging* should keep the interior gas free and permit continuous running. If instant starting is a requirement, periodic purging should continue during the period the motor is not running. The additional purge cycles are applied either at regular intervals throughout the required period or immediately when any gas release has been detected. It is essential that purge air be applied before the existing air within a motor has had time to become laden with gas to a level above its LEL. In all cases, pressurization or purge air should be drawn from a nonhazardous area.

6.12.2 Use of gas detection equipment

The installation of gas detectors is not required, but may be considered to minimize further the possibility of gas being present within a motor. These devices are generally set to alarm or shutdown before the gas concentration in and around a motor reaches the LEL. Positioning gas detectors inside motors may have an immediate appeal, but has often failed on evaluation due to the virtual impossibility of predicting where they should be placed, how many would be needed, their stability and maintenance schedules, and whether or not their integration into existing control systems would be feasible.

Motors should be shutdown in a programmed and controlled manner to minimize the introduction of unknown effects on the surrounding environment. However, it is recognized that there are times when quickly shutting motor driven systems down when a gas release occurs may be preferred over a slower controlled shutdown.

Testing has shown that when an operating motor is shutdown (such as a TEFC motor), its temperature rises before it starts to cool down. The practice of shutting down an operating motor during a gas release should be carefully considered. During testing conducted by the Working Group, operating motors did not ignite a flammable mixture, but when the motors were shut off with a low AIT gas present, the heat rise and loss of circulating air immediately caused an ignition in some motors where the operating temperature was significantly greater than the AIT of the gas.

7. Operation and maintenance considerations

This clause discusses the operating and maintenance considerations that mitigate hot surface temperatures and sparking when motors are located in a Division 2 location. Motors should be operated and maintained in accordance with the manufacturer's recommendations. The manufacturer's operating manual and nameplate information should be consulted for specific guidelines on the operation of motors.

7.1 Commissioning considerations

The considerations for commissioning a motor installed in a Class I, Division 2 location compared to those for a nonhazardous location are identical. When properly installed, a motor should run continuously for many years. Without proper installation methods, the motor could experience premature failure. However, for some combinations of flammable vapors and motor failures, an ignition source may be created by the motor failure, and the probability of ignition of a flammable vapor is increased.

Commissioning of a motor should include verification of the following:

a) Proper motor alignment.
b) Proper bearing lubrication.
c) Motor lead connections are tight and properly insulated, shielded cable is properly equipped with stress cones, and the shield is properly grounded.
d) Proper ground connections, including grounding straps and equipment ground.
e) For motors with arcing devices, the device enclosure should be suitable for the application.
f) For motors with belt drives
    1) The belt should not generate static electricity;
    2) The sheaves on the load and bearing should be sized properly to prevent excessive side loading on the bearings; refer to NEMA MG-1-1998, Part 14.42.
g) Motor vibration should be within manufacturer's specifications. Investigate and resolve any vibration levels that are above the manufacturer's recommendations.
h) Ensure bearing insulation integrity is not jeopardized.

7.2 Maintenance considerations for existing motors in Class I, Division 2 locations

7.2.1 General

Motor maintenance programs generally include lists of items to check. The manufacturer's recommendations and the user's experience should provide the basis for motor maintenance. In general, the maintenance required for motors located in Class I, Division 2 locations require no additional consideration than motors located in nonhazardous areas. This subclause identifies some of the motor prefailure symptoms that should be evaluated by knowledgeable personnel and may require a more aggressive action.

7.2.2 Motor prefailure symptoms

When routine maintenance is performed on motors in Division 2 locations, maintenance personnel should be aware of the following motor prefailure symptoms:

a) Frame discoloration or hot spots.
b) Motor lead/insulation discoloration and surface tracking.
c) Loose connections.
d) Inspect bearings for signs of shaft currents.
e) Unbalanced phase current.
f) Check for proper oil levels for oil lubricated bearings. For systems with oil heaters, the level should be maintained above the heating element.
g) Arcing across enclosure sections. (Refer to Annex F for a generic multisection motor inspection procedure.)
h) Symptoms of broken rotor bars include
    1) Signs of air gap sparking or rotor-to-stator contact
    2) Ammeters swinging
    3) Abnormal vibration
    4) Changes in pitch of magnetic noise

Each of these symptoms may indicate that a motor is not operating within the original design parameters and that the risk of creating a source of ignition has been increased.

Where practicable, maintenance personnel may also do a visual inspection of the insulation systems. Insulation that is discolored indicates insulation degradation has occurred, which could lead to failure. Dirty insulation and windings can cause excessive heating, which leads to higher than normal external and internal temperatures. Evidence of surface tracking indicates deterioration of the insulation integrity (see Dymond et al. [B17]). Corona can sometimes be detected by visual insulation system inspection, built-in sensors, or external sensors.

7.2.3 Rewind/repair considerations

Electric motor repair requires much the same level of manufacturing expertise as new motor manufacturing. For motor applications that require a specific maximum surface temperature, a motor repair shop should be made aware of this requirement and the remanufactured or repaired motor should meet the temperature limits.

For motor applications that utilize listed explosion-proof enclosures, the motor shop that repairs the motor should be licensed from Underwriters Laboratories Inc. (UL) to relabel the listed motor.

A careful audit of the motor shop's capabilities should be conducted by knowledgeable motor repair personnel. Audit guidelines can be obtained from several sources, including IEEE Std 1068-1996™.

8. Motor surface temperature test methods

This clause describes the nondestructive paint test method for determining internal and external motor surface temperatures. Testing all motors is not recommended. However, users may request maximum surface temperature data, particularly when a motor is applied in an area with an AIT less than the values in Table 1. The user may also want to request surface temperature data for motors applied in Uncommon application conditions as described in Clause 6.

When the maximum exposed surface temperature data for a motor are requested, the paint test is the preferred method of nondestructive testing at this time. For low-voltage explosion-proof motors, the UL 674-1994 [B39] test method should be used and is described in I.2. In some situations, paint testing is not practicable; therefore, a thermodynamic model should be used as described in I.1.

The preferred paint test method for determining the maximum rotor temperature is as follows:

a) The temperature-indicating material recommended is a liquid-type lacquer suspension of the temperature-sensitive material, referred to as "paint".
b) The paint should be striped diagonally at equal spacing for each temperature range and opposite to the skew direction of the rotor over the entire length of the rotor.
c) The paint should be 0.5–0.10 mm (2–4 mils) thick.
d) To be more consistent, one manufacturer of paint should be used for all of the temperature ranges of interest. The suggested temperatures for the paint are as follows: 59 °C, 87 °C, 101 °C, 111 °C, 121 °C, 135 °C, 149 °C, 163 °C, 177 °C, 198 °C, 218 °C, 232 °C, 260 °C, 302 °C, 343 °C, and 427 °C. Some or all of the paint temperatures may be used for a given motor test.
e) The accuracy of the paint should be ± 1%.
f) Unless otherwise specified, the motor should be operated at full-load steady-state base nameplate conditions at 1.0 SF until the maximum temperature is considered stable in accordance with IEEE Std 112-1996 [B24] or IEEE Std 115-1995 [B25] as appropriate.
g) The actual ambient temperature should be noted during the test.
h) The value of temperature should be given as "less than" the value of paint not affected during the temperature test.
i) The maximum surface temperature should be given as the temperature rise above a 40 °C ambient.

Testing experiences using the paint method are discussed in H.3.2 and item b) of I.3.

Annex A

(informative)

Bibliography

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[B4] API RP 540-1999, Recommended Practice for Electrical Installations in Petroleum Processing Plants, 4th ed., April 1999.

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Supplemental Bibliography for Annex B

These references, which appear only in Annex B, are for information only.

[B40] API RP 505-1997, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class 1, Zone 0, Zone 1, and Zone 2, 1st ed. Nov. 1997.

[B41] CSA Certification Notice #672, Motors Used in Division 2 Locations, Feb. 1990.

[B42] CSA C22.2 #100-1995 (Reaff 2001), Motors and Generators; Industrial Products.

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[B44] BS 5000 P16-1997, Rotating Electrical Machines with Type of Protection 'n'.

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[B50] IEC 60079-19-1993, Electrical Apparatus for Explosive Gas Atmospheres—Part 19: Repair and Overhaul for Apparatus Used in Explosive Atmospheres (Other than Mines or Explosives).

Annex B

(informative)

Regulations and standards for motors used in areas where flammable gases or vapors may be present

This annex lists information regarding motor applications in areas where flammable gases or vapors may be present.

B.1 Occupational Safety and Health Administration (OSHA)

OSHA has two major sections commonly referenced when applying motors in Class I, Division 2 locations and these are as follows:

— OSHA 1910.307, Subpart S, Electrical – Design Safety Standards for Electrical Systems [B34].
— OSHA 1926.407, Subpart K, Electrical – Installation Safety Requirements [B35].

B.2 National Fire Protection Association

There are several NFPA documents that have information regarding motor applications in Division 2 locations. The document that is mainly addressed in this guide is NFPA 70-1999, also known as the *NEC*. The two FPNs in Section 500-8(b) are discussed throughout this guide and are as follows:[16]

> FPN No. 1: It is important to consider the temperature of internal and external surfaces that may be exposed to the flammable atmosphere.
>
> FPN No. 2: It is important to consider the risk of ignition due to currents sparking 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.

When purging, prepurging, or pressurization of an enclosure is needed, the following standard should be referenced:

— NFPA 496-1998, Standard for Purged and Pressurized Enclosures for Electrical Equipment [B31].

When determining the appropriate area classification including group designation and AIT, the following recommended practice should be referenced:

— NFPA 497-1997, Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas [B32].

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B.3 American Petroleum Institute

When determining the appropriate area classification including Class and Division, the following recommended practice should be referenced.

— API RP 500-1997, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2, 2nd ed. Nov. 1997 [B3].

When determining the appropriate area classification including Class and Zone, the following recommended practice should be referenced.

— API RP 505-1997, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2, 1st ed. Nov. 1997 [B40].

API specifications that can assist the designer with larger motors applied in Division 2 locations are as follows:

— API 541-1995, Form-Wound Squirrel-Cage Induction Motors—250 Horsepower and Larger, 3rd ed., April 1995.
— API 546-1997, Brushless Synchronous Machines—500 kVA and Larger, 2nd ed., June 1997.

API Recommended Practices that apply to motor installations in Division 2 areas are as follows:

— API RP 14F-1999, Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Division 1 and Division 2 Locations, 4th ed., June 1999 [B2].
— API RP 540-1999, Electrical Installations in Petroleum Processing Plants, 4th ed., April 1999 [B4].

B.4 International standards

These are standards that are used in applying motors in flammable atmosphere in various parts of the world, but are not specifically referenced in this guide.

B.4.1 British Standards Institution

— BS 5000 P16-1997, Rotating Electrical Machines with Type of Protection 'n' [B44].

B.4.2 Canadian Standards Association International

— C22.1-1998, Canadian Electrical Code, Part I—Standard Safety for Electrical Installations [B15].
— CSA Certification Notice #672, Motors Used in Division 2 Locations [B41].
— CSA C22.2 #100-1995 (Reaff 2001), Motors and Generators; Industrial Products [B42].
— CSA C22.2 #145-1986 (Reaff 1999), Motors and Generators for Use in Hazardous Locations [B43].

Motor installations in Canada or designed to the CEC to operate in a Division 2 location are tested and labeled as suitable for the area classification.

B.4.3 European Committee for Electrotechnical Standards

— CENELEC Working Group #31-0113 (concluding report) type testing for possibility of sparking [B45].

B.4.4 International Electrotechnical Commission

— IEC 60034-5-2000, Rotating Electrical Machines—Part 5: Degrees of Protection Provided by the Integral Design for Rotating Electrical Machines (IP Code)—Classification [B46].

— IEC 60079-10-1995, Electrical Apparatus for Explosive Gas Atmospheres—Part 10: Classification of Hazardous Areas [B47].

— IEC 60079-11-1999, Electrical Apparatus for Explosive Gas Atmospheres—Part II: Intrinsic Safety "I" [B48].

— IEC 60079-15-2001, Electrical Apparatus for Explosive Gas Atmospheres—Part 15: Type of Protection 'n' [B49].

— IEC 60079-19-1993, Electrical Apparatus for Explosive Gas Atmospheres—Part 19: Repair and Overhaul for Apparatus Used in Explosive Atmospheres (Other than Mines or Explosives) [B50].

Annex C

(informative)

AIT and group designations for Class I materials

This annex describes the AIT characteristic of flammable gases and vapors and shows the group designations as defined in the 1999 *NEC*.

C.1 AITs

The AIT of a flammable gas or vapor is important in determining the acceptability of equipment that operates at relatively high exposed surface temperatures, such as lighting fixtures, heaters, and motors. For example, explosion-proof equipment is designed to contain an internal explosion and prevent the explosion from escaping to the surrounding flammable atmosphere. However, if the external surface of the explosion-proof enclosure is at a temperature above the AIT of the flammable gas or vapor, the external surface may act as an ignition source, creating a potentially dangerous situation. For equipment that is acceptable for use in Division 2 locations and does not require an explosion-proof enclosure, the surface temperature of any internal or external component exposed to the gas–air mixture should also be below the AIT of potential flammable sources so that the surface does not become a potential ignition source.

C.1.1 Test methods and why results differ

Autoignition temperatures observed under one set of conditions may be changed substantially by a change of conditions, including a change in test method. For this reason, the AIT of a material varies with the test method. Some of the variables known to affect AITs are percentage composition of the vapor– or gas–air mixture, shape and size of the space where the autoignition occurs, rate and duration of heating, type and temperature of the ignition source, catalytic or other effect of materials that may be present, and oxygen concentration.

The majority of the data reported in various publications for the determination of AIT have been obtained by one of two standard procedures: ASTM D286 or ASTM D2155. ASTM has now withdrawn both standards. ASTM D286 was withdrawn many years ago and ASTM D2155 was withdrawn in November 1980. ASTM D2155 has been replaced by ASTM E659-1978 [B5]. Both ASTM D286 and ASTM D2155 were withdrawn in favor of ASTM E659-1978 because the newer method was easier to run and produced more consistent results by eliminating much of the judgment and variation due to different observers.

The differences among the various test methods are basically as follows:

a) The size and shape of the test vessel
b) The method of heating the test vessel
c) The method of detecting autoignition

In all test methods, a test vessel consisting of a borosilicate glass flask is used. The test vessel is heated thoroughly in an insulated enclosure to a known temperature. A carefully measured amount of the material to be tested is injected into the test vessel. If no ignition occurs the test vessel temperature is raised and the test repeated. The test is also repeated using various concentrations until the lowest temperature of autoignition for any concentration is found. Increasing the volume of the test vessel normally results in a lowering of the observed AIT. Changing the shape of the test vessel (surface-to-volume ratio) also affects the temperature observed, as does the material of the test vessel. The borosilicate glass has been found to give the lowest temperatures of any materials that do not result in a catalytic action.

Because tests are designed to heat the entire flammable mixture in its most easily autoignited concentration, there is a degree of safety factor in the test. In most installations of electrical equipment the flammable mixture is heated as it contacts the hot surface, and turbulence at the surface results, so that the flammable mixture is never as hot as the heated surface. On the other hand, if the flammable mixture is in a closed heated chamber such as a drying oven that is much larger in volume that the test vessel, autoignition can occur at lower than the recorded AIT.

As an illustration of the effects of test methods, the AIT of hexane, as determined by three different methods, are as follows:

Method 1 225 °C
Method 2 336 °C
Method 3 510 °C

The effect of percentage composition is shown by the following AITs for pentane

1.5% 548.4 °C
3.75% 502.4 °C
7.65% 476.3 °C

The following AITs for carbon disulfide demonstrate the effect of the size of the test vessel

120 °C in a 200 ml flask,
110 °C in a 1 liter flask,
96 °C in a 10 liter flask.

The effect of the material of construction of the test vessel is shown by the following AITs for benzene

572 °C in a quartz vessel
678 °C in an iron vessel

API 2216-1991, Ignition Risk of Hydrocarbon Vapors by Hot Surfaces in the Open Air [B1], based on experimental data and field experience, concluded that ignition of flammable hydrocarbon vapors by a hot surface in the open air requires temperatures well above the laboratory determined minimum AIT of the material involved. As a rule of thumb, the document stated ignition by a hot surface in the open air should not be assumed unless the surface temperature is about 200 °C above the accepted minimum AIT. Table C.1 summarizes the test results. (See API 2216-1991 [B1].)

Table C.1—Published AIT versus hot surface ignition

Material	AIT in NFPA 497-1997 [B32] (°C)	Hot surface without ignition [B1] (°C)
Gasoline	280–425	540–725
Lube oil	370	650
Light naphtha	330	650
Ethyl ether	160	565

C.1.2 History of AIT in the *NEC*

Prior to publication of the 1971 edition of the National Electrical Code the AIT of the flammable material was part of the group classification process. Equipment intended for Group D locations was limited to a maximum surface temperature of 280 °C, as was equipment intended for Group A and Group B. However, equipment for use in Group C was limited to an external surface temperature of 180 °C, the AIT of ethyl ether at that time. Subsequent tests indicated an AIT of ethyl ether of 160 °C. Thus, a new material being investigated for classification, even though it might be classified as a Group D material because of explosion pressure and MESG considerations, would have to be classified as Group C if the AIT of the material was less than 280 °C. If the material had an AIT less than 180 °C it could not be classified. Carbon disulfide with an AIT of 100 °C is one such material.

The National Electrical Code Committee recognized this problem and in the 1971 edition of the *NEC* removed the AIT as a criterion for group classification. A system of marking equipment to identify the external surface temperature was instituted in its place, and a requirement established that equipment could not be used in locations where the AIT of the flammable material was less than the marked external surface temperature of the equipment.

C.1.3 *NEC* temperature identification numbers

In the 1971 edition of the National Electrical Code a system of numbers was also established giving specific temperatures or temperature ranges. This system was based on the International Electrotechnical Commission (IEC) system, with additional levels based on the traditional dividing lines in the United States. The international level of 300 °C was the dividing level to go from T1 to T2 for the IEC system. There was no IEC level at 280 °C, one of the traditional dividing lines in the United States, so a new identification T2A was established. This permitted equipment used in the United States to be marked T2A. The equipment also complied with the T2 marking traditionally used in Europe, since the temperature did not exceed 300 °C. The temperature identification numbers are shown in Table C.2.

Table C.2—Temperature identification numbers[17]

Temperature (°C)	IEC	*NEC*
450	T1	T1
300	T2	T2
280		T2A
260		T2B
230		T2C
215		T2D
200	T3	T3
180		T3A
165		T3B
160		T3C
135	T4	T4
120		T4A
100	T5	T5
85	T6	T6

[17]Reprinted with permission from NFPA 70 *National Electrical Code*® Copyright © 1999, National Fire Protection Association. 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.

The AIT for which equipment was approved prior to this requirement was assumed to be as follows (1993 *NEC*, Section 500-3(e) [B30]). The 1996 and 1999 *NEC* did not have this assumption.

Group A – 280 °C   Group C – 180 °C
Group B – 280 °C   Group D – 280 °C

C.2 *NEC* Class I group designations

Because a nonexplosion-proof motor (e.g., TEFC or WPII) is not designed to contain an explosion, the group designation is not relevant and is not needed on the motor nameplate. However, the group designation is necessary for explosion-proof motors and other equipment and motors tested by third-party agencies for use in classified locations. The group designation is also necessary on accessory enclosures containing sparking components (explosion-proof accessory enclosures) even though the motor may be a nonexplosion-proof type.

Some of the more common group designations are as follows:

Group A   Acetylene
Group B   Hydrogen
Group C   Ethylene
Group D   Gasoline, propane

For more detailed information on groups, refer to 1999 *NEC* 500-5(a).

The 1999 *NEC* modified the group designation method. Excerpts from the 1999 *NEC* are reprinted below.[18]

500-5(a) Class I Group Classifications. Class I groups shall be as follows:

1) **Group A.** Acetylene.

2) **Group B.** Flammable gas, flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value less than or equal to 0.45 mm or a minimum igniting current ratio (MIC ratio) less than or equal to 0.40.

FPN: A typical Class I, Group B material is hydrogen.

Exception No. 1: Group D equipment shall be permitted to be used for atmospheres containing butadiene provided all conduit runs into explosion-proof equipment are provided with explosion-proof seals installed within 18 in (457 mm) of the enclosure.

Exception No. 2: Group C equipment shall be permitted to be used for atmospheres containing allyl glycidyl ether, *n*-butyl glycidyl ether, ethylene oxide, propylene oxide, and acrolein provided all conduit runs into explosion-proof equipment are provided with explosion-proof seals installed within 18 in (457 mm) of the enclosure.

3) **Group C.** Flammable gas, flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value greater than 0.45 mm and less than or equal to 0.75 mm, or a minimum igniting current ratio (MIC ratio) greater than 0.40 and less than or equal to 0.80.

FPN: A typical Class I, Group C material is ethylene.

[18]See Footnote 17.

4) **Group D.** Flammable gas, flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value greater than 0.75 mm or a minimum igniting current ratio (MIC ratio) greater than 0.80.

FPN: A typical Class I, Group D material is propane.

Exception: For atmospheres containing ammonia, the authority having jurisdiction for enforcement of this Code shall be permitted to reclassify the location to a less hazardous location or a non-hazardous location.

FPN No. 1: For additional information on the properties and group classification of Class I materials, see Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, NFPA 497-1997 [B32], and Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids, NFPA 325-1994.

FPN No. 2: The explosion characteristics of air mixtures of gases or vapors vary with the specific material involved. For Class I locations, Groups A, B, C, and D, the classification involves determinations of maximum explosion pressure and maximum safe clearance between parts of a clamped joint in an enclosure. It is necessary, therefore, that equipment be approved not only for class but also for the specific group of the gas or vapor that will be present.

FPN No. 3: Certain chemical atmospheres may have characteristics that require safeguards beyond those required for any of the above groups. Carbon disulfide is one of these chemicals because of its low AIT [100 °C (212 °F)] and the small joint clearance permitted to arrest its flame.

FPN No. 4: For classification of areas involving ammonia atmosphere, see Safety Code for Mechanical Refrigeration, ANSI/ASHRAE 15-1994, and Safety Requirements for the Storage and Handling of Anhydrous Ammonia, ANSI/CGA G2.1-1989.

C.3 Gases and vapors, heavier-than-air and lighter-than-air

In the absence of a wall or other barriers and in the absence of air currents or similar disturbing forces, it may be assumed that a gas or vapor disperses uniformly in all directions, as governed by the gas or vapor density and velocity. Heavier-than-air vapors disperse principally downward and outward and lighter-than-air gases and vapors disperse principally upward and outward.

Gases, vapors, and combinations of gases and vapors should be carefully analyzed to determine whether they are heavier-than-air or lighter-than-air under all operating conditions. Mixtures often contain both lighter-than-air and heavier-than air components.

Once inside a motor enclosure a heavier-than-air vapor may take longer to disperse than a lighter-than-air gas and should be considered when applying motors in Division 2 locations.

Annex D

(informative)

Motor enclosures types

General-purpose enclosures are acceptable in Division 2 locations for nonsparking devices as long as surface temperatures meet the requirements of the 1999 *NEC* and the equipment listing. Enclosures meeting the requirements of Division 1 locations can be used in Division 2 locations provided that they are applied within the equipment listing and labeling requirements, including the T Code and group designations on their nameplates. Table D.1 summarizes some of the commonly applied motor enclosures used in the petrochemical industry in Division 2 locations, and brief descriptions from NEMA MG-1-1998 are given in the following subclauses.

Table D.1—Commonly applied motor enclosures

Enclosure type	Reference subclause	Most commonly applied
Motors 1000 V and less		
Totally enclosed fan-cooled motor (TEFC)	D.2.2	Three-phase, indoor or outdoor environments
Explosion-proof motor (TEFC-XP)[a]	D.2.3	Single-phase with centrifugal switch
Open dripproof motor (ODP)	D.1.1	Three-phase, clean indoor environments
Motors over 1000 V		
Open dripproof motor (ODP)	D.1.1	In older installations in clean indoor environments
Open externally ventilated motor	D.1.2	
Open pipe-ventilated motor	D.1.3	
Weather-protected motor Type I (WPI)	D.1.4	
Weather-protected motor Type II (WPII)	D.1.5	Clean outdoor and indoor environments
Totally enclosed nonventilated motor (TENV)	D.2.1	
Totally enclosed pipe-ventilated motor (TEPV)	D.2.4	In Division 1 indoor locations and some low-speed ASD Division 2 applications
Totally enclosed water-to-air cooled motor (TEWAC)	D.2.5	Hostile environments
Totally enclosed air-to-air cooled motor (TEAAC)	D.2.6	Hostile environments
Totally enclosed air over motor	D.2.7	

[a]Applied within the T Code, class, and gas group listing. See 1999 *NEC* 500-5(c). Used for single-phase motors with centrifugal switch.

D.1 Open motor

An open motor is one having ventilating openings that permit passage of external cooling air over and around the windings of the motor. The term *open motor*, when applied to large apparatus without qualification, designates a motor having no restriction to ventilation other than that necessitated by mechanical construction. Types of open motors are described in D.1.1 through D.1.5.

D.1.1 Open dripproof motor

An open dripproof motor (ODP) is an open motor in which the ventilating openings are so constructed that successful operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle from 0° to 15° downward from the vertical.

D.1.2 Open externally ventilated motor

An open externally ventilated motor is one that is ventilated by means of a separate motor-driven blower mounted on the motor enclosure. This motor is sometimes known as a blower-ventilated or forced-ventilated motor.

D.1.3 Open pipe-ventilated motor

An open pipe-ventilated motor is an open motor except that openings for the admission of the ventilating air are so arranged that inlet ducts or pipes can be connected to them. Open pipe-ventilated motors shall be self-ventilated (air circulated by means integral with the motor) or forced-ventilated (air circulated by means external to and not a part of the motor). These motors are sometimes referred to as separately ventilated.

D.1.4 Weather-protected Type I motor

A weather-protected Type I (WPI) motor is an open motor with its ventilating passages so constructed as to minimize the entrance of rain, snow, and airborne particles to the electric parts and having its ventilated openings so constructed as to prevent the passage of a cylindrical rod 1.9 cm in diameter.

D.1.5 Weather-protected Type II motor

A weather-protected Type II (WPII) motor has, in addition to the enclosure defined for a weather-protected Type I motor, its ventilating passages at both intake and discharge so arranged that high-velocity air and airborne particles blown into the motor by storms or high winds can be discharged without entering the internal ventilating passages leading directly to the electrical parts of the motor itself. The normal path of the ventilating air that enters the electric parts of the motor is arranged by baffling or separate housings as to provide at least three abrupt changes in direction, none of which are less than 90°. In addition, to minimize the possibility of moisture or dirt being carried into the electrical parts of the motor, the intake air path velocity does not exceed 193 m/min.

D.2 Totally enclosed motor

A totally enclosed motor is one so enclosed as to prevent the free exchange of air between the inside and the outside of the case, but not sufficiently enclosed to be termed airtight. Types of totally enclosed motors are described in D.2.1 through D.2.7.

D.2.1 Totally enclosed nonventilated motor

A totally enclosed nonventilated motor (TENV) is a totally enclosed motor that is not equipped for cooling by means external to the enclosing parts.

D.2.2 Totally enclosed fan-cooled motor

A totally enclosed fan-cooled (TEFC) motor is a totally enclosed motor equipped for exterior cooling by means of a fan or fans integral with the motor, but external to the enclosing parts.

D.2.3 Explosion-proof motor

An explosion-proof (TEFC-XP) motor is a totally enclosed motor whose enclosure is designed and constructed to withstand an explosion of a specified gas or vapor (as noted by the group designation on the nameplate), which may occur within the motor enclosure. The enclosure is also designed to prevent the ignition of the specified gas or vapor surrounding the motor by containing and cooling the gases after an internal explosion as the gases escape from the motor enclosure. The outside surface of an explosion-proof motor is also designed to be temperature limited during normal running conditions to the T-Code designation on the nameplate so that the outside surface temperature is below the AIT of the surrounding gases or vapors.

D.2.4 Totally enclosed pipe-ventilated motor

A totally enclosed pipe-ventilated (TEPV) motor is a motor with openings so arranged that when inlet and outlet ducts or pipes are connected to them there is no free exchange of the internal air and the air outside the case. Totally enclosed pipe-ventilated motors may be self-ventilated (air circulated by means integral with the motor) or forced-ventilated (air circulated by means external to and not a part of the motor).

D.2.5 Totally enclosed water-to-air cooled motor

A totally enclosed water-to-air cooled (TEWAC) motor is a totally enclosed motor that is cooled by circulating air, which, in turn, is cooled by circulating water. It is provided with a water-cooled heat exchanger for cooling the internal air and a fan or fans, integral with the rotor shaft or separate, for circulating the internal air. TEWAC motors are used in hostile atmospheric environments.

D.2.6 Totally enclosed air-to-air cooled motor

A totally enclosed air-to-air cooled (TEAAC) motor is a totally enclosed motor that is cooled by circulating the internal air through a heat exchanger, which, in turn, is cooled by circulating external air. It is provided with an air-to-air heat exchanger for cooling the internal air and a fan or fans, integral with the rotor shaft or separate, for circulating the internal air and a fan or fans integral with the rotor shaft, or separate, but external to the enclosing part or parts for circulating the external air. TEAAC motors are used in hostile atmospheric environments.

D.2.7 Totally enclosed air-over motor

A totally enclosed air-over motor is a totally enclosed motor intended for exterior cooling by a ventilating means external to the motor.

Annex E

(informative)

Motor information tables

These tables contain recommended information that is typically furnished to a manufacturer when a motor is to be applied in a Class I, Division 2 location. This information is generally documented in a data sheet and provided to the manufacturer.

Table E.1 has the information that should be furnished to a manufacturer for any motor that is installed in a Division 2 location. If the motor application complies with the Common application conditions in 5.1, then the information in Table E.2 should be given to the manufacturer in addition to the information in Table E.1. If the application does not comply with all of the Common application conditions, then the information in Table E.3, in addition to that in Table E.1 and Table E.2, should be given to the manufacturer for the Uncommon condition(s) as discussed in Clause 6. Table E.4 contains some other information that may be needed by the manufacturer for the Division 2 application. These information tables are not intended to include all of the requirements for manufacturing a motor, but highlight the information that is important for Division 2 applications. Manufacturers and users may require additional information for particular applications.

Table E.1—Information for all motors in a Division 2 location

Information furnished to manufacturer	Comment
Class and Division, Group, autoignition temperature.	Furnish area classification information.
Size (kW or hp)	Motors should be operated at or below their base nameplate kW or hp rating to correspond to the temperatures in Table 1.
Enclosure type	See Annex D.
Space heater maximum surface temperature, if applicable.	Furnish space heater information: maximum surface temperature, nameplate, voltage, warning label, etc. (see 5.4.3.1).
Optional auxiliary devices that may experience sparking during normal operation and/or may need to be approved for use in Division 2 locations.	Some devices are differential pressure switches, surge arresters, thermostats, vibration sensors, leak detectors, etc. (see 5.4.3).

Table E.2—Information for all Common application conditions

Information furnished to manufacturer	Comment
Motors should have a maximum Class B rise at 1.0 service factor when tested with sinewave power at rated nameplate conditions.	Refer to NEMA MG-1-1998, Parts 12.43, 12.44, 20.7, 20.8, and 21.10.1.
The ambient temperature range should be –15 °C to 40 °C; or when water-cooling is used, the ambient temperature range should be 5 °C to 40 °C.	
The maximum altitude should not exceed 1000 m above sea level.	
The motors should have sinewave power and fixed speed operation.	Provide motor speed.
The motors should be designed with a continuous duty cycle.	
The number of starts should not exceed the motor's design requirements.	Provide starting requirements.
The load inertia should be within NEMA MG-1-1998 requirements.	
The motor torque characteristic at rated load should be low slip.	i.e., NEMA Design A or B.
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%.	Provide voltage, phase, and frequency.
The voltage unbalance should be within 1%.	

Table E.3—Additional information for Uncommon applications

Information furnished to manufacturer	Reference subclause	Comment
High or low ambient temperature	6.1	Refer to NEMA MG-1-1998, Parts 12.43.3, 20.8.3, and 21.10.3.
High altitudes	6.2	Refer to NEMA MG-1-1998, Parts 14.4, 20.8.4, and 21.10.4.
ASD application (nonsinusoidal power)	6.3	Indicate type of ASD, speed range, and constant or variable torque load.
Duty cycle other than continuous	6.4	Note if it is coast to stop, brake to stop, plug to stop.
Excessive starts	6.5	Provide starts/hour, run time, and rest time.
High load inertia	6.6	
NEMA Design C or D motors	6.7	
Excessive voltage and frequency variation	6.8	
Overload operation	6.9	See Table H.12 for 1.15 SF operation temperatures.
Atmospheres with an AIT less than Table 1 values	6.10	
Other considerations	6.12	For special applications, consider pressurization, prepurging, periodic purging, gas detection equipment.

Table E.4—Other information that may be needed by the manufacturer

Information furnished to manufacturer	Comment
Main specification that should apply	NEMA MG-1-1998, IEEE Std 841-1994™, API 541-1995, API 546-1997, UL 674-1994 [B39], etc.
Thermal protection	RTDs, thermostats, number per phase.
Type of load	Variable torque, constant torque, constant horsepower, load inertia, breakaway torque, running torque.
Drive method	Couple duty, coupling weight, direct drive, thrust load, belt duty, dynamic load, static load.
Any additional motor nameplate information	See 5.4.3.5.

Annex F

(informative)

Multisection motor inspection procedure

The following is a generic procedure for inspecting multisection motors. This procedure may be supplemented with the specific motor manufacturer's instructions for the motor being inspected. Prior to beginning the inspection, the following items should be available: Inspection light, basic hand tools and wrenches, overhead lifting equipment, electric/pneumatic wire brush suitable for the area classification, roughing/sanding pads, safety solvent, personal protective equipment, etc. Inspections should be conducted by qualified personnel.

Step 1: Inspect exterior bolting – all bolts should be present, tight, and free of rust and dirt. Bolts should not show evidence of sparking (pitting, burned, or blackened areas or paint powdering would be evidence of sparking). Clean and reinspect.

Step 2: Remove end covers and side panels – inspect all mating surfaces, flange overlaps, and areas where covers are adjacent to metal parts on motor exterior for indications of sparking or localized heating. Clean and reinspect.

Step 3: Inspect interior – look for evidence of sparking on interior joints, bearing brackets, bearing bolts, etc. Clean and reinspect.

Step 4: Inspect rotor – look for evidence of sparking at rotor bar to shorting ring bolts and rotor bolts and between the rotor bars and the laminations at the edges of the slots at the end of the core and at each air duct. Clean and reinspect.

Step 5: Inspect gaskets – look for evidence of spark damage to gaskets.

Step 6: General inspection – while motor is open, inspect interior for cleanliness, filter conditions, insulation cracks, loose bolts or brackets, oil leaks, or evidence of end-turn movement. Clean, repair, or schedule shop maintenance as needed.

Step 7: Test – station observers should view internal joints and the rotor to stator air gap and start motor while watching for sparks. Repeat test start if needed.

Step 8: Clean – using safety solvent, wire brush, and roughing/sanding pads, clean both sides of mating surfaces of air shields and end and side covers at bolt connection points. Be sure to clean both metal components and not just under bolt heads. Bare metal should be showing.

Step 9: Reassemble – reinstall air shields. Test start and watch for sparking at joints and bolted connections.

Step 10: Reassemble – reinstall end covers and side panels using new gasket materials if needed. Test start and watch for sparking at joints and bolted connections.

Annex G

(informative)

Motor sparking considerations

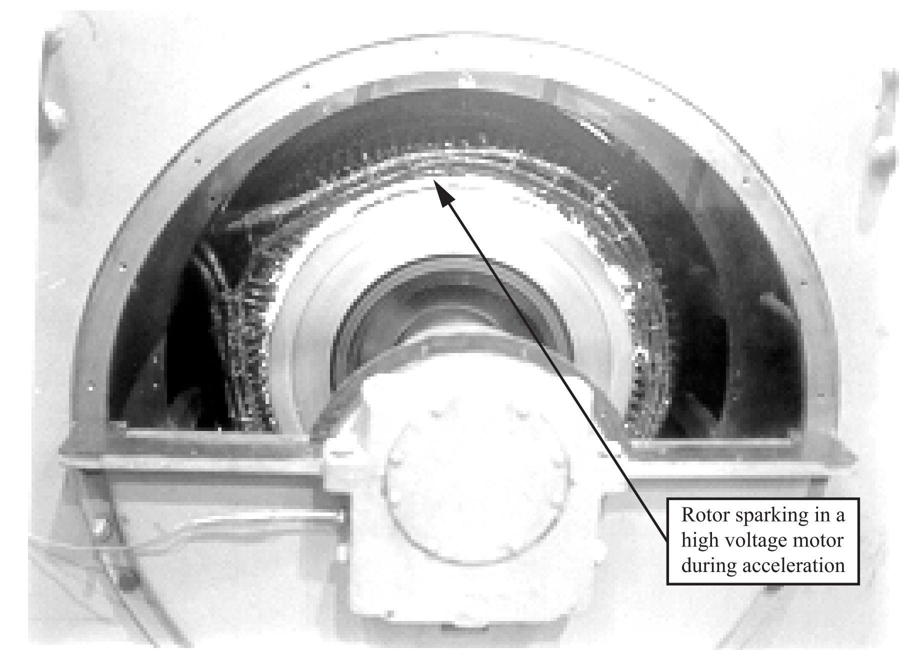
Annex G discusses sparking that can occur due to design, installation, and maintenance problems.

When three-phase induction and synchronous motors are properly designed, built, installed, and maintained, uncontained sparking is not expected except at higher speeds and higher voltages. (See Clark et al. [B13], Merrill and Olsen [B27], and Ong et al. [B33].)

G.1 General

Catastrophic failure of one or more components of a motor, or a fault on the power system, can obviously cause sparking during the event. These are not normal operating conditions.

The phenomenon of sparking occurs when the potential voltage between two conductive materials (e.g., steel) separated by an air gap is high enough to break down the air and current flows across the air gap. The further apart the two surfaces, the higher the potential voltage needs to be to create the spark. If the air in the air gap is moist or contaminated, then the lower the potential voltage needs to be to create the spark. Refer to Figure G.1, which illustrates the phenomenon of sparking.



Source: Courtesy of General Electric.

Figure G.1—Rotor sparking phenomenon in a high-voltage motor during acceleration

Proper installation and equipment selection can mitigate sparking. The motors are normally grounded by an equipment grounding conductor to provide a designated path to allow sufficient current flow so the upstream protective device will quickly trip should a fault occur in the motor. Improper or inadequate grounding can lead to sparking along the ground return path(s) during fault conditions.

The larger motors may have temperature sensors installed in the end-turns or imbedded in the windings to detect high winding temperatures. The temperature sensors need to be nonsparking-type devices for Division 2 locations.

G.2 Motors over 1000 V

Some common sources of electrical sparking in both synchronous and induction motors aside from actual winding failures are broken or loose rotor bars (sparking most easily seen during starting), stray load currents circulating in major motor components (strongest tendency during starting or asymmetrical operation), and stator winding surface discharge. The types, causes, and features of each source of sparking are discussed in detail in the following subclauses.

G.2.1 Air gap between the rotor and stator

Sparking in the air gaps of ac motors is a phenomenon that has been investigated by a number of individuals, but for which there currently is no published mathematical model that can be used to predict reliably when and if a motor actually sparks in the air gap. When a motor is prone to spark, the discharge is usually visually detectable during a stall or locked rotor condition and during a portion of the acceleration period.

G.2.2 Stator winding discharges

Above 5.5 kV, corona from the higher operating voltage and contaminants on the windings are a concern.

Contamination and moist air can be drawn into any ambient breathing motor. When the contamination settles on to the winding end arms, it changes the electric field and surface charge on the winding. When the moisture mixes with the contamination, surface discharge can occur and surface tracking can take place especially on high-voltage windings where it may short out the grading and grounding tapes as shown in Dymond et al. [B17]. This phenomenon has caused winding failures usually in the form of grounds, but it can cause a turn-to-turn fault. Clean cooling air, clean windings, and totally enclosed motors reduce the chance of discharge from contamination.

The air deflector or air baffle components can be either metallic or nonmetallic.

The nonmetallic deflector or baffle should present no opportunities for discharges. The nonmetallic deflector or baffle may develop static charges due to high-velocity airflow in some designs and these charges should be drained. One method is to use a copper shield embedded in a plastic baffle to protect it from contact with the winding, and the shield is grounded to drain static charges. Any bolts in the baffle should not contact the shield and should not project through the baffle into the electric and magnetic fields of the winding end-turn; otherwise, electrical discharge can occur between the winding and the bolts if the clearances are too small.

Metallic baffles, on the other hand, present a problem because if they are too close to the winding end-turn, the air can be broken down and a discharge may occur between the winding and the baffle. In addition, if the metallic baffles are of magnetic material and are located within the magnetic field of the winding, stray currents may be induced in them, which can cause localized heating problems. These baffles may be attached to the stator frame or enclosure by bolts. At these connection points there can be current flow and the bolts should be sized to handle the current without overheating and expanding, which can cause loss of rigidity. Where induced currents are present in the metallic baffles, the forces could be high enough to cause the baffles to rotate or vibrate. Loose metallic baffles may cause sparking.

G.2.3 Rotor components

The phenomenon of rotor sparking has been in the literature for quite a few years as discussed in Merrill and Olsen [B27] in 1959. The rotor sparking phenomenon is discussed in this subclause.

G.2.3.1 Rotor ducts

Many factors create variations in the potential on the many parallel bars of a rotor, which increases the probability for interbar current flow and therefore the probability of an interruption in this current and the creation of a spark. These factors include variations in the locations of the air ducts, offset air ducts, skewed rotor bars, and variations in bar lengths and conductivities and in the end-ring materials.

Rotors with ventilating ducts provide a distance over which the bar has no support except at the exit from the core packet and the entrance to the next. This arrangement gives rise to the probability of clearances where the bars could vibrate. A nonducted rotor does not have this potential problem.

G.2.3.2 Rotor design

In Division 2 applications, rotor sparking is of concern. Rotor sparking can be the result of loose fits between the rotor bar and its slot or broken rotor bars, either at the bar to end-ring connection or from broken bars in the slot if the bar is allowed to vibrate. Methods to limit rotor sparking include cast rotors, insulated rotor bars, and mechanical means to insure tight fits within the slots including swedging or pinning of fabricated rotor bars.

G.2.3.3 Rotor attachment

Inspection of motor rotors has shown that sparking and localized heating can occur. The most common areas are between fans attached to motor end rings or shorting rings, between shafts and rotor core flanges or pressing plates, and in welds that secure parts to the shaft.

G.2.3.4 Broken or open bars and end rings

Broken or open rotor bars and end rings or shorting rings are possible rotor failure modes for ac motors. There are numerous reasons for these failures, but many are traced to thermal fatigue of the materials, delamination of the materials, poor machining practices, poor brazing or welding methods, porous materials, and sometimes improper design. Occasionally, poor operating practices, maintenance, and abuse are factors that can cause broken rotor bars and end rings.

If a motor continues to operate with a broken rotor bar(s), the chances of a significant motor failure are increased.

G.2.4 Multisection enclosures

All large motors and many smaller motors are constructed from what one might call modules or components. This means that there are a number of contact interfaces between the components that form the active material, i.e., stator core, and the enclosure. Whenever an ac motor is starting, high values of stray current can circulate in the frame components and in any attached metal that forms a part of the enclosure. If applicable, manufacturers provide various methods for adequately bonding each section.

The literature, Bredthauer et al. [B11], has reported instances of sparking occurring between the main stator frame and the enclosure parts.

G.3 Conclusions

In summary, there are several factors that contribute to the chances of having uncontained sparking in motors. Also, there are several design and installation features that can be used to mitigate sparking in motors. These have been incorporated into the recommendations in this guide.

Annex H

(informative)

Surface temperature study results

Annex H discusses surface temperature considerations for motors applied in Class I, Division 2 locations. H.1 gives a general discussion of hot motor surfaces (excluding accessories) and their source, while H.2 presents data on measured motor surface temperatures, along with their relationship to published AITs of some low-AIT flammable gases. H.3 gives conclusions based on these data.

H.1 Hot motor surfaces

For general-purpose enclosures, internal as well as external component surface temperatures should be considered, since many motor enclosures are open and even the typical totally enclosed motor is not gas tight. All components generating heat should be evaluated to understand the design and application requirements for Class 1, Division 2 locations. (See Hamer et al. [B19].)

H.1.1 Enclosures

For explosion-proof motors, which are typically applied in Class I, Division 1 locations, the enclosure is designed to contain any flammable gas ignition within the motor when the motor is properly applied. Therefore, internal surface temperatures are not a concern. The outer surface temperature should be kept below the applicable AIT to prevent the outer surface from becoming an ignition source. Explosion-proof motors have a temperature code (T code) on their nameplate to indicate the maximum surface temperature as tested for that motor, so the motor can be applied within its design rating.

Open and/or totally enclosed motors, which are commonly applied in Class I, Division 2 locations, are not sealed to prevent the ingress of gasses and vapors from the environment surrounding the motor. Also, these enclosures are not designed to contain explosive events. Therefore, the temperatures of both inside and outside surfaces should be considered for these motors. For these enclosures, the outer surface may exhibit significantly lower temperatures than the inner components, such as the stator, rotor, and space heaters, so the outer surface temperature is not generally the limiting factor when considering the suitability of such motors for Division 2.

H.1.2 Rotor

The temperature of the rotor is a result of rotor losses and the relative cooling capabilities. Heating losses occurring in or on the surface of the rotor include rotor conductor losses and a portion of losses normally considered as stray load losses. The rotor temperature rise is a combination of design factors including loss distribution, cooling design, geometry, and relative heat transfer rates between the various components. The total temperature of the rotor is affected by the various rotor temperature rises and the cooling ability of the air reaching the rotor. Since the rotor losses are a function of load, the temperature rise of the rotor is a function of the load.

There are three types of rotor cooling: nonducted (air gap only), axial ducts (ducts parallel to the shaft), and radial ducts (ducts perpendicular to the shaft). Figure 2 shows the axial and radial rotor ventilation ducts. Motors with a nonducted rotor and motors with axial ducts only in the rotor generally are hotter than similar motors with axial and radial ducts in the rotor. Two-pole motors typically have nonducted rotors. Slower speed motors in ratings greater than a few hundred horsepower often have ducted rotor designs. Thus, in these larger ratings, two-pole motors often have hotter rotors than slower speed motors.

Many NEMA Design B, TEFC and ODP motors have nonducted rotors and typically operate with the rotor temperature rise higher than the stator winding temperature rise. This observation is based on numerous manufacturers' experience and is supported in the test data presented in H.2.2 and H.2.3. Based on the testing and the calculations, the maximum rotor temperature for NEMA Design B, TEFC and ODP, Class B rise motors would typically be less than 200 °C in a 40 °C ambient. Some NEMA Design B motors may have operating rotor temperatures higher than this, so 200 °C should not be considered an absolute maximum.

Motors fed from ASDs generally have rotors with higher temperatures than the stator because the harmonic voltages and currents induced in the rotor increase the rotor stray load losses. (Refer to 6.3.)

H.1.3 Stator

The temperature of the stator is a result of motor heating losses and the relative cooling arrangements and capabilities of the motor design. Heating losses occurring in or on the surface of the stator include magnetic core losses, stator winding losses, and a portion of stray load losses. The stator may also be subject to heating from the rotor as a result of rotor heating losses. The stator temperature is a combination of temperature rise resulting from the various local losses and the heat transferred across the air gap from the rotor, plus the ambient temperature. Since the losses are a function of load, the temperature rise of the stator is also a function of the load. The total temperature of the stator winding is the sum of the temperature rise and the outer ambient temperature, except for motors with air-to-water (TEWAC) heat exchangers where the total temperature is the sum of the stator rise plus the temperature of the air out of the cooler. One additional exception occurs for motors ventilated from a remote source, where the total temperature of the stator winding is the sum of the stator rise plus the temperature of the air entering the motor from the remote location.

The stator winding rise by resistance is the average temperature rise of the winding. Variations in the winding temperature result from variation in localized heat transfer rates within the motor. A typical motor winding may have a 10 °C hot-spot temperature rise above the rise by resistance. Some higher speed motors, two-pole and four-pole motors, may have a higher temperature difference between the rise by resistance measured temperature and the imbedded detector temperature (usually located at the hot spot), 15 °C to 20 °C, because the coil extensions are longer. For example, a motor operating at 80 °C stator winding rise by resistance in a 40 °C ambient would have an approximate average stator winding temperature of 120 °C and a stator winding hot-spot temperature of 130 °C ($40\,^\circ\text{C} + 80\,^\circ\text{C} + 10\,^\circ\text{C} = 130\,^\circ\text{C}$). A motor with an average stator temperature rise of 80 °C has an approximate average temperature rise of 105 °C when operating at 1.15 service factor [$80\,^\circ\text{C} \times (1.15)^2 = 105\,^\circ\text{C}$]. The stator hot-spot temperature may reach a total of 155 °C after including the 10 °C hot-spot allowance at a 40 °C ambient temperature ($40\,^\circ\text{C} + 105\,^\circ\text{C} + 10\,^\circ\text{C} = 155\,^\circ\text{C}$).

H.2 Surface temperature study results

Three sets of data are presented here. The data in H.2.1 explore the relationship between motor surface temperature and AIT, while H.2.2 presents motor surface temperature test data collected by the Working Group, and H.2.3 presents some independent manufacturers' tests and calculations on motor surface temperature.

H.2.1 AIT test results

An extensive series of tests was conducted on behalf of the P1349 task group in the years 1997–2000, attempting to quantify the temperatures and conditions under which hot rotor surfaces could ignite a low AIT flammable gas. The intent was to confirm or refute thereby the applicability of the API 2216-1991 [B1] conclusions for hot surfaces as it may apply to an induction motor. The initial results of this effort were discussed in Hamer et al. [B19], and further results are discussed in H.2.1.2. For the purposes of this discussion, the results referenced in Hamer et al. [B19] are referred to as Phase 1 results in H.2.1.1 and those referenced in H.2.1.2 are referred to as Phase 2 results. The Phase 1 results include both TEFC and ODP motor constructions, while the Phase 2 results include ODP constructions only for a larger number of manufacturers. It is felt that the Phase 2 results are more reliable with respect to AIT conclusions, since the instrumentation for these tests was improved over that used in Phase 1.

Tests were made with instrumented test motors at locked rotor, running under overload conditions, and/or suddenly stopped. The tests also substantiated that there was insufficient sparking present inside the test motors to cause any ignitions. It is important to note that special motor constructions and/or unusual loading methods, far beyond what is normally encountered in operation, were required to produce the temperatures of interest.

H.2.1.1 Phase 1 AIT test results on TEFC and ODP motors

Explosion-proof, TEFC and ODP three-phase induction motors, rated 3 hp and 20 hp with a rated voltage of 380 V, were tested to determine the internal surface temperatures under varying operating and load conditions. The flammable mixtures, with AITs of 160 °C (diethyl ether) to 225 °C (*n*-hexane) were released into the test area. For each flammable mixture, tests were conducted on these motors with the flammable mixture present during starting, running, overloading, locked rotor, and stopping conditions.

During starting and normal running conditions there were no ignitions, even with the 160 °C AIT mixture. Under overloaded running conditions, the 160 °C mixture ignited with a rotor temperature of 229 °C. Under overloaded running conditions, no ignition was achieved for the 218 °C and 225 °C AIT mixtures, despite motor loading to achieve rotor temperatures over 350 °C. As seen in 5.2, such rotor temperatures would not be expected for standard Design B motors under any normal balanced sinewave operating condition.

Under locked rotor conditions, ignition did occur with the 160 °C and 218 °C AIT mixtures, exothermic activity occurred with the 204 °C and 225 °C AIT mixtures, and no ignition was achieved for the 204 °C and 225 °C AIT mixtures (with rotor temperatures above 400 °C). Under locked-rotor conditions, the rotor heated up at a rate of 1 °C to 10 °C per second. This range correlates with manufacturers' experience for motors in this size range. Table H.1 from Hamer et al. [B19] illustrates the pertinent results.

Tests were also made to attempt to determine running rotor temperature at ignition. Another set of tests conducted was to load the motors, stop the motors, and witness if ignition occurred. The load was increased until ignition would occur when the motor stopped rotating (or the thermal limit was reached). Ignition occurred for 160 °C and 218 °C AIT mixtures. No ignition occurred for the 225 °C mixture (with rotor temperatures above 340 °C). Table H.2 from Hamer et al. [B19] illustrates the pertinent results, and Table H.3 gives a comparison of laboratory AIT values versus the minimum test ignition temperatures found in Phase 1 testing.

H.2.1.2 Phase 2 AIT test results on ODP motors

A comparison of the ignition temperature results for 3 hp and 20 hp ODP induction motors is shown in Table H.4. If ignition of the flammable gas did not occur when the maximum permissible motor test

Table H.1—Summary of results of TEFC 3 hp and 20 hp induction motor stationary (locked-rotor) tests for the ignition of low-AIT gas mixtures[a]

Gas mixture (motor tested)	Published AIT of gas mixture (°C)	Peak rotor temp. (at start of gas purge) (°C)	Rotor temperature at time of ignition (°C)	Test conclusion, minimum ignition temperature (°C)
Diethyl ether/Air (3 hp motor)	160	200	180	180
Diethyl ether/Air (20 hp motor)	160	205	195	195
n-Heptane/Air (20 hp motor)	204	415	No ignition; some gas exothermic activity	None
TFE/Air (3 hp motor)	218	310	290	290
TFE/Air (20 hp motor)	218	355	340	340
n-Hexane/Air (3 hp motor)	225	400	No ignition; some gas exothermic activity	None
n-Hexane/Air (20 hp motor)	225	480	No ignition; some gas exothermic activity	None

[a]Source: Reprinted from Hamer et al. [B19], Copyright © 1997 IEEE.

Table H.2—Summary of results of TEFC and ODP induction motor running (overload) and locked-rotor tests for the ignition of low-AIT gas mixtures[a]

Gas mixture (motor tested)	Published AIT of gas mixture (°C)	Running rotor temperature at ignition (°C)	Stopped rotor temperature at ignition (°C)	Locked-rotor ignition temperature (from Table H.1)
Diethyl ether/Air (3 hp TEFC motor)	160	>315 (Note 1)	250	180
Diethyl ether/Air (3 hp ODP motor)	160	Not determined (Note 3)	238	Not determined
Diethyl ether/Air (20 hp TEFC motor)	160	>350 (Note 2)	215	195
Diethyl ether/Air (20 hp ODP motor)	160	229 (Note 3)	226	Not determined
TFE/Air (3 hp TEFC motor)	218	>350 (Note 2)	>325 (Note 2)	290
TFE/Air (20 hp TEFC motor)	218	>350 (Note 2)	300	340
Hexane/Air (3 hp ODP motor)	225	>362 (Note 2)	>340 (Note 2)	>400 (Note 2)
Hexane/Air (20 hp ODP motor)	225	>355 (Note 2)	>340 (Note 2)	>400 (Note 2)

NOTES:
1—No ignition during running; some evidence of steady oxidation without autoignition of gas.
2—No ignition during test.
3—During a series of five across-line starts from rest with the inertia of the 50 hp motor as the load, no ignitions occurred.

[a]Source: Reprinted from Hamer et al. [B19], Copyright © 1997 IEEE.

Table H.3—Comparison of laboratory AIT values with minimum Phase 1 test ignition temperatures

Flammable gas	Published gas AIT (°C)	Minimum test ignition temperature (°C)	Ignition temperature as a percentage of laboratory AIT (%)
Diethyl ether/Air	160	180	112
TFE/Air	218	290	133
Hexane/Air	225	>340	>151

temperature was reached or due to significant decomposition of the flammable gas, the entry in the "Temperature at ignition" column indicates the rotor temperature reached with a "greater than" sign, indicating that the ignition temperature was greater than the maximum temperature reached in the test. Table H.5 compares the minimum Phase 2 test ignition temperature for each flammable gas/air mixture with the laboratory determined AIT. These results are felt to be more reliable than those presented in Table H.3, due to superior instrumentation being used for the Phase 2 tests.

Notice that for the test motors used here, 200% to 300+% loading was typically required to produce these temperatures of interest. Also note that the ignition temperatures measured here were determined by means of thermocouples and are hence more accurate and lower than motor temperatures determined by means of rotor paint.

Table H.4—Phase 2 motor test results: three-phase induction motors with ODP enclosures

Flammable gas	Published gas AIT (°C)	Motor description	Running-rotor temperature at ignition (°C)	Stopped-rotor temperature at ignition (°C)
Diethyl ether/Air	160	20 HP ODP – Manuf. B	235, 240, 257	
Diethyl ether/Air	160	20 HP ODP – Manuf. A	245	215, 226, >260
Diethyl ether/Air	160	3 HP ODP – Manuf. B		215
Diethyl ether/Air	160	3 HP ODP – Manuf. A		195
Hexane/Air	225	20 HP ODP – Manuf. B	>375, 400[a]	>375
Hexane/Air	225	20 HP ODP – Manuf. A	>375	>375
Hexane/Air	225	3 HP ODP – Manuf. B	320	
Hexane/Air	225	3 HP ODP – Manuf. A	390	

[a]Ignition occurred when the motor stator electrically failed.

Table H.5—Comparison of laboratory AIT values with minimum Phase 2 test ignition temperatures

Flammable gas	Published gas AIT (°C)	Minimum test ignition temperature (°C)	Ignition temperature as a percentage of laboratory AIT (%)
Diethyl ether/Air	160	195	122
Hexane/Air	225	320	142

H.2.2 Working Group motor surface temperature test results

The tests discussed here were performed by participating manufacturers for the Working Group, and intended to find maximum internal temperatures of some common motors typically used in the petrochemical industry.

TEFC and ODP three-phase induction motors, from 5 hp to 20 hp with a rated voltage of 460 V, were tested to determine the internal surface temperatures under varying load conditions. The results generally validate the comments on maximum internal temperature in 5.2.

H.2.2.1 TEFC energy efficient motors

The surface temperature test results shown in Table H.6 were obtained from three manufacturers in 1995, based on their respective design/production of a 20 hp four-pole 460 V, TEFC energy efficient motor intended for chemical industry service.

Table H.6—Measured maximum temperature rise versus loading condition for 20 hp TEFC four-pole energy efficient motors

Loading condition	Maximum stator temperature rise (°C)	Maximum rotor temperature rise (°C)
75% FLT	27–37	39–114 (+0–28)
100% FLT	41–58	77–128 (+0–15)
115% FLT	52–77	86–152 (+0–21)
125% FLC	65–99	123–153 (+0–21)
140% FLC	86–121	128–194 (+0–14)

In all cases, the highest measured temperature rises were obtained from tests made with temperature-sensitive paint applied to the rotor surface. The ranges shown in Table H.6 illustrate the variance from manufacturer to manufacturer, with parenthesized values representing the uncertainty due to the discrete bands of temperature-sensitive paint.

The results are shown graphically in Figure H.1 for a motor with a Class B rise at 100% FLT. The maximum rotor temperature at full load was below 200 °C as expected, based on a 40 °C ambient.

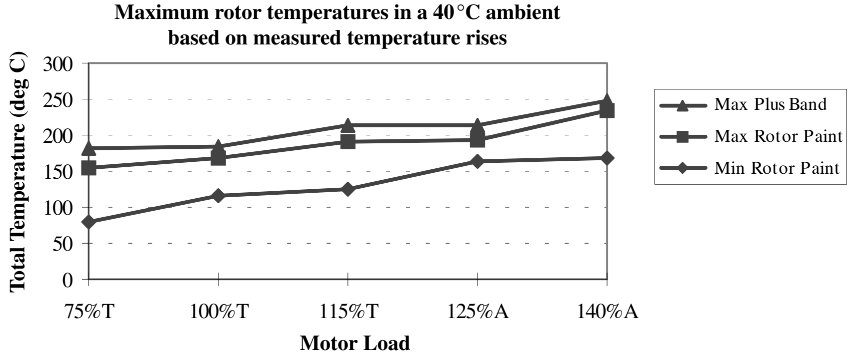


Figure H.1—20 HP energy efficient motor, range of highest temperature measured

H.2.2.2 TEFC standard efficiency motors

Only limited test data were obtained for this type of motor. The data indicated worst-case peak rotor temperature rises of about 150 °C at 100% FLC, 220 °C at 125% FLC, and 240 °C at 140% FLC. The data for a worst-case motor are shown in Figure H.2, for a motor with a Class B rise at 100% FLT. Notice that the temperature-sensitive paint seems to be a very conservative measure.

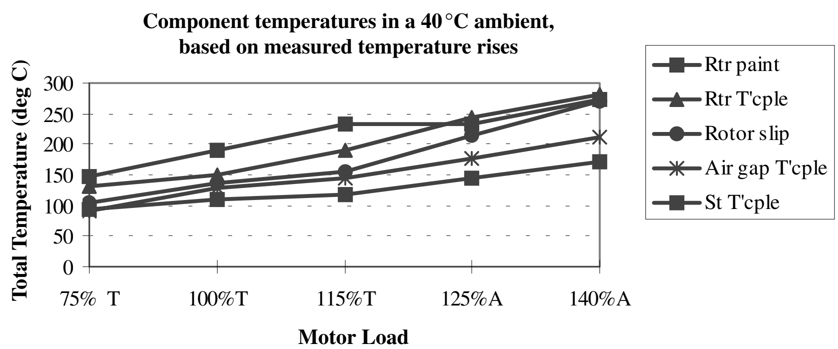


Figure H.2—10 hp four-pole standard efficiency TEFC motor, measured temperature

H.2.2.3 ODP standard efficiency motors

Only very limited test data were obtained for this type of motor. The data indicated normal peak rotor temperatures very similar to those for high-efficiency TEFC motors.

H.2.3 Independent manufacturers' tests and calculations

Several independent manufacturers conducted surface, stator, and/or rotor temperature tests and calculations on their motors and shared the data with the Working Group. Some of those data are given in this subclause for informational purposes. Refer to Table H.7, Table H.8, Table H.9, Table H.10, Table H.11, Table H.12, Table H.13, and Table H.14.

Table H.7—Single-phase induction motors, totally enclosed explosion-proof enclosure, up to 2 hp; total temperature based on 40 °C ambient, 1.0 SF, continuous duty, Class B rise

Size (hp)	Voltage (V)	External surface temperature (°C)	Nameplate Class, Group, and T-Code	Surface temperature test method
0.25	115	<160	Class I, Group D, T3C	UL 674
0.33	115	<160	Class I, Group D, T3C	UL 674
0.5	115	<160	Class I, Group D, T3C	UL 674
0.75	115	<160	Class I, Group D, T3C	UL 674
1.0	115	<160	Class I, Group D, T3C	UL 674
1.5	115	<160	Class I, Group D, T3C	UL 674
2.0	115	<160	Class I, Group D, T3C	UL 674

Table H.8—NEMA frame sizes: three-phase induction, ODP enclosure, up to 450 hp, nonducted rotor ventilation (air-gap cooling only); total temperature based on 40 °C ambient, 1.0 SF, continuous duty, Class B rise

Size (hp)	Voltage (V)	Rotor cooling type	Stator temperature (°C)	Rotor temperature (°C)	Rotor temperature test method[a]
125	4000	Nonducted	Class B	123	Calculated
150	4000	Nonducted	Class B	127	Calculated
150	4000	Nonducted	Class B	123	Calculated
200	4000	Nonducted	Class B	130	Calculated
250	4000	Nonducted	Class B	123	Calculated
300	4000	Nonducted	Class B	119	Calculated
300	4000	Nonducted	Class B	123	Calculated
350	4000	Nonducted	Class B	125	Calculated
350	4000	Nonducted	Class B	103	Calculated
400	4000	Nonducted	Class B	126	Calculated
450	4000	Nonducted	Class B	126	Calculated
			Average	121.8	
			Standard deviation	7.7	

[a]Calculated values may be within 20% of measured values.

Table H.9—NEMA frame sizes: three-phase induction, TEFC enclosure, up to 400 hp [B10], nonducted or axial duct rotor ventilation; total temperature based on 40 °C ambient, 1.0 SF, continuous duty, Class B rise

Size (hp)	Voltage (V)	Rotor cooling type	Stator temperature (°C)	Rotor temperature (°C)	Rotor temperature test method[a]
10	460	Axial ducts	95 by resistance	154	Paint
20	460	Axial ducts	80.7 by resistance	156	Paint
20	460	Nonducted	96 average	119	Calculated
50	460	Nonducted	115 average	133	Calculated
60	460	Axial ducts	101.3 by resistance	179	Paint
75	460	Axial ducts	126 by resistance[b]	184	Paint
75	460	Axial ducts	121.9 by resistance[b]	171	Paint
100	460	Nonducted	104 average	124	Calculated
100	4000	Nonducted	Class B	123	Calculated
125	4000	Nonducted	Class B	130	Calculated
150	4000	Nonducted	Class B	130	Calculated
200	460	Nonducted	109 average	138	Calculated
200	4000	Nonducted	Class B	130	Calculated
350	460	Axial ducts	117	171	Calculated
400	460	Axial ducts with internal fan	111	159	Calculated
			Average	146.7	
			Standard deviation	22.1	

[a]Calculated values may be within 20% of measured values.
[b]Stator rise is above Class B.

Table H.10—Above NEMA frame sizes: three-phase induction, TEFC enclosure, 200 hp to 400 hp, nonducted or axial duct rotor ventilation; total temperature based on 40 °C ambient, 1.0 SF, continuous duty, Class B rise

Size (hp)	Voltage (V)	Rotor cooling type	Stator temperature (°C)	Rotor temperature (°C)	Rotor temperature test method[a]
200	4000	Nonducted	Class B	130	Calculated
250	4000	Axial ducts	109 by resistance	140	Paint
250	4160	Nonducted	111 by resistance	181	Paint
250	4000	Nonducted	Class B	130	Calculated
300	4000	Axial ducts	99 by resistance	136	Paint
300	4000	Nonducted	Class B	130	Calculated
350	4000	Nonducted	Class B	130	Calculated
400	4000	Axial ducts	122.6 by resistance[b]	225	Paint
400	4000	Axial ducts	114 by resistance	162	Paint
400	4000	Nonducted	Class B	130	Calculated
			Average	149.4	
			Standard deviation	31.7	

[a]Calculated values may be within 20% of measured values.
[b]Stator rise is above Class B.

Table H.11—Above NEMA frame sizes: three-phase induction, TEFC enclosure, above 400 hp, nonducted or axial duct rotor ventilation; total temperature based on 40 °C ambient, 1.0 SF, continuous duty, Class B rise

Size (hp)	Voltage (V)	Rotor cooling type	Stator temperature (°C)	Rotor temperature (°C)	Rotor temperature test method[a]
450	4000	Nonducted	Class B	130	Calculated
500	4000	Nonducted	Class B	130	Calculated
600	4000	Axial ducts	120	189	Calculated
600	4000	Nonducted	Class B	130	Calculated
700	4000	Axial ducts	112.5 by resistance	231	Paint
700	4000	Nonducted	Class B	126	Calculated
800	4000	Axial ducts	120.6 by resistance[b]	240	Paint
800	4160	Nonducted	119	186	Calculated
800	4000	Nonducted	Class B	128	Calculated
900	4000	Nonducted	Class B	129	Calculated
1000	4000	Nonducted	Class B	125	Calculated
1250	4000	Nonducted	Class B	128	Calculated
1500	4000	Nonducted	Class B	130	Calculated
1750	4000	Nonducted	Class B	124	Calculated
2000	4000	Nonducted	Class B	120	Calculated
2250	4000	Nonducted	Class B	122	Calculated
			Average	148.0	
			Standard deviation	40.0	

[a]Calculated values may be within 20% of measured values.
[b]Stator rise is above Class B.

Table H.12—1.15 SF load: three-phase induction, TEFC enclosure, nonducted or axial duct rotor ventilation; total temperature based on 40 °C ambient, continuous duty, Class B rise at 1.0 SF

Size (hp)	Voltage (V)	Rotor cooling type	Stator temperature by resistance (°C)	Rotor temperature (°C)	Rotor temperature test method[a]
2.3	230	Nonducted	83	128	Paint
2.3	230	Nonducted	86	131	Paint
5.75	230	Nonducted	107	157	Paint
5.75	460	Nonducted	130	194	Paint
8.625	460	Nonducted	103	147	Paint
11.5	460	Nonducted	120	212	Paint
11.5	460	Nonducted	113	144	Paint
20	460	Nonducted	115 Average	140	Calculated
23	460	Nonducted	112	156	Paint
28.75	460	Nonducted	121	204	Paint
28.75	575	Nonducted	95	150	Paint
50	460	Nonducted	142 Average	166	Calculated
75	460	Axial ducts	148	228	Paint
75	460	Axial ducts	139	236	Paint
86.25	460	Nonducted	110	172	Paint
100	460	Nonducted	120 Average	147	Calculated
115	460	Nonducted	120	160	Paint
115	460	Nonducted	113	176	Paint
200	460	Nonducted	120 Average	170	Calculated
287.5[b]	460	Axial ducts	119	184	Paint
350	460	Axial ducts	143	223	Calculated
400[b]	4000	Axial ducts	142	239	Paint
400	460	Axial ducts with internal fan	134	205	Paint
600[b]	4000	Axial ducts	149	235	Paint
800[b]	4160	Nonducted	153	244	Paint
			Average	181.9	
			Standard deviation	37.2	

[a]Calculated values may be within 20% of measured values.
[b]Above NEMA frame sizes.

Table H.13—Above NEMA frame sizes: three-phase induction, WPII enclosure, above 400 hp, nonducted or axial duct rotor ventilation; total temperature based on 40 °C ambient, 1.0 SF, continuous duty, Class B rise

Size (hp)	Voltage (V)	Enclosure type	Rotor cooling type	Stator temperature (°C)	Rotor temp. (°C)	Rotor temperature test method[a]
450	4000	WPII	Nonducted	Class B	110	Calculated
700	4160	WPII	Axial ducts	120 Calculated	146	Calculated
800	4160	WPII	Axial ducts	98 by RTD	149	Calculated
920	4160	WPII	Axial ducts	124 Calculated	176	Calculated
1000	4160	WPII	Axial ducts	110 by RTD	197	Calculated
1250	4160	WPII	Axial ducts	130 by RTD	218	Calculated
1500	2300	WPII	Nonducted	124.6 by RTD	190	Calculated
1500	2300	WPII	Axial ducts	Class B by RTD	218/184	Calculated/ Thermocouple
2500	4160	WPII	Nonducted	82.6 by RTD	118	Calculated
3000	4000	WPII	Nonducted	Class B	114	Calculated
				Average	160.2	
				Standard deviation	38.2	

[a]Calculated values may be within 20% of measured values.

Table H.14—Above NEMA frame sizes: three-phase, all enclosure types,[a] above 150 hp, axial duct and radial duct rotor ventilation; total temperature based on 40 °C ambient, 1.0 SF, continuous duty, Class B rise

Size (hp)	Voltage (V)	Enclosure type	Rotor cooling type	Stator temp. (°C)	Rotor temp. (°C)	Rotor temperature test method[b]
200	4000	WPII	Axial and radial ducts	Class B	99	Calculated
250	4000	WPII	Axial and radial ducts	Class B	104	Calculated
300	4000	WPII	Axial and radial ducts	Class B	106	Calculated
350	4000	WPII	Axial and radial ducts	Class B	111	Calculated
400	4000	WPII	Axial and radial ducts	Class B	96	Calculated
450	4000	WPII	Axial and radial ducts	Class B	97	Calculated
500	4000	WPII	Axial and radial ducts	Class B	92	Calculated
600	4000	WPII	Axial and radial ducts	Class B	97	Calculated
700	4000	WPII	Axial and radial ducts	Class B	93	Calculated
800	4000	WPII	Axial and radial ducts	Class B	96	Calculated
900	4000	WPII	Axial and radial ducts	Class B	101	Calculated
1000	4000	WPII	Axial and radial ducts	Class B	103	Calculated
1250	4000	WPII	Axial and radial ducts	Class B	99	Calculated
1500	4000	WPII	Axial and radial ducts	Class B	102	Calculated
1750	4000	WPII	Axial and radial ducts	Class B	101	Calculated
2000	4000	WPII	Axial and radial ducts	Class B	106	Calculated
2250	4000	WPII	Axial and radial ducts	Class B	93	Calculated
2500	4000	WPII	Axial and radial ducts	Class B	93	Calculated
3000[c]	6000	TEWAC	Axial and radial ducts	Class B by RTD	77	Thermocouple
3500	4000	TEFV	Axial and radial ducts	Class B by RTD	95	Thermocouple
4250	4160	TEFV	Axial and radial ducts	Class B by RTD	95	Thermocouple
6000	6000	TEWAC	Axial and radial ducts	Class B by RTD	105	Thermocouple
6000[c]	6000	WP-I	Axial and radial ducts	Class B by RTD	95	Thermocouple
7500	13 200	TEWAC	Axial and radial ducts	Class B by RTD	95	Infrared camera
				Average	96.6[d]	
				Standard deviation	6.2[d]	

[a]Radial ventilation is currently not used for NEMA frame-sized TEFC enclosures and is rare for above NEMA frame-sized TEFC enclosures.
[b]Calculated values may be within 20% of measured values.
[c]Synchronous motor.
[d]The average and standard deviation for a larger population of motors may be higher. Some motors, particularly synchronous motors, may be expected to have higher rotor temperatures, depending on the duct design and other factors.

H.3 Temperature test observations

H.3.1 AIT observations

Table H.15 gives a comparison of Phase 1 and Phase 2 test ignition temperatures versus the laboratory AIT. Again please note that the Phase 2 results are felt to be more reliable, due to superior instrumentation used for the Phase 2 tests.

Table H.15—Comparison of published AIT values with minimum test ignition temperatures in motors

Flammable gas	Published gas AIT (°C) [B32]	Minimum Phase 1 test ignition temperature (°C)	Minimum Phase 2 test ignition temperature (°C)	Minimum ignition temperature as a percentage of published AIT (%)
Diethyl ether/Air	160	180	195	112
TFE/Air	218	290	N/A[a]	133
Hexane/Air	225	>340	320	142

[a]N/A = not available.

The following observations were made from the AIT Phase 1 and Phase 2 tests conducted on TEFC and ODP motors discussed in H.2.1.

a) Phase 1 and Phase 2 AIT tests all confirmed that the ignition temperature of the flammable test gases and vapors in a motor enclosure was higher than the published AIT. (See NFPA 497-1997 [B32].) This extra margin is one reason why industry has an excellent safety record regarding installation of open and totally enclosed induction motors in Class I, Division 2 locations.

b) During testing conducted by the Working Group, operating motors did not ignite a flammable mixture, but when the motors were shut off with a low AIT gas present, the heat rise and loss of circulating air immediately caused an ignition in some motors where the operating temperature was significantly greater than the published AIT of the gas. The ignition temperature of the flammable gases and vapors in the motor enclosure was generally higher when the motor was running than when the motor was stopped. This suggests that it is not always a good practice to shutdown running ODP or TEFC motors in a classified hazardous area when a flammable gas is present. Motors should be shutdown in a programmed and controlled manner to minimize the introduction of unknown effects on the surrounding environment. However, it is recognized that there are times when quickly shutting motor-driven systems down when a gas release occurs may be preferred over a slower controlled shutdown.

c) The lowest flammable gas AIT occurred in the smaller 3 hp ODP motor enclosures. This suggests that the smaller motor enclosures may present the largest risk relative to ignition of flammable gases and vapors by hot motor surfaces, as might be expected due to their greatest departure from the API 2216-1991 test conditions [B1].

d) For a given size motor, the AIT of the flammable gas for the three different motor manufacturers was relatively consistent.

e) At the elevated test temperatures, decomposition of the flammable gas sometimes occurred before ignition.

f) No ignition of the flammable gases and vapors was experienced during motor starting, demonstrating that none of the test motors exhibited sufficient sparking or surface temperatures during starting to cause an ignition.

g) For applications involving flammable materials with AITs below 200 °C (notably, diethyl ether), users should work closely with the manufacturers to address the exposed surface temperatures of the motors.

h) The elevated rotor temperatures during a motor acceleration presents a low risk of ignition for even low-AIT flammable gas/air mixtures due to the turbulent gas/air flow, which deters ignition.

i) The probability is low for a flammable vapor ignition by hot surfaces within an induction motor, except for the few materials with AITs below 200 °C.

H.3.2 Surface temperature observations

The following observations were made from the surface temperature tests conducted by the Working Group and participating motor manufacturers discussed in H.2.2 and H.2.3, respectively.

a) The rotor temperatures presented in 5.2, including a maximum recommended Division 2 exposed surface temperature of 200 °C for most motor types during normal operation, are fairly well validated by actual motor testing results and calculations.

b) For motors with nonducted rotors or those with axial rotor ducts only, the rotor was generally determined to be the hottest motor component (excluding in some cases the space heater). For motors with axial and radial ducted rotors, the rotor is generally slightly cooler than the stator.

c) Motors with a nonducted rotor and motors with axial ducts only in the rotor generally are hotter than similar motors with axial and radial ducts in the rotor.

d) Two-pole motors typically have nonducted rotors. Slower speed motors in ratings greater than a few hundred horsepower often have ducted rotor designs. Thus, in these larger ratings, two-pole motors often have hotter rotors than slower speed motors.

e) For a given motor, the calculated rotor temperatures were generally within 20% of measured values using paint, thermocouples, or infrared camera. For a given motor, calculated values were generally more conservative (higher) than measured values. For a given motor, the paint test values were generally within 20% of thermocouple measurements. For a given motor, the paint was generally the most conservative measurement, giving the highest value for surface temperatures.

Annex I

(informative)

Surface temperature test methods

This annex describes methods other than paint testing for determining surface temperature. Paint testing is discussed in Clause 8.

I.1 Thermodynamic computer model

Thermodynamic computer models are used to model stator and rotor temperatures in motors to assist motor designers. The detail input into the computer model and the accuracy of the output can vary.

I.2 UL 674 test method

The test method used for determining the surface temperature of explosion-proof motors is paraphrased here.

UL 674-1994, "Electric Motors and Generators for use in Division 1 Hazardous (Classified) Locations" [B39], is the standard UL uses to evaluate motors for use in a Division 1 location. UL is concerned with two things. First, the motor construction, which should have the capability of withstanding an internal explosion and at the same time not ignite the surrounding atmosphere; second, the external maximum surface temperature of the motor should stay within temperature limits.

To ensure the motor external surface temperature does not exceed allowable limits, the explosion-proof motor should have some mechanism to remove it automatically from the power source before the frame surface reaches the operating Temperature Code specified on the UL nameplate. This nameplate gives the Group, Class, and Temperature Code the motor is listed for.

For evaluation of the construction, the radial and axial joints of the enclosure are checked for maximum and minimum clearance specified in the standard. A spark plug is also installed in the frame of the motor, which is later used to create an electrical spark to ignite the test gas. The motor is filled with the appropriate testing gas mixture and installed in a test chamber which is also filled with the same gas mixture. For Class I, Group D, the test gas is propane; and for Class I, Group C, the test gas is ethylene. For this test, pressure measuring devices are installed in the test chamber. The motor is then energized and the test gas inside the motor is then ignited. The motor should have the capability of containing the flames or sparks and withstand an internal explosion and at the same time not ignite the surrounding atmosphere.

The pressure that is measured in the test chamber is used to evaluate the strength of the enclosure, which can be done by calculation or by a hydrostatic pressure test.

For the external surface temperature test, UL has two test methods as follows:

a) A running overload test that employs a temperature-limiting device
b) A running overload test, where the motor runs until the motor experiences burnout

For these tests, thermocouples are used to monitor the external surface temperature of the motor.

For a motor that is provided with a temperature-limiting device in the motor circuit (sometimes used for about 10 hp and less) or in a control circuit, the load is gradually increased until the temperature-limiting device trips. The temperature-limiting device is selected to remove the motor from the power source under running and locked-rotor conditions before the frame reaches the T Code specified on the UL nameplate. This device is normally selected to meet a T Code of T2C (230 °C) or below.

For a motor that does not have a temperature-limiting device, the manufacturer's insulation system is used to determine the maximum surface temperature of the motor. The insulation system acts as a fuse. Under full-load running conditions, the load to the motor is gradually increased until the motor winding opens and a burnout occurs, removing power to the motor. The maximum surface temperature of the motor housing is determined when the hottest thermocouple has started to descend. The surface temperature is generally less than 260 °C (T2B). The motor is normally listed for Class I, Group D only with a T Code of either T2A (280 °C) or T2B. However, a motor listed for Class I, Group C and Group D, T2B can be used as long as the gases and vapors have an AIT above 260 °C. Gases and vapors that have an AIT less than 260 °C would require a temperature-limiting device.

I.3 Motor surface temperature testing methodology and limitations

This guide's Working Group conducted surface temperature tests on several low-voltage motors. Testing measurements were conducted using the following methods.

a) Rotor thermocouple
b) Heat-sensitive paint (with a single type of paint applied in a consistent pattern)
c) Hot versus cold slip
d) Air-gap thermocouples (in a common orientation and placement)
e) Stator thermocouples (again in a common orientation and placement)

There was an effort made to ensure the consistency of testing methodology between the three manufacturers that participated in the survey referenced above.

Limitations and difficulties associated with each method are listed below. See H.3.2 for additional surface temperature observations.

a) *Rotor thermocouple*. Generally gives very accurate results, but there are difficulties associated with getting the thermocouple placed in a hot spot and insulated from cooler media or surfaces. Also, bringing the thermocouple leads to a measuring device requires drilling the axis of the shaft and either installing special slip rings on a test motor, or measuring the temperature after shutdown (method used for Working Group tests), and accepting the associated cooling period and related potential inaccuracies. The results were consistent. This method is not a recommended method for production motors. The motors should be drilled and fitted with test instruments and are not usable.

b) *Heat-sensitive paints*. Again gives the most conservative results. However, there are potential inaccuracies related to variance between different makes of paint and different patterns of application. These inaccuracies and variance between motor manufacturers were minimized by ensuring that identical paint and consistent test methods were used for this study. However, there are other potential inaccuracies stemming from an apparent tendency of this type of paint to exhibit a time-versus-temperature reaction characteristic, rather than change state at a specific peak temperature, as is desired. In some cases, the paint has been observed to change state following longer periods at a lower temperature than the paint is intended to react to, yielding measured temperatures higher than actual. The paint test consistently produced the highest temperatures. This nondestructive test is usually done by manufacturers for production motors.

c) *Hot versus cold slip*. These were calculated values and were consistently less than the paint values. Slip speed is heavily dependent on rotor resistance and hence temperature. This method calculates an average rather than a peak temperature.

d) *Thermocouples placed in the air gap*. This method attempts to measure rotor temperature across the air gap. There are no special difficulties associated with bringing the thermocouple leads out in this case, but there are inherent limitations in the accuracy of measured rotor surface temperatures, due to the insulating effect of the air gap, and the fact that an average rotor surface is presented because a full rotor surface spins past the fixed thermocouple. The results were not consistent. This method is not a recommended method. The motors are drilled and fitted with test instruments and are not usable.

e) *Stator thermocouples*. This method gives an accurate reading of peak stator winding temperatures, but these temperatures are lower than peak rotor temperatures for most motor designs. The results were consistent. This method is not a recommended method for determining the rotor temperature. It could be used to confirm the temperature rise of the motor. The thermocouples are fitted on the windings (either the end-turns or core), not necessarily the hot spot. This is not a destructive test, and the motor could be used.

Annex J

(informative)

Event history

A small number of nonexplosion-proof, constructed motors have been involved in events resulting in visible sparking to explosions within these motors. Following these events, an independent electrical engineering research group was commissioned to perform a study to identify whether motors have the capability to be an ignition source. (See Bartels and Bradford [B7].) Additionally, other independent engineering and manufacturing groups also began investigating this phenomenon. (See BEAMA Ltd. [B37].)

The results of these investigations have identified five events with known information involving motors. The area classification is not known for the events cited. In all of the known events the motor rated voltage exceeded 5.5 kV. In three of the events, the motor installation method allowed a flammable mixture to be readily introduced inside the motor housing, i.e., a common bearing lubricating system coupled to a gas compressor. Four of the events involved gas compressor installations and one involved a crude oil pump application. One of the events indicated sparking occurring between motor enclosure parts. All of the enclosures were type "n."

These studies, ERA Report 92-0474 [B7] and a report by BEAMA Ltd. [B37], have identified the events listed in Table J.1.

Table J.1—Motor event history

	Year	Location	Voltage	Size	Speed	Type	Application
1	1984	Offshore platform, North Sea	13.8 kV	3.17 MW	3560 rpm	"n"	Crude oil pump motor
	Ignition source: visible sparking observed between the terminal box and motor enclosure.						
	Source of flammable vapor: none						
2	1985	Offshore platform, North Sea	11 kV	6.56 MW	3560 rpm	"n"	Gas compressor motor
	Ignition source: unknown						
	Source of flammable vapor: flammable gas cloud had been in the area of the motor some days before and believed to have been trapped in the motor enclosure.						
3	1988	Onshore terminal, UK	11 kV	5.5 MW	1485 rpm	"n"	Gas compressor motor
	Ignition source: unknown, evidence of electrical fault within stator winding.						
	Source of flammable vapor: flammable gas was transferred via a common bearing lubrication/cooling system from the compressor to the motor.						
4	1989	Offshore platform, North Sea	13.8 kV	5.3 MW	1780 rpm	"n"	Gas compressor motor
	Ignition source: unknown, possible evidence of circulating currents and electrical fault.						
	Source of flammable vapor: flammable gas was transferred via a common bearing lubrication/cooling system from the compressor to the motor.						
5	1991	Oil refinery, UK	6.6 kV	N/A	N/A	"n"	Gas compressor motor
	Ignition source: manufacturer identified mechanical failure in rotor end ring.						
	Source of flammable vapor: installation method allowed hydrogen gas to enter motor enclosure.						

N/A = not available.