Motor Standards for the Chemical Process Industry

Standard IEEE-841

Introduction

IEEE-841 identifies the recommended practice for chemical industry severe duty squirrel-cage induction motors, 600 V and below. It was first issued in 1986 and was significantly revised and reissued as a Standard in 1994. Minor revisions were also made in 2001. The scope has been increased to severe duty TEFC squirrel-cage induction motors with anti-friction bearings in sizes up to and including 500 HP. Motor voltages of 2300 V and 4000 V have been added. Changes to the standard are reviewed in detail below. Requirements are identified that improve motor reliability and increase motor life.

History

Due to the mutual effort of users and motor manufacturers, IEEE-841-1986, Recommended Practice for Chemical Industry Severe Duty Squirrel-Cage Induction Motors – 600 V and below (RP841) was created. It recognized and addressed the special motor requirements of the continuous-process petrochemical industry. These requirements included the need for a reliable motor to reduce costly downtime, a corrosion resistant motor enclosure, low noise levels, high efficiency and interchangeability.

IEEE standards are required to be revised and updated every 5 years. In 1990, a Project Authorization Request (PAR) was submitted by the IAS Petroleum and Chemical Industry Committee to revise RP841. The IEEE Standards Board approved the PAR and a new P841 Working Group was formed.

Some shortcomings were noted in the original standard:

1. A significant number of large petrochemical users were still purchasing severe duty NEMA frame TEFC motors using internal company specifications.
2. The language used was "should" and not "shall". This language made it difficult to use it as a specification reference in a purchase order.
3. Several important technical requirements were optional on the part of manufacturers. Examples are the "preference for cast iron frames" and the "recommendation" that bearing temperature rise at a rated load not to exceed 45°C (50°C on two-pole motors).
4. Motor design criteria in a number of areas failed to meet the need of the petrochemical industry. Areas of specific concern were vibration levels, terminal box size, shaft runout and bearing life.
5. Users recognized that bearing failures were the leading cause of NEMA frame motor failures. Lubricant contamination and lack of lubrication/overlubrication were believed to be the primary causes of these failures. Users wanted new requirements in the revised standard to significantly reduce bearing failures.
6. There was a demand to expand the scope beyond NEMA frame sizes. European manufacturers were beginning to compete in the North American marketplace with TEFC designs up to 500 HP. When purchasing TEFC designs from 250 to 500 horsepower, users generally would purchase a custom design based on standard API 541 or their own specifications. If the standard could incorporate requirements up to 500 HP, users felt that manufacturers would produce lower cost standardized designs that could be stocked and made readily available for routine purchases and emergency situations.

Revised Scope

Based on the above recommendations, the decision was made to expand the scope of the standard to include TEFC designs up through 500 horsepower with anti-friction bearings. Both low voltage (up to 600V) random wound and medium voltage form wound insulation systems are now included. Excluded from the scope of this standard are motors with sleeve bearings and additional specific features required for Division 1 explosion-proof motors. The user now has the option of using either API 541 or IEEE 841 in the event that anti-friction bearings are specified for motors up to 500 horsepower. These changes were incorporated in 1994.

Review of IEEE Standard 841-1994

This section will review the new requirements and the reasons for the changes. An overview of the mechanical design features required by the standard is shown in Table 1 on page 2.

Service Conditions

The ambient temperature range for "Usual Service Conditions" was modified by reducing the lower temperature limit from –15 to –25°C, more closely reflecting actual temperatures experienced by motors in petrochemical plants.

"Load inertia greater than and/or starting conditions more severe than specified in Section 12.54 of NEMA MG-1-1993" was added to the list of "Usual Service Conditions."

Ratings

A note was added recommending that users apply motors within their rating based upon a 1.0 service factor. (Do not extend operation into the 1.15 service factor for normal use.) This practice provides for long

Table 1. Mechanical Construction Features IEEE 841 Motor

Component	Requirement	Benefit
Bearings	Regreasable	Maintainability
	Grease outlet external to fan cover	Ease of relubrication
	Inner bearing cap	Lubricant containment
	IP55 protection on 324 T/TS frames and larger	Reduced lubricant contamination
	45°C temperature rise limit (50° on 2 pole)	Longer lubricant and bearing life
Shaft	Limit on shaft runout	Reduced vibration
Frames, endshields and fan covers	All cast iron construction	Structural integrity, corrosion resistance and longer life
	Motor foot flatness/planity and draft angle	Reduced installation time and improved alignment
Terminal boxes	Cast iron up to 445T frames	Rugged design
	Minimum size defined	Oversized to improve quality of terminations

term reliability and still allows for short-term overload operation (but not more than 15%). Continued operation above the 1.0 service factor significantly decreases motor life due to increased winding and bearing temperature rise. Manufacturers still plan to continue marketing motors with 1.15 service factor on their nameplate to meet current market expectations.

Frame assignments continue to be in accordance with NEMA MG-13-1984. Note that for frame numbers above 445, motor dimensions may not always be uniform from manufacturer to manufacturer. Ending designations (beyond the T) are also subject to individual interpretations.

Rated voltages of 200 V for low voltage systems and 2300 V and 4000 V for medium voltage systems were added consistent with the revised scope. The standard lists normally used voltages for 60 Hz systems. Other voltages may be available by special order or by re-rating. Dual voltage motors are acceptable only for 2300/4000 V.

The standard limits the enclosure to totally enclosed, which is the North American designation covering both enclosure type and cooling style. TEFC is customarily supplied except when TENV may be the only practical alternative on smaller frame sizes.

The international IP codes, which classify degrees of protection by enclosures, are newly referenced. Protection for terminal boxes is required by IP-55. The first code digit (5) indicates a machine protected against dust entry. The second digit (4) indicates protection against splashing water or (5) indicates protection against water jets.

If a replaceable shaft seal is used to achieve IP-55 bearing protection, it is required to be the noncontact or noncontacting-while-rotating type with a minimum expected seal life of 5 years under usual service conditions. The introduction of the new requirement to meet IP-55 for bearing protection is expected to result in a significant reduction in bearing failures.

Electrical Design

Motors continue to be NEMA design B, with NEMA starting capabilities and power supply variations in accordance with the current version of NEMA MG-1-1993. The specified performance of the machine does not require a special electrical design that could adversely impact the availability of new motors.

The new standard, in addition to pointing out the need for consultation with the manufacturer to avoid problems when using the IEEE-841 motor with adjustable speed drives, also lists the type of problems one might experience. These problems include excessive winding temperatures due to higher harmonics and insufficient cooling, insufficient motor accelerating torque at reduced speeds, increased noise levels, winding failures due to repetitive high amplitude voltage spikes, motor and drive damage due to improper application of power factor correction capacitors, high shaft voltages and mechanical failure of the motor or coupling due to torque pulsations, mechanical resonance or operation at excess speeds.

Insulation System and Temperature Rise

The thermal rating of the insulation system, including the lead cables, has been increased from a minimum of Class B to Class F with a permissible temperature rise of 80°C at 1.0 service factor. This change reflects the current insulation system designs provided by most manufacturers for severe duty motors.

The new standard covers rated voltages up to 4000 V versus voltages up to only 600 V for RP841. Both form wound and random wound stator windings are allowed. Vacuum pressure impregnated form windings are required for 2300 V and 4000 V machines, and are optional for voltages less than 600 V for motors above 200 HP. The thermal classification of the insulation system to form windings is per IEEE Std. 275-1992. Form wound insulation systems are also required for sealed and capable of passing the water immersion test. Additional requirements include a surge withstand capability of 3.5 per unit at a rise time of 0.1 - 0.2 microseconds and 5.0 per unit at a rise time of 5.0 microseconds or greater.

Random windings meeting the thermal classification requirements of IEEE Std. 117-1974 are the standard requirements for voltages up to 600 V. Since there is less evidence of problems with steep-fronted surges in random winding up to 600 V, the standard imposes no surge performance requirements for random windings. Phase insulation, however, in addition to varnish, is required to be used between the phases of random windings to improve insulation integrity.

The insulation system, including leads, must be compatible with mineral oil. This provision ensures that the motor insulation system will be suitable for use with oil mist lubrication systems. Some additional modifications, however, are usually required to make the IEEE 841 motor suitable for use with oil mist lubrication systems.

Bearings and Lubrication

Inner bearing caps are now required to protect bearings from dirt and moisture inside the motor as well as to restrict grease and oil flow from the bearing chamber into the interior of the motor. A grease drain with plug that extends beyond the fan cover (if present) is also now specifically required to facilitate relubrication.

Bearing temperature rise limits are mandatory as opposed to suggested in RP841-1986. When direct coupled, the stabilized bearing temperature rise at rated load must not exceed 45°C (50°C on two-pole motors). A minimum bearing L-10 life requirement based on NEMA defined external belt loads was included in RP841-1994. The new standard also defines belt loads for determining bearing L-10 life in above NEMA frame size motors. Bearing life will improve due to the lower limits imposed on bearing temperature rise.

Rotor and Shaft

The specifications impose no new requirements on the rotor, but new shaft runout limits are about one-half of those in NEMA MG-1-1993. Motors with shafts that meet these limits for TIR should be easier to properly install and align. The lower limits will also result in reduced bearing loads and system vibration.

Frames and Endshields

RP841-1986 primarily offered suggestions for materials and performance. The new standard requires that frames, endshields and fan covers shall be cast iron. The old standard would have allowed aluminum and even plastic material for these components. In addition to improving the durability and structural integrity of the motors, the standard has new performance requirements on foot flatness (0.005 inch maximum foot differential) and specifies a maximum draft angle of 1.5 degrees on the top surface of the casting surrounding the foot mounting holes. These requirements were designed to eliminate soft foot conditions and shifting of the motor position during alignment due to the tightening of the mounting bolt on a sloping surface. A drilled and tap hole for a frame ground is also a requirement.

Terminal Boxes and Terminal Leads

Terminal boxes on 600 V NEMA frame motors are now required to be cast iron. Terminal box volume must have a minimum of at least twice the volume specified in Section 11.06.2 of NEMA MG-1-1993.

Vibration

RP841-1986 referred to ANSI/NEMA-MG1-1978 for vibration limits. These limits allowed vibration displacements as high as 1 mil on two-pole motors and 1.5 mils on four-pole motors (0.1 to 0.14 inches per second velocity assuming all vibration at running speed). Users felt that this level of vibration was excessive and resulted in unnecessary bearing failures. On the other hand, manufacturers were reluctant to reduce vibration levels on production line motors due to the potential impact on manufacturing cost.

Data was requested from manufacturers and users on the average vibration of a large population of motors, running uncoupled and unloaded. Data provided by one manufacturer indicated a mean vibration level of 0.03 inches/second for 3,048 new motors rated from 15 to 250 horsepower. One user had also collected data on vibration levels of several thousand motors rebuilt in a dedicated repair facility on a plant site. The data showed that vibration levels significantly below 0.08 inches per second were achieved on most of the rebuilt motors. From the data submitted, the P841 Working Group felt that the overall (unfiltered) vibration limits should be reduced to about one-half of the levels specified in NEMA MG1-1978. Accordingly, the unfiltered vibration limits were set at 0.08 inches/sec.

The other concern of users was the vibration at twice running speed (2x) and twice line frequency (2f). At these frequencies the vibration displacement has a much greater detrimental effect than the same displacement at running speed. Also, the twice frequency (2f) vibration is inherent to the motor design and the user can do nothing to reduce this vibration component after the motor is manufactured. A consensus was reached to place a limit of 0.05 inches/sec on the 2x and 2f filtered vibration levels. Motor unfiltered axial vibration was also limited to 0.06 inches/sec on bearing housings. This axial vibration limit does not apply to roller bearings.

Corrosion-Resistant Treatment

A new requirement was added to apply a lubricant during assembly to all unplated threaded surfaces to facilitate removal. The provision to protect stator and rotor air-gap surfaces against moisture and corrosion was strengthened by including protection for all exposed internal stator, rotor and shaft surfaces.

Efficiency

During the early 60's, NEMA introduced the T frame design that increased motor operating temperatures and had the effect of reducing efficiency and power factor.

Energy conservation programs during the 1980's, due to the high cost of building new power facilities, fostered the need to use energy efficient motors.

In 1992, the Energy Act of 1991 was amended to include nominal efficiency requirements at full load for most general-purpose polyphase squirrel cage induction motors between 1 and 200 horsepower (manufactured for sale in the U.S.). The new IEEE-841 standard has a motor efficiency table, which includes these legislated values of nominal efficiency. In addition, the table also includes full load efficiency requirements for motors above 200 horsepower at both low and medium voltage levels. Efficiency values for low voltage motors about 200 horsepower are derived from Table 12-10 in NEMA MG-1-1993. Efficiency values for medium voltage motors (2300/4000 V) were developed by the P841 Working Group.

Two values are defined in the table. The nominal efficiency, which is to be nameplated on the motor, represents the average efficiency of a large population of motors of the same design. The second value indicates the minimum values of efficiency that any motor of that design would have, due to variations in materials, manufacturing processes and test repeatability.

*Table 2. Efficiencies of Enclosed Motors**

kW	HP	Voltage Class	2-Pole Nom. Effic. %	2-Pole Min. Effic. %	4-Pole Nom. Effic. %	4-Pole Min. Effic. %	6-Pole Nom. Effic. %	6-Pole Min. Effic. %	8-Pole Nom. Effic. %	8-Pole Min. Effic. %
.75	1	600 V	77.0	74.0	84.0	81.5	81.5	78.5	75.5	72.0
1.1	1.5	600 V	84.0	81.5	85.5	82.5	86.5	84.0	78.5	75.5
1.5	2	600 V	85.5	82.5	85.5	82.5	87.5	85.5	84.0	81.5
2.2	3	600 V	86.5	84.0	88.5	86.5	88.5	86.5	85.5	82.5
3.7	5	600 V	88.5	86.5	88.5	86.5	88.5	86.5	86.5	84.0
5.5	7.5	600 V	89.5	87.5	90.2	88.5	90.2	88.5	86.5	84.0
7.5	10	600 V	90.2	88.5	90.2	88.5	90.2	88.5	89.5	87.5
11	15	600 V	91.0	89.5	91.7	90.2	91.0	89.5	89.5	87.5
15	20	600 V	91.0	89.5	91.7	90.2	91.0	89.5	90.2	88.5
19	25	600 V	91.7	90.2	93.0	91.7	92.4	91.0	90.2	88.5
22	30	600 V	91.7	90.2	93.0	91.7	92.4	91.0	91.7	90.2
30	40	600 V	92.4	91.0	93.6	92.4	93.6	92.4	91.7	90.2
37	50	600 V	93.0	91.7	93.6	92.4	93.6	92.4	92.4	91.0
45	60	600 V	93.6	92.4	94.1	93.0	94.1	93.0	92.4	91.0
55	75	600 V	93.6	92.4	94.5	93.6	94.1	93.0	93.6	92.4
75	100	600 V	94.1	93.0	95.0	94.1	94.5	93.6	93.6	92.4
95	125	600 V	95.0	94.1	95.0	94.1	94.5	93.6	94.1	93.0
110	150	600 V	95.0	94.1	95.4	94.5	95.4	94.5	94.1	93.0
150	200	600 V	95.4	94.5	95.4	94.5	95.4	94.5	94.5	93.6
190	250	600 V	95.4	94.5	95.0	94.1	95.0	94.1	94.5	93.6
		2300\4000 V	95.0	94.1	95.0	94.1	95.0	94.1	95.0	94.1
220	300	600 V	95.4	94.5	95.4	94.5	95.0	94.1	-	-
		2300/4000 V	95.0	94.1	95.0	94.1	95.0	94.1	95.0	94.1
260	350	600 V	95.4	94.5	95.4	94.5	95.0	94.1	-	-
		2300/4000 V	95.0	94.1	95.0	94.1	95.0	94.1	95.0	94.1
300	400	600	95.4	94.5	95.4	94.5	-	-	-	-
		2300/4000 V	95.0	94.1	95.0	94.1	95.0	94.1	95.0	94.1
340	450	600 V	95.4	94.5	94.5	94.5	-	-	-	-
		2300/4000 V	95.0	94.1	95.0	94.1	95.0	94.1	95.0	94.1
370	500	600 V	95.4	94.5	95.4	94.5	-	-	-	-
		2300/4000 V	95.0	94.1	95.0	94.1	95.0	94.1	95.0	94.1

* Minimum efficiency based on 20% loss difference. Nominal efficiency values in this table, up to and including 150 kW (200 hp), exceed the requirements of the Energy Policy Act of 1992. For the definition of nominal and minimum efficiencies, see Section 12.59.2 of NEMA MG 1-1998.

The standard also revises the test method by which motor efficiency must be determined. IEEE 112-1991 Method B, which utilizes a dynamometer, is required for all motor efficiency testing.

The efficiencies also improved for Std. 841-2001 on some motors that are 200 HP and less. The efficiency for 2001 revision is given in Table 2.

Space Heaters

Manufacturers are now required to provide on the motor nameplate the maximum surface temperature of the heater when operated at a rated voltage in a 40°C ambient. A note was added in the standard to remind users to specify the maximum heater surface temperature allowed for gas or vapor involved.

Nameplate

The nameplate material is now required to be stainless steel consistent with manufacturers' normal practice. Motor weight, maximum space heater surface temperature and guaranteed minimum efficiency have been added to the nameplate.

Tests

Prior to the time of shipment, manufacturers are now required to take five unfiltered vibration readings (velocity) at no load using an elastic or rigid mount. Vibration measurements are made on the drive end (horizontal, vertical and axial) and the opposite drive end (horizontal and vertical). Measured vibration levels must comply with specification levels. Vibration measurements are recorded and supplied, along with other required test information, with each individual motor, and should assist users in setting up baseline vibration data for new motors at plant sites.

The standard was modified to clarify that prototype tests defined in the Annex are to be utilized for testing motor performance and resistance to corrosion and humidity on new or prototype motor designs.

Cost Benefits Analysis

Cost data obtained from several motor manufacturers indicates that for TEFC motors up to 200 horsepower, the cost of a new motor complying with IEEE 841-1994 will be approximately 10-12% higher than the cost of a new motor of the same efficiency class that complies with the original standard RP841. Accurate cost data for motors in the range of 250-500 horsepower is not available, since most manufactures have not designed a sufficient number of motors meeting the new standard in this size range. Users who elect to make the change from a standard efficiency motor meeting RP841 to an energy efficient motor complying with IEEE-841-1994 may expect an increase in price of as much as 35%. The largest portion of the increase, approximately 25%, is due to the change from a standard to an energy efficient design.

Data from one large industrial plant indicates that because of the design improvements in IEEE-841 motors, the number of motor failures would be expected to decrease to approximately 50% of failure levels experienced with older designs of severe duty induction motors. If all motors in a plant facility were replaced with the new design over a period of time, this would translate into a doubling of the *mean time between failures* for motors at the plant, and could result in a significant reduction in production losses attributable to motor failures.

If the *mean time between failure* for a motor were to double, say from 5 to 10 years, the minimum savings (not counting production loss savings) would be the avoided cost of repairing the motor one time in 10 years. If the purchase price of a severe duty motor meeting IEEE-841-1986 (RP841) is "n" dollars, the incremental additional dollars to purchase a motor meeting the requirements of IEEE-841-1994 is equal to (0.1n). If the repair cost is equal to "r" per unit of the new motor cost or (r)(n), then the calculated return on investment in percent for the purchase of the new IEEE-841 motor is:

ROI = (savings per year x 100)/incremental investment

ROI = (r) (n) (1/10) (100)/ (0.1 n)

ROI = 100 r

If the minimum expected return on investment is 25%, then the minimum repair cost at which it would be beneficial to purchase a new IEEE 841 motor would be 25% of the new motor cost "n". Typically, for motors in NEMA frame sizes, the average repair cost exceeds 25% of the new motor costs. The conclusion reached is that purchase of the IEEE-841 motor appears to be attractive from a business perspective based on the assumptions made in this analysis.

Users who invest in new IEEE-841-1994 motors should also remember that to insure continual benefit, motor maintenance and repair standards should also reflect the minimum requirements of the new standard. Users should contact their local motor repair shop and discuss repair procedures to insure that repaired motors also comply with applicable sections of the new standards.

Conclusion

IEEE-841-1994 has made a number of significant improvements to RP841 in order to enhance the reliability and maintainability of severe duty motors used in the petrochemical industry. The initial response to the new standard has been positive, with inquiries coming from various other industries such as automotive and pulp and paper.

References

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