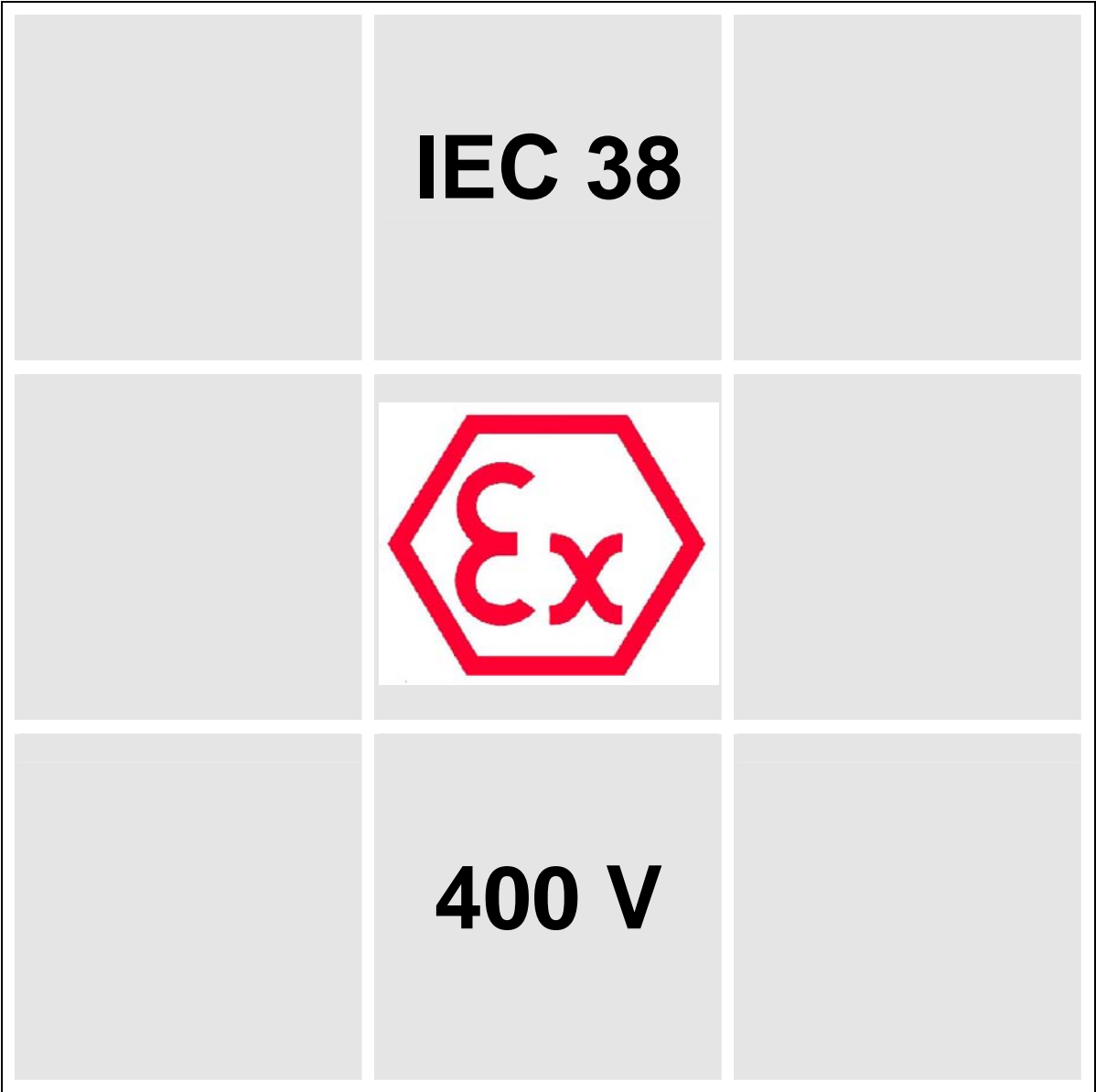




**The New 400 V Standard Voltage**

Consequences for explosion protected motors type "e" and "d"

Reprint from  EX-Magazine 2004



## The New 400 V Standard Voltage

Consequences for explosion protected three - phase motors  
type of protection Flameproof Enclosure "d" and Increased Safety "e".

Obering. 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 protracted 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 networks and 400 V + 10 % / - 6 % for the old 415 V networks, 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 monitoring agencies evaluate the discrepancy between the rated values of the network and motor winding?*

*Continued operation of an explosion protected motor wound and designated on the plate for 380 V must determined not only from the point of view of service life and function: Because safety and explosion protection of the equipment can be compromised, the relevant data must be determined and documented by the manufacturer or a competent person. The result of this testing must be confirmed as a manufacturer's certification (in the case of the type of protection Flameproof enclosure "d" ) or in an amendment to the EC –type examination certificate by a notified body (in the case of the type of protection Increased Safety "e"). On the basis of the Betriebs-sicherheitsverordnung ("German regulation of health and safety protection of workers at risks of 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.*

## 1 Standard for the Networks

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 N<sup>o</sup> 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 in the case of 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 networks. 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 V Δ/Y (e.g. 3~ 230 / 3~ 400 V Δ/Y) makes no sense and accordingly should be avoided. A layout for 3 x 230 V can occur only in the case of converter drives .

## 2 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  $\pm 5\%$  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.

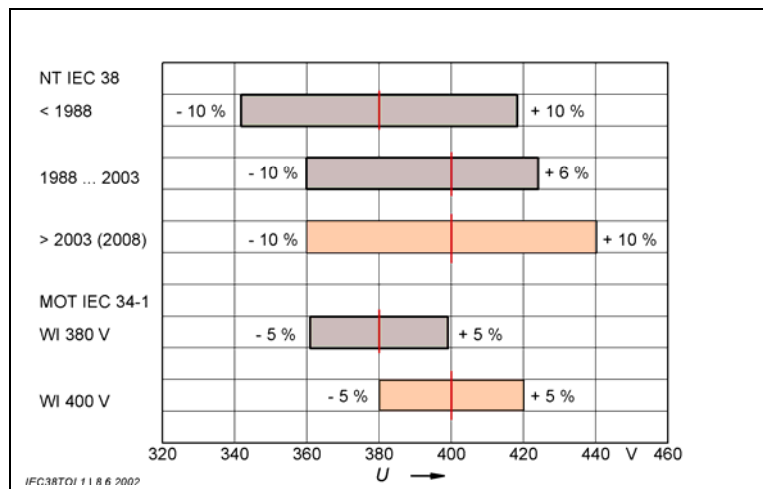
The standardised tolerance  $\pm 5\%$  is not marked on the rating plate (cf. EN 60034 Part 1, Section 12.3). Accordingly, a relatively narrow variation of supply voltage is permissible for electrical machines – in contrast with the determinations for the mains voltage and tolerances of many other plant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

Consequently, for motors with the usual "A" tolerance specification (Tab. 1) with  $\pm 5\%$  a more narrow voltage tolerance applies than the  $\pm 10\%$  for the mains network.

This state of affairs is not new, it applied also before the discussions on IEC 60038, as shown in Fig. 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 38 = IEC 60038  
IEC 34-1 = IEC (EN) 60034-1



This discrepancy is taken into consideration in the standard for the motors, in that an expanded tolerance range "B" was created. 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, that go beyond the  $\pm 5\%$  "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 increase) may have greater deviations from the data determined for the rated voltage.

<b>Nominal or Rating point</b>	$\Delta U$ in % 10	<p style="text-align: center;"><b>Range B</b></p> <p style="text-align: center;">The motor must be functional but may exhibit larger deviations from the characteristics; operation over protracted periods at the B limits is not recommended; not permitted for Ex e</p>
	5	<p style="text-align: center;"><b>Range A</b></p> <p style="text-align: center;">Motor must be operational in continuous operation</p> <p style="text-align: center;">At the tolerance limits, temperature increase may be 10 K higher than at limit value; also permissible at Ex e</p>
	0	
	- 5	<p style="text-align: center;"><b>Range B</b></p> <p style="text-align: center;">The motor must be functional but may exhibit larger deviations from the characteristics; operation over protracted periods at the B limits is not recommended; not permitted for Ex e</p>
	- 10	

Tab. 1 Permissible voltage variations for motors according to EN 60034-1 and IEC 60034-1, Fig. 14

The B tolerance ranges represents a concession for **normal, non-explosion –protected** machines, which can be taken advantage of by the manufacturer and user, on their own responsibility, after examination of the effect on the operating data and the service life of the windings 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 documented in compliance with the relevant standards (e.g., EN 50018 and EN 50019) and the particular motor configuration.

### 3 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 test 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 test, 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 increase – in the following called "optimum."

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

The diagrams of Figs. 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**  $I_u$  (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  $I_u$ .
- 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 (Fig. 2)

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

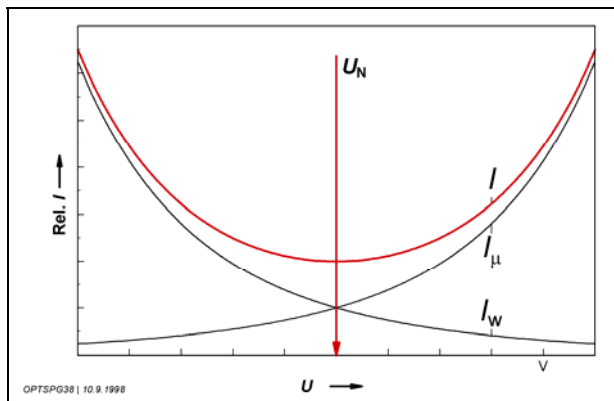


Fig. 2

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)

#### Assessment of the Operating Behaviour

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

### Rated Voltage (flux density) below the Optimum (Fig. 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 increase, which cannot be reliably detected by thermistors, for example.

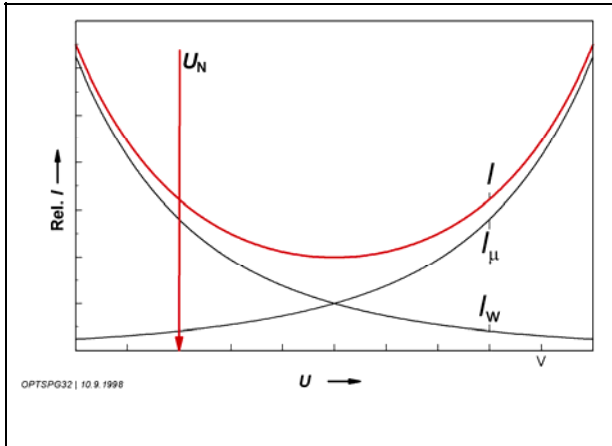


Fig. 3

Current consumption / 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)

#### 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.

### Rated Voltage (flux density) above the Optimum (Fig. 4)

This critical configuration may be necessary for motors with rated powers 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 network, this is the critical group!

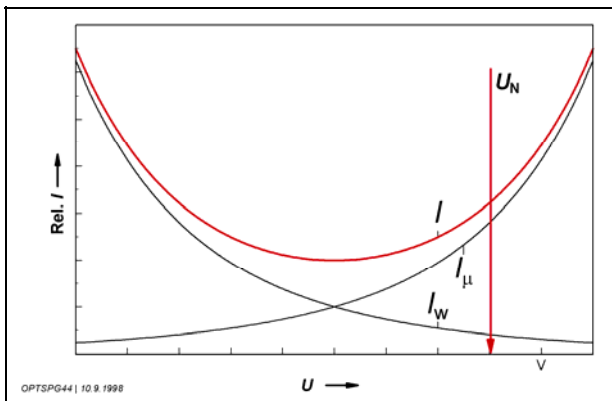


Fig. 4

Current consumption / 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 increase) 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 increase in actual operation; consult the manufacturer.

In Section 8 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.

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

For the verification of the reliability of the continuation of operation, different points of view apply in the two types of protection. In the type of protection "d" a higher winding temperature increase caused by the higher voltages acts only indirectly on the surface of the housing.

In the 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, in the case of *new installation* and in the case of *further operation*, in consideration of the "A" and "B" tolerance ranges according to Section 2, the following applies:

- *Type of protection Flameproof enclosure "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.

#### 5 New Procurement

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

##### 5.1 Winding and Plate for 400 V

The permissible *voltage variation* is:  $400\text{ V} \pm 5\%$  = 380 ... 420 V

Operation on the 380 V network is permissible, insofar as it is assured that the terminal voltage  $\geq 380\text{ V}$ .

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  $\geq 400\text{ V}$ .

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

##### 5.2 Winding and Plate for 400 V $\pm 10\%$

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

For motors in the *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 augmentation, reduction in power, additional charge or delivery delay are possible but generally are not to be expected.

For motors in the *type of protection "e"* a special verification by a Notified Body is required. As a rule, this means type augmentation 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.

#### 6 Continuation of Operation

If it is established that the mains voltage is  $< 400\text{ V}$ , then further 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 Section 7 is necessary.

In re-labelling the rating plate of an *flameproof* motor for 400 V, the manufacturer must verify whether the temperature rise limits will be maintained at the extended voltage range (Section 7). 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 increase limits are not maintained, a new winding for 400 V is necessary.

In motors in the *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, however, 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, Section 7. The testing authority (Notified Body) generates a re-write of the EC-type examination certificate. The protection relay must be re-set in accordance with the changed values. In the alternative – 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.

## 7 Test Criteria for Continuation of Operation on 400 V

For the decision whether further 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
- Seals of connection boxes
- Plastic parts.

In **flameproofmotors**, 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 2 or 3.

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

Rows 3 or 4 can be applied optionally.

Table 2 Permissible Surface Temperature



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

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

If a motor wound for 380 V is operated on 400 V, the values 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.

Fig. 5 shows, by way of example, that the temperature rise in 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:

- |                                       |   |                                    |           |
|---------------------------------------|---|------------------------------------|-----------|
| Rated temperature rise consistent     | ⇒ | Change of the time $t_E$ from 12.7 | to 11.5 s |
| Rated temperature rise by 10 K higher | ⇒ | Change of the time $t_E$ from 12.7 | to 10 s   |
| Rated temperature rise by 10 K lower  | ⇒ | Change of the time $t_E$ from 12.7 | to 13.2 s |

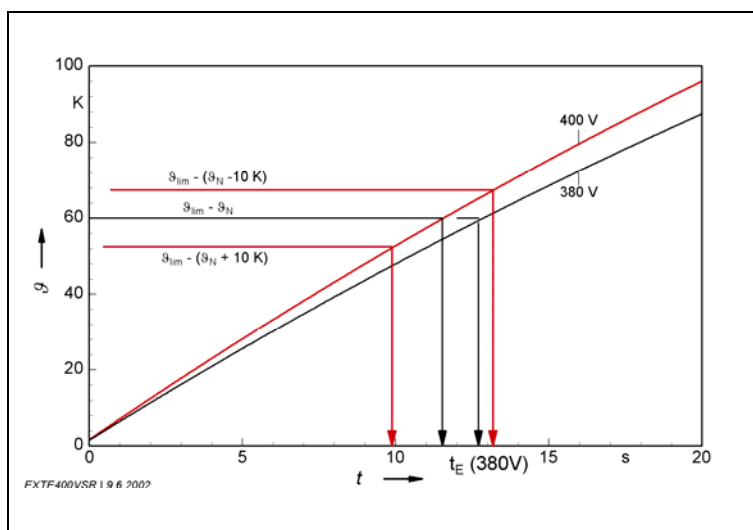


Fig. 5  
Example for the change of time  $t_E$   
upon operation of a 380 V motor  
on 400 V

## 8 Power factor as the Measure for Optimum Flux Density

The process described in Section 5 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 network 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 (Fig. 6).

Low power factor  $\Rightarrow$  high portion of reactive current  $\Rightarrow$  above optimum  
 High power factor  $\Rightarrow$  low portion of reactive current  $\Rightarrow$  below optimum

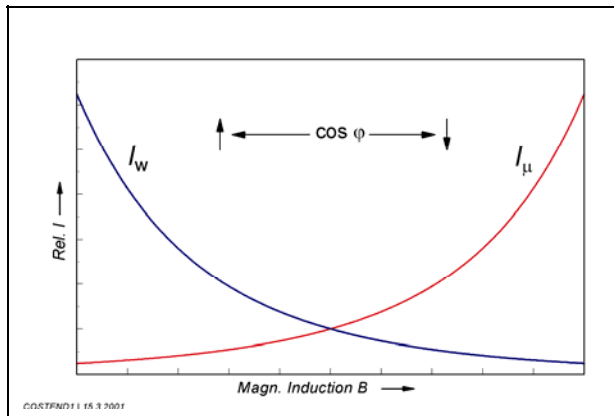


Fig. 6  
 Power factor as the Measure for Optimum Flux Density

On comparison with Section 3, 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  $0.7 \dots 0.85$  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 increase time  $t_E$  clearly greater than 5 s

Group	$\cos \varphi$	Nominal current at 400 V	Further Operation
A	$> 0.85$	100 %	possible
B	$0.70 \dots 0.85$	105 %	likely possible
C	$< 0.70$	-	not possible; new winding for 400 V

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

### Conditions: Winding 415 V, 50 Hz

Ex d: Overall certification of conformity for T4

Ex e: Temperature increase time  $t_E$  clearly greater than 5 s

Group	$\cos \varphi$	Nominal current at 400 V	Further 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	$0.70 \dots 0.85$	105 %	likely possible
C	$< 0.70$	$< 100 \%$	possible, insofar as reduced breakdown torque and reduced rated power are permissible

## 9 Abstract

As the condition for the technically and formally correct continuation of 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 test done.

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

In the case of **motors in 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  $\pm$  10 %.

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



In the case of **motors in 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.

## 10 Danfoss Bauer Authority for 400 V Test Certificates

Danfoss Bauer have an authorized competent person to check and confirm compliance of 380 V-windings with the requirements for explosion protection if supplied from a 400 V or 380 ... 420 V network.

An example of such Test Certificate is given below:

<b>Danfoss Bauer GmbH</b> Postfach 10 02 08 Eberhard-Bauer-Str. 36-60 D-73726 Esslingen D-73734 Esslingen	
<b>PRÜFBESCHEINIGUNG</b> Reg. Nr.: 03/04 für explosionsgeschützte elektrische Betriebsmittel Zündschutzart: Erhöhte Sicherheit »e« nach EN 50 014 und EN 50 019 Typ: DK 94-241 EEx e II T3	
Der typengeprüfte Drehstrom-Kurzschlussläufer-Motor	
BAUER Fertigung Nr.: 1 586 838-7	PTB-Konformitätsbesch. Nr.: Ex-79/3385
PTB-Prüfungsschein Nr.: II B/M-22 033	PTB-Rahmenbesch. Nr.: Ex-79/3011 U
wird in folgender Weise geändert:	
<b>Bemessungsspannung : 380 ... 420 V Y</b>	
Das geänderte Betriebsmittel und seine Genehmigungsunterlagen wurden geprüft. Es entspricht den Anforderungen des Explosionsschutzes.	
<b>Elektrische Daten:</b>	
Bemessungsleistung: 1,5 kW	Betriebsart: S1
Drehzahl 1390 r/min	Frequenz: 50 Hz
Bemessungsspannung: 380 ... 420 V	Ständerschaltung: Y
Bemessungsstrom: 3,75 ... 3,75 A	Wärmeklasse: B
Leistungsfaktor: 0,85 ... 0,77	
Verhältnis $I_A/I_N$ : 5,1 ... 5,6	Temperaturklasse: T3
Erwärmungszeit $t_E$ : 16 ... 13 s	
Die für den Explosionsschutz relevanten Daten dürfen zur Vereinfachung der Ablesung am Aufstellungsort auch in gekürzter Form angegeben werden:	
Bemessungsspannung: 380 ... 420 V	
Bemessungsstrom: 3,75 A	
Verhältnis $I_A/I_N$ : 5,1	
Erwärmungszeit $t_E$ : 13 s	
Das Betriebsmittel erhält am Leistungsschild die zusätzliche Kennzeichnung: Reg.-Nr. 03/04	
Ort: Esslingen Datum: 30.05.04 Die amtlich anerkannte befähigte Person	Anerkennung durch das Ministerium für Arbeit, Gesundheit und Sozialordnung Baden - Württemberg am 30.05.1995 Aktenzeichen: 25-5546.2-15 umgeschrieben durch das Ministerium für Umwelt und Verkehr auf §14, Abs. 6 der BetrSichV im Januar 2003; AZ 5551.24-5.40/2
 (H. Greiner)	

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Sonderdruck SD 302 der Fa. Danfoss Bauer GmbH D-73726 Esslingen  
Abschnitt 16