The new 400 V Standard Voltage

Consequences for explosion protected three – phase motors type of protection Flameproof enclosure ″d“ and Increased safety ″e“

by H. Greiner

With the standard originally published in 1983 as IEC 38 (now IEC 60038), the new 400 V rated voltage was introduced. Because a long transition time was expected for adaptation of the two internationally widespread 380 and 415 V 50 Hz mains, initially the 400 V + 6 %/ –10 % tolerance was recommended for the old 380 V mains and 400 V + 10 % / –6 % for the old 415 V mains, respectively, up to 2003. This transitional period was extended by five years with IEC 60038: 2002. Starting in 2008, the tolerance for mains voltage will be 400 V ± 10 %.

Millions of 380 V 3-phase motors – known for their long service life – can now be operated on a voltage that with 424 ... 440 V goes appreciably beyond their limit value of 380 V + 5 % = 399 V designated and standardised at the time of their type test.

How do these motors react to the overvoltage?

How, for instance, do the underwriters, factory inspection or other trade association agencies evaluate the discrepancy between the rated values of the mains and motor winding?

Continued operation of an explosion protected motor wound and designated on the plate for 380 V must be determined not only from the point of view of service life and function: Because safety and explosion protection of the equipment can be jeopardized, the relevant data must be determined and documented by the manufacturer or a competent person. The result of this test must be confirmed as a manufacturer's declaration (in case of type of protection Flameproof enclosure ″d“) or in an amendment to the EC –type examination certificate by a notified body (in case of type of protection Increased Safety ″e“). On the basis of the Betriebssicherheitsverordnung (“German regulation of health and safety protection of workers at risk due to explosive atmospheres“), in Germany this verification of Ex ″e“ motors can also alternatively be performed by an officially recognised qualified competent person on the basis of the existing EC type examination certificate.

This paper contains several technical responses to this battery of questions and accordingly is intended to provide an aid in the decision, that the user must make on his own responsibility and in certain cases must also justify vis-à-vis the supervisory authorities.

Standard for the Mains Voltage

The efforts aimed at international standard voltages culminated provisionally in 1983 with IEC 38. The identical national German standard, DIN IEC 38, made its debut in 1987. In an estimated 20 year transitional period, the 380, 415, 420 and 440 V voltages conventional in 50 Hz networks were to be superseded by the standard 400 V. Analogously, then 230 V applies to single-phase networks.

The new standard values and their tolerances were to be implemented by 2003. In the CENELEC memorandum No 14, it was even recommended that the new values be introduced by 1993. Since, however, Great Britain (415, 420 and 440 V voltages) had formally agreed only in 1993 and there the conversion using the amendments to the "Wire regulations" BS 7671 introduced at the end of 1994 will be implemented with some delay, the actual goal of an international standard voltage for 50 Hz was not yet attainable.

Significance of the 230 V voltage designation

The 230 V voltage is almost always a single-phase voltage for lighting and control.circuits The 230 / 400 V voltage designation can therefore be understood only as a mains designation 1 ~ 230 V / 3 ~ 400 V. For ordering and rating plate labelling motors for mains operations, the designation 230 / 400 ΔY (e.g. 3 ~ 230 / 3~ 400 ΔY) makes no sense and accordingly should be avoided. A layout for 3 x 230 V can occur only in the case of converter drives.

Permissible Voltage Variation for Electrical Machines

EN 60034 Part 1 continues to apply to electrical machines, which are harmonised with IEC 60034-1 and in whose section 12.3 a permissible voltage variation of ± 5 % is made standard. This tolerance refers to the respective voltage stated on the power rating plate.

A motor, rated for 380 V can be used for 361 to 399 V, for 400 V can be used for 380 to 420 V.

The standardised tolerance ± 5 % is not marked on the rating plate (cf. EN 60034 Part 1, Section 12.3). Accordingly, a relatively narrow variation of supply voltage is permissible for electrical machines – in contrast with the determination for the mains voltage and tolerances of various other equipment. There are technical reasons for this: Small motors (e.g. less than approximately 1.1 kW) and motors with a high number of poles frequently operate close to magnetic saturation and therefore react relatively sensitive to overvoltage.

Consequently, for motors with the usual "A" tolerance specification (Table 1) with ±5 % a more narrow voltage tolerance applies than the ± 10 % for the mains operation.

This state of affairs is not new – it applied also before the discussions on IEC 60038, as shown in Figure 1.

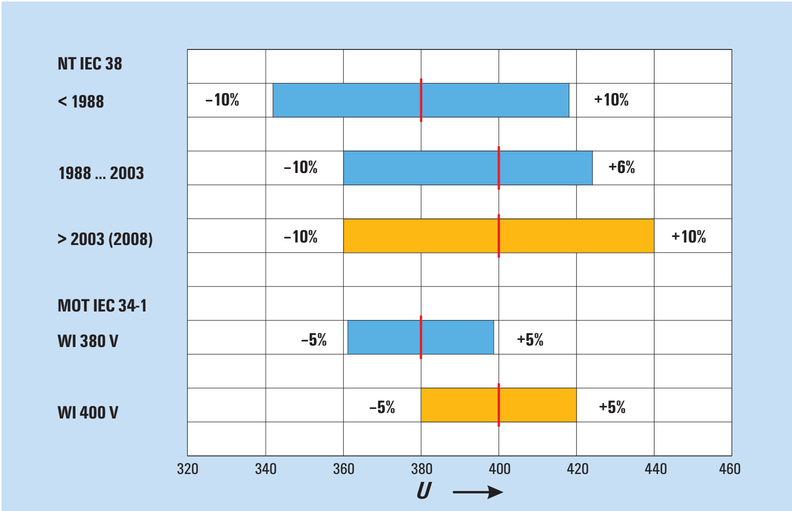

Figure 1: Comparison of the permissible voltage tolerance for network (NT) and motor (MOT)with winding configuration (WI) according to different stages of standardisation IEC 60038 and IEC (EN) 60034-1

This discrepancy is taken into consideration in the standard for the motors, by creating an expanded tolerance range "B". The considerable limitations to usability of this range, however, make clear that the particular physical circumstances in a motor set certain limits for voltage tolerance (Table 1).

For operation with voltage variation going beyond the ± 5 % "A" range, EN 60034 Part 1 provides that the motors should be capable of operating: They can develop their rated torque, whereby the other characteristics (e.g. also temperature rise) may have greater deviations from the data determined for the rated voltage.

The B tolerance ranges represent a concession for industrial, non-explosion protected machines, which can be taken advantage of by the manufacturer and user, at their own responsibility, after examination of the effect on the operating data and the service life of the winding insulation. Because in the case of explosion protected motors safety is affected, in this instance the conversion to the 400 V voltage must be approached and →

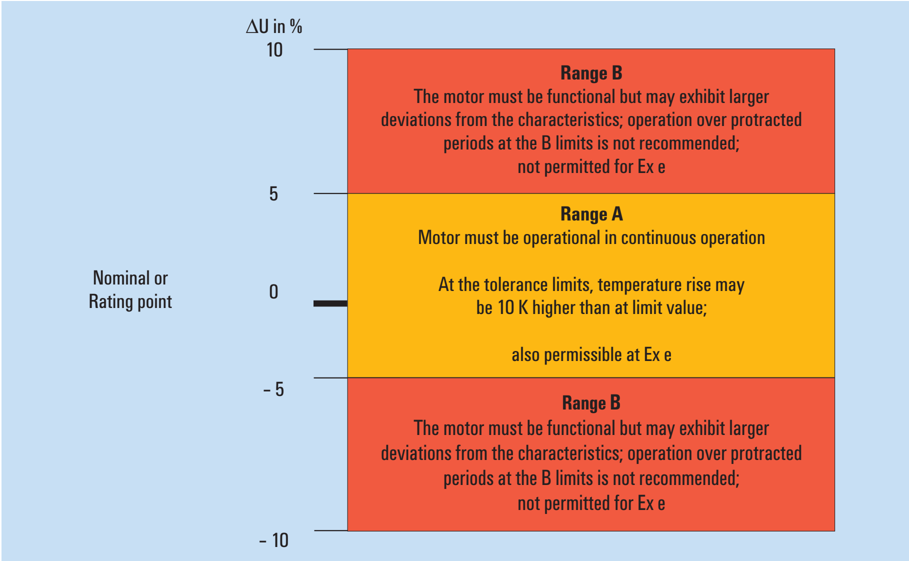

Table 1: Permissible voltage variations for motors according to EN 60034-1 and IEC 60034-1, Figure 14

→ documented in compliance with the relevant standards (e.g., EN 50018 and EN 50019) and the particular motor configuration.

Operating Behaviour in the event of Voltage Variation

For assessing the operating behaviour of 3-phase asynchronous motors with variation of the supply voltage, a test series can be drawn upon that is frequently implemented in the framework of type testing for fine tuning the winding configuration: constant power output at different voltages. Basically, in this instance the magnetic flux density (induction) is determined at the time of type testing, at which the most favourable operating characteristics result. The winding is then configured for the series so that when operating at rated voltage, just this most favourable flux density is set. If at all possible, the flux density is selected so that at rated voltage the lowest losses occur. In this arrangement, the motor at the rating point has the lowest temperature rise – in the following called "optimum".

Nonetheless, there are compelling reasons for selecting the flux density lower or higher than the optimum.

The diagrams of Figures 2–4 must be considered purely qualitatively. The trend will be particularly clear by a simplified and exaggerated representation. They are inappropriate for a quantitative interpretation.

- The active current I_W (which contributed to the mechanical power output) has a decreasing trend with increasing voltage (flux density) (inter alia because the slip becomes smaller).
- The magnetisation current I_μ (which forms magnetic flux) has an increasing trend with increasing voltage (flux density), which is disproportionately steep primarily upon reaching the saturation limit.
- The total current I (which is measured in the supply line) is composed geometrically of the components I_W and I_μ.
- The minimum of the total current I (which also represents the losses) characterises the optimum of the flux density.

Rated Voltage (flux density) in the Optimum (Figure 2)

This configuration should, if possible, be strived for and is typical for motors with rated power from 1.1 ... 11 kW.

Assessment of the Operating Behaviour:

- Voltage changes in the context of usual tolerances have relatively little effect on current consumption (temperature rise).
- Continuous operation at the new rated primary voltage of 400 V is generally permissible.

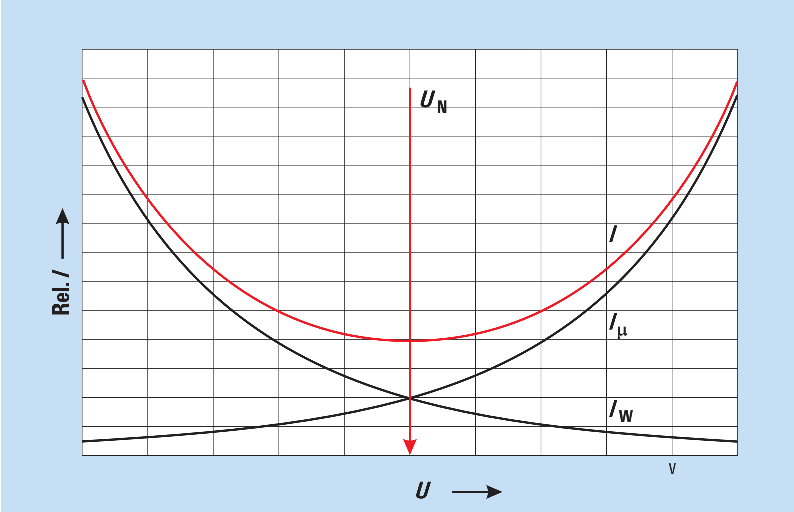

Figure 2: Current consumption I trend of medium motors (1.1 ... 11 kW) upon change of supply voltage U. Arrangement of the rated voltage U_N in the "optimum" (qualitative representation)

Rated Voltage (flux density) below the Optimum (Figure 3)

This configuration is typical for motors with rated powers of over approx. 11 kW, because excessively high starting torques and starting currents would result at optimum flux density. While the starting torques represent a hazard only for downstream transmission elements (gear motors) and driven machines, high locked rotor current densities result – in a stalling event – in a dangerously fast and intense temperature rise, which cannot be reliably detected by thermistors, for example.

Assessment of the Operating Behaviour:

- Reduction in voltage results in higher current consumption (temperature rise)
- Increase in voltage results in lower current consumption (temperature rise)
- Continued operation at the new 400 V rated voltage is permissible,if increased M_A and M_K is safe for the working machine.

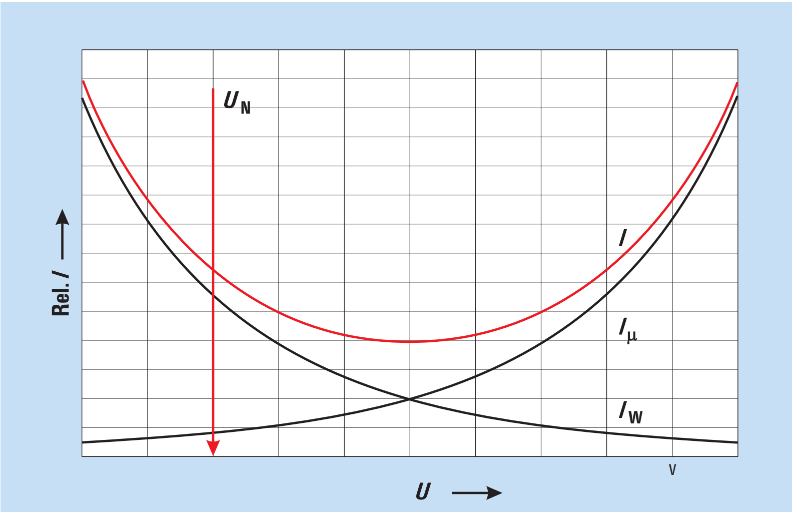

Figure 3: Current consumption I trend of larger motors (approx. > 11 kW) with change of supply voltage U. Arrangement of the rated voltage U_N below the "optimum" (qualitative representation)

Rated Voltage (flux density) above the Optimum (Figure 4)

This critical configuration may be necessary for motors with rated power under approx. 1.1 kW, because with the optimum flux density, the standardised overload capacity $M_K/M_N \geq 1.6$ would not be reached. For continued operation of 380 V motors on the new 400 V mains, this is the critical group!

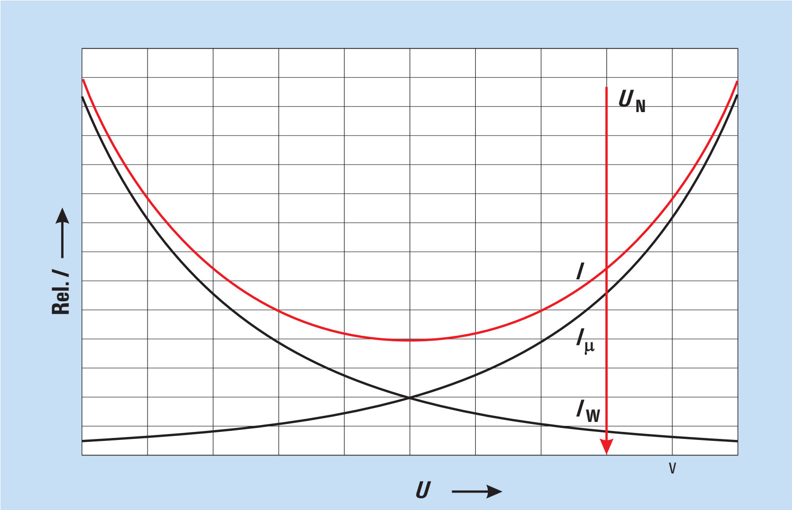

Figure 4: Current consumption I trend of smaller motors (approx. < 1.1 kW) with change of supply voltage U. Arrangement of the rated voltage U_N above the "optimum" (qualitative representation)

→ **Assessment of the Operating Behaviour:**

- Reduction of voltage results in lower current consumption but the overload capacity $M_K/M_N \geq 1.6$ required pursuant to the standard is questionable.
- Increase of voltage results in (much) higher current consumption (temperature rise) because of saturation. No-load current is frequently greater than rated current!
- Continued operation at the new rated primary voltage of 400 V is questionable. Verify current consumption and temperature rise in actual operation; consult the manufacturer.

In a later section it will be shown how, with the aid of the power factor, a preliminary decision regarding the foreseeable operating behaviour of a particular 380 V drive on 400 V is possible.

Differences in the types of protection Flameproof enclosure "d" and Increased safety "e"

For the verification of the reliability of continued operation, different points of view apply to the two types of protection. With type of protection "d" a higher winding temperature rise caused by the higher voltages acts only indirectly on the surface of the housing.

With type of protection "e", even the directly affected surface temperature of the rotor as well as the necessarily expected change in the variant pair I_A/I_N and t_E must be taken into account.

Therefore for procuring new equipment and continued operation tolerance ranges "A" and "B" are to be taken into consideration.

- **Type of protection Flameproof encl. "d"**
  Operation in "B" range is permissible. Temperature rise test for the frame surface at the limits of the "B" range (cf. Table 2).
- **Type of protection Increased safety "e"**
  Operation in "A" range is permissible. Temperature rise test for the winding at the rating point "RP" (cf. EN 50019: 2000, Table 3).
  Adjustment of the motor protection relay (MR) as an essential element of the type of protection "e" must be observed.

New Procurement

The following recommendation can be given pursuant to the current state of affairs for new procurement of explosion protected 3-phase motors:

Winding and Plate for 400 V

The permissible voltage variation is: 400 V ± 5 % = 380. .. 420 V

Operation on the 380 V network is permissible, insofar as it is assured that the terminal voltage ≥ 380 V.

The existing EC Type Examination Certificate includes the 400 V voltage, insofar as the maximum certified rated voltage on the EC Type Examination Certificate is ≥ 400 V.

Additional charges should not be expected. Delivery time is normal.

Winding and Plate for 400 V ± 10 %

Required only to comply formally with the new mains designation starting in 2003 (2008).

For motors, type of protection "d" of temperature classes T1 ... T4, a verification by the manufacturer of whether the surface temperature is maintained at the limits of the tolerance range is required. Type expansion, reduction in power, additional charge or delivery delay are possible but generally are not to be expected.

For motors, type of protection "e" a special verification by a Notified Body is required. As a rule, this means type expansion or power reduction. Additional charges and delivery delay can result.

A special configuration of the winding and a plate for 380 ... 400 V or even for 380 ... 420 V is generally unnecessary.

Continued Operation

If it is established that the mains voltage is < 400 V, then continued operation using the previous 380 V rating plate labelling and the previous setting of the motor protection relay is permissible. However, if the voltage can reach or exceed the 400 V value, a verification in each individual case by the manufacturer or an officially authorized competent person with the support of the manufacturer in accordance with the criteria described in greater detail in the subsequent section is necessary.

In re-labelling the rating plate of a flameproof motor for 400 V, the manufacturer must verify whether the temperature rise limits will be maintained at the extended voltage

Table 2: Permissible Surface Temperature

Temperature class	T3	T4	T5	T6
Ignition temperature (°C)	> 200	> 135	> 100	> 85
Max. permissible reduced frame surface temperature (°C) at the time of testing with U_N	180	120	90	75
Max. permissible housing surface temperature (°C) at the time of individual testing U_N ± 10% in accordance with EN 50014, 23.4.6.1	195	130	95	80

range. If applicable, this must be confirmed in a manufacturer's declaration. A new, adapted rating plate must be applied and the setting of the motor protection relay checked. If the temperature rise limits are not maintained, new winding for 400 V is necessary.

In motors, type of protection "e" the possibility of continued operation depends heavily on the motor size. In smaller motors, rewinding to 400 V is generally accompanied by new rating plate labelling and changed setting of the protection relay is required or a new 400 V motor must be used immediately.

In the case of medium and large motors of this type of protection, the manufacturer must verify whether a recalculation or a supplemental test is possible within the thermal reserves in compliance with the testing criteria as explained in the subsequent section. The testing authority (Notified Body) generates a re-write of the EC-Type Examination Certificate. The protection relay must be reset in accordance with the changed values. Alternatively– in the Federal Republic of Germany – an officially authorized competent person, on the basis of the manufacturer's documentation, can verify whether continued operation together with any changed setting of the motor protection relay is permissible.

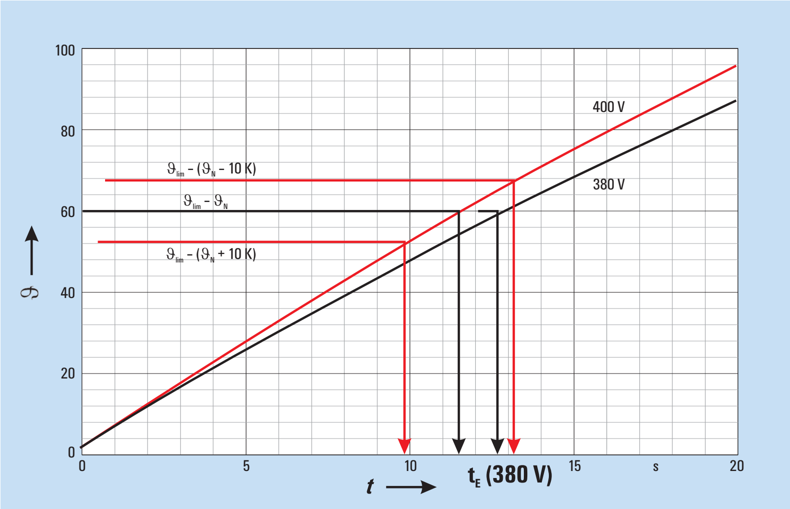

Figure 5: Example for the change of time t_E upon operation of a 380 V motor on 400 V

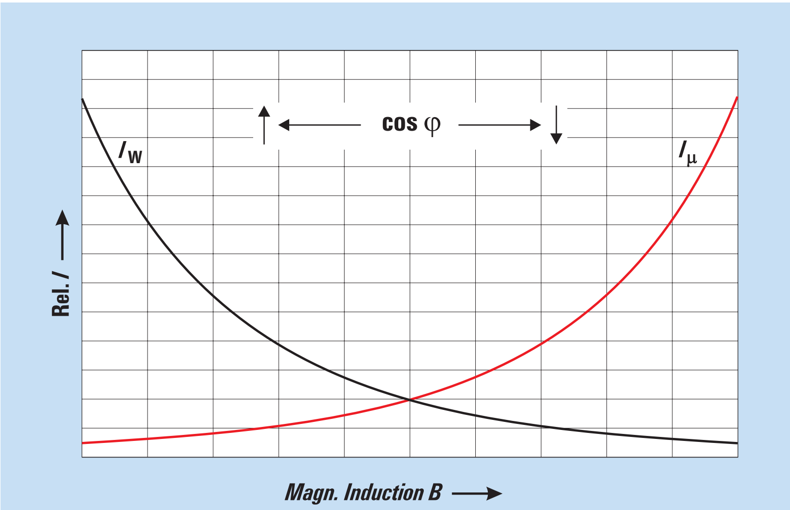

Figure 6: Power factor as the Measure for Optimum Flux Density

Test Criteria for Continued Operation on 400 V

For the decision whether continued operation on 400 V is permissible, the following safety – relevant values must be verified or determined:

Regardless of the type of protection applied, these are the permissible limiting temperatures of plastic parts, specifically on:

- Insulation of bushings
- Cable entries
- Wire junction
- Gaskets of junction boxes

In flameproof motors, in addition, the permissible maximum frame surface temperatures are affected whose maximum permissible values are dependent on the temperature class indicated in Table 2 at rows 3 or 4.

For motors, type of protection "e", the critical values are:

- Temperature rise in the stator and the rotor
- Rated current
- Temperature –risetime t_E
- The starting current ratio of I_A / I_N

If a motor wound for 380 V is operated on 400 V, the value pair I_A / I_N and t_E – important for marking and for safety in the event of stalling – changes independently of configuration and load factor.

Figure 5 shows, by way of example, that the temperature rise under locked rotor conditions increases by approx. 10%. For the temperature rise during operation at rated power – depending on the configuration of the motor in accordance with the aforementioned considerations – three different assumptions were made:

Table 3: Winding 380 V, 50 Hz			
Group	cos φ	Nominal current	Continued operation
A	> 0,85	100%	possible
B	0,70. .. 0,85	105%	likely possible
C	< 0,70	--	not possible; new winding for 400 V

Table 4: Winding 415 V, 50 Hz			
Group	cos φ	Nominal current	Continued operation
A	> 0,85	100%	possible, insofar as the actual, maximum load current on 400 V does not exceed the rated value for 415 V
B	0,70. .. 0,85	105%	likely possible
C	< 0,70	< 100%	possible, insofar as reduced breakdown torque and reduced rated power are permissible

→ ϑ_N consistent
=> Change of the time from t_E 12.7 to 11.5 s

ϑ_N by 10 K higher
=> Change of the time from t_E 12.7 to 10 s

ϑ_N by 10 K lower
=> Change of the time from t_E 12.7 to 13.2 s

Power factor as the Measure for Optimum Flux Density

The process described in the section "Continued Operation" requires corresponding measurements under nominal load, which generally are done only by the manufacturer during type development. An assessment on the continued usability of a motor on the new 400 V mains consequently requires consultation with the manufacturer. A process is therefore desirable that allows immediate assessment using the rating plate information. The power factor states where the magnetic flux density (induction) is situated in the rating point relative to the optimum (Figure 6).

- Low power factor => high portion of reactive current => above optimum
- High power factor => low portion of reactive current => below optimum

In comparision with the section "Operating Behaviour in the event of Voltage variation" the following correlations can be deduced:

- With a power factor of > 0.85 the rated voltage is below the optimum
- With a power factor of 0.7 ... 0.85 the rated voltage is almost at optimum
- With a power factor of < 0.7 the rated voltage is above the optimum.

The following rules for the presumptive results in the individual case of the compulsory testing by the manufacturer can be deduced herefrom:

Conditions: Winding 380 V, 50 Hz

- Ex d: Overall certification of conformity for T4
- Ex e: Temperature rise time t_E clearly greater than 5 s
  consequences see Table 3

For motors that have been optimised for 415 V and which will continue to be used, there is a different rule:

Conditions: Winding 415 V, 50 Hz

- Ex d: Overall certification of conformity for T4
- Ex e: Temperature rise time t_E clearly greater than 5 s
  consequences see Table 4

Abstract

As the condition for the technically and formally correct continued operation of an explosion protected motor wound and rating plate labelled for 380 V on 400 V mains voltage, the involvement of the manufacturer is required. As a rule, the manufacturer's decision alone is possible on the basis of the documents available from type tests done.

A third-party recertification by repeating the complete type test on 400 V is theoretically conceivable, but comparatively very costly.

In the case of motors, type of protection Flameproof enclosure "d" the calculated verification of the limits for the frame surface temperature is sufficient and this can frequently be maintained even at 400 V ± 10 %.

The manufacturer confirms the positive results of its verification in the form of a manufacturer's declaration.

In the case of motors, type of protection Increased safety "e", an extensive calculated verification and a re-determination of the I_A / I_N and t_E values is required. In Germany the manufacturer's officially authorized competent person issues a compliance test certification as supplement to the EC-Type Examination Certificate. Depending on legislative requirements in the respective concerned state, this verification is the alternative of the authority provided for this purpose. This testing would ultimately be performed by a notified body.

In both instances, the manufacturer shall provide new rating plates, which shall be applied in an appropriate manner – that is, without impairment of IP- degree of protection and the requirements of the relevant type of protection – on the motor.

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