

Tape wound cores for (RCCB) residual current circuit breaker

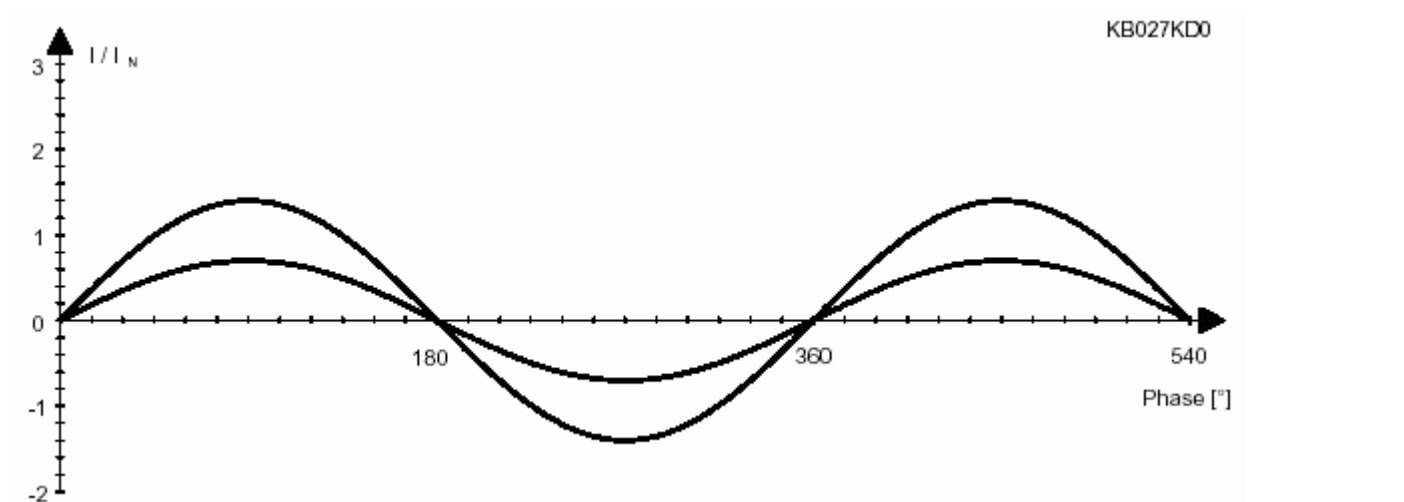
Differential current switches independent from mains („circuit breakers“) are in widespread use in electrical installation engineering. The high safety value of these switches does not only become evident in the case of indirect contact but also and in particular in cases of direct contact of live parts (nominal differential current $I_{\Delta N} \leq 30 \text{ mA}$).

Crystalline VAC materials such as ULTRAPERM and PERMAX have played a decisive part in the development of these highly sensitive differential current switches. Due to the consistent optimization of our crystalline materials with regard to maximum permeability (ULTRAPERM 250) and high linearity at a large induction stroke (ULTRAPERM F 80), we are able to offer a wide basis for new solutions.

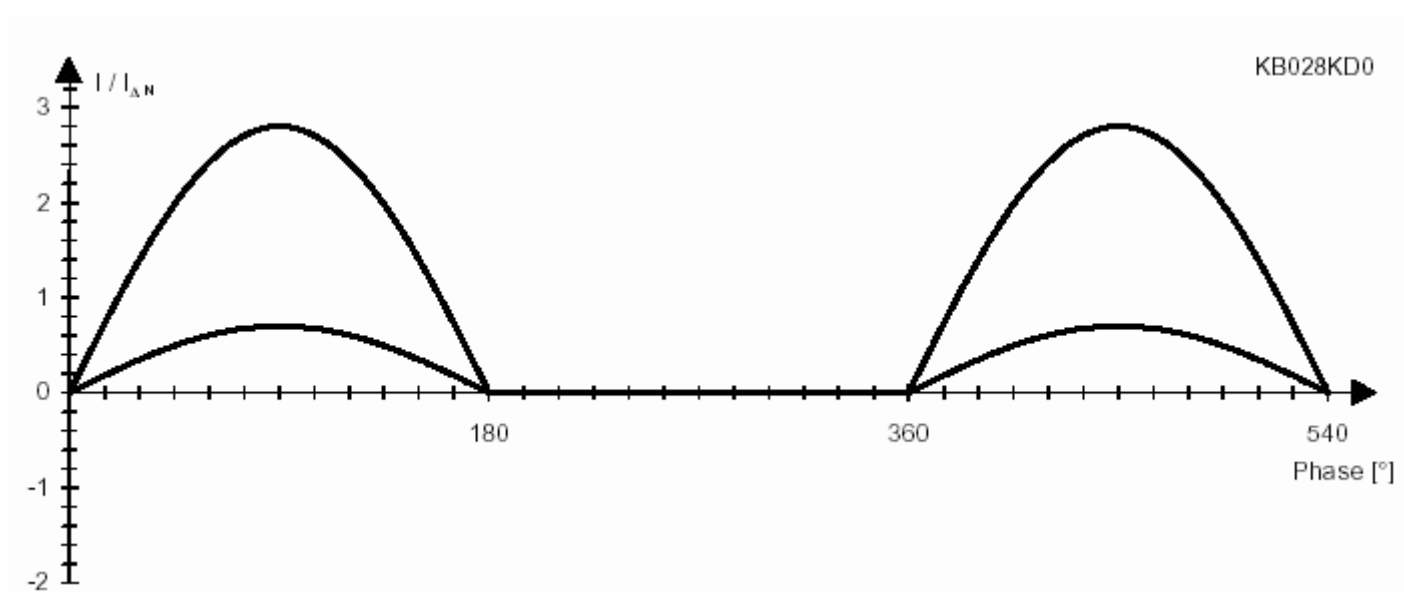
The recent introduction of the nano-crystalline material VITROPERM, with its excellent soft-magnetic properties, has provided new impulses in particular in the area of application for pulse current sensitive - but also for alternating current sensitive - circuit breakers. Here, innovative solutions have become possible for the switch engineer, which far exceed the limits of crystalline alloys.

Applications and materials

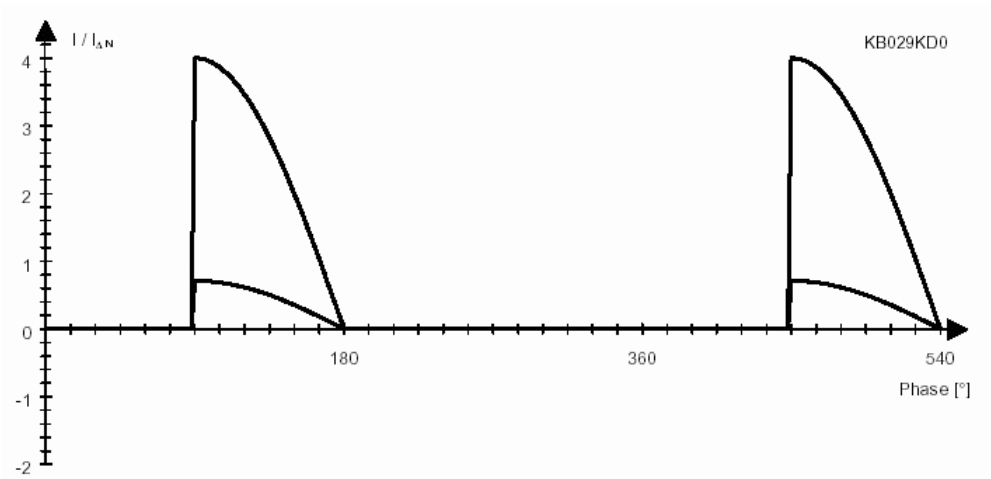
Depending on the intended use, stepped nominal differential currents $I_{\Delta N}$ apply to differential current switches; these nominal differential currents $I_{\Delta N}$ are defined by international standards; the associated minimum and maximum differential current limits result from these nominal values:



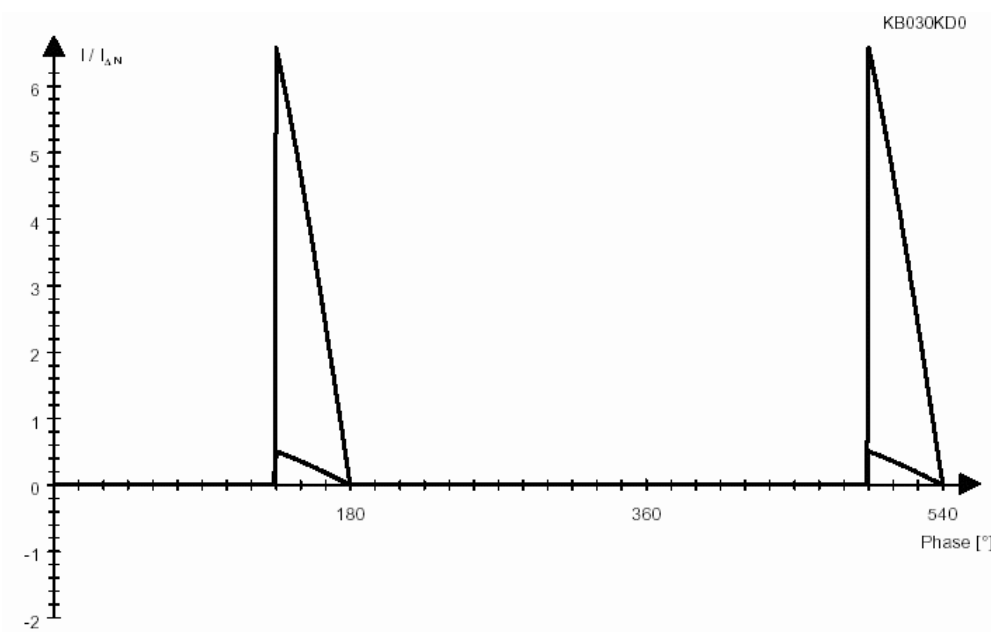
differential current, sinus



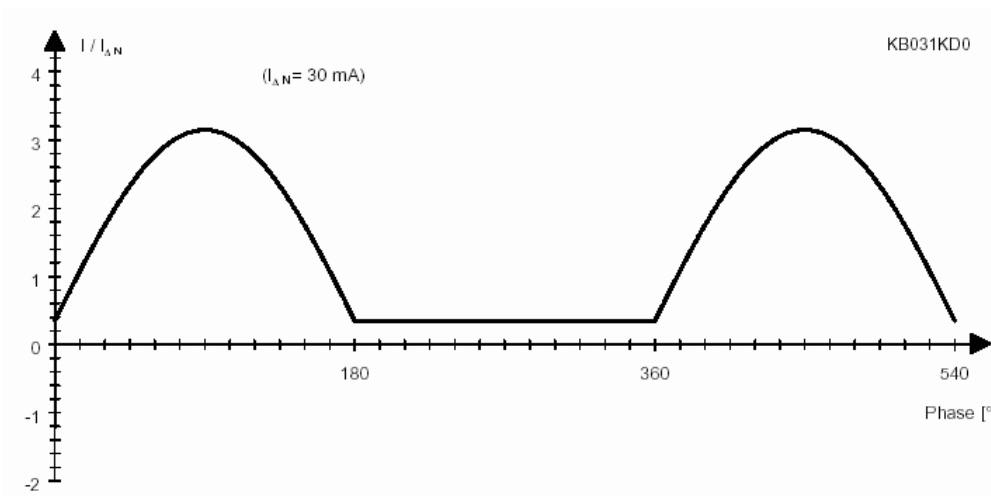
differential current, sinus half wave



differential current, half wave phase control 90°



differential current, half wave phase control 135°



differential current, half wave and superimposed direct current of 6 mA

$I_{\Delta N}$ related differential current limit values

| Differential current course | Sine | Sine half wave | Half wave phase slice | | Half wave + superimposed DC current of 6 mA |
|-----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|---|
| | | | 90° | 135° | |
| Top trip limit | | | | | |
| Effective value | $1.0 \times I_{\Delta N}$ | $1.4 \times I_{\Delta N}$ | $1.4 \times I_{\Delta N}$ | $1.4 \times I_{\Delta N}$ | $1.4 \times I_{\Delta N} + 6\text{mA}$ |
| Peak value | $1.4 \times I_{\Delta N}$ | $2.8 \times I_{\Delta N}$ | $4.0 \times I_{\Delta N}$ | $6.6 \times I_{\Delta N}$ | $((2.8 \times I_{\Delta N} + 12 \text{ mA})^2 - 85.6 \text{ mA}^2 - 1.64 \text{ mA})^{1/2}$ |
| Bottom Trip limit | | | | | |
| Effective value | $0.50 \times I_{\Delta N}$ | $0.35 \times I_{\Delta N}$ | $0.25 \times I_{\Delta N}$ | $0.11 \times I_{\Delta N}$ | |
| Peak value | $0.71 \times I_{\Delta N}$ | $0.71 \times I_{\Delta N}$ | $0.71 \times I_{\Delta N}$ | $0.52 \times I_{\Delta N}$ | |

The multitude of materials and their modifications, which are available to us, enable us to offer an optimum core solution at all times for the resulting design requirements:

Materials for residual current circuit breakers (A-type)

| Application (nominal triggering current $I_{\Delta N}$ [mA]) | Material | density [g/cm ³] | B _s [T] | permeability μ_{15} |
|--|-----------------|------------------------------|--------------------|-------------------------|
| 10 - 100 | VITROPERM 800 F | 7.35 | 1.2 | 160 000 |
| | VITROPERM 800 F | 7.35 | 1.2 | 135 000 |
| | ULTRAPERM F80 | 8.70 | 0.74 | 110 000 |
| Application (nominal triggering current $I_{\Delta N}$ [mA]) | Material | density [g/cm ³] | B _s [T] | permeability μ_{15} |
| 300-500 | VITROPERM 500 F | 7.35 | 1.2 | 20 000 - 80 000 |

Materials for residual current circuit breakers (AC-type)

| Application (nominal triggering current $I_{\Delta N}$ [mA]) | Material | density [g/cm ³] | B _s [T] | permeability μ_{15} |
|--|-------------------|------------------------------|--------------------|-------------------------|
| 10 - 100 | ULTRAPERM 200/250 | 8.7 | 0.74 | 200 000 - 300 000 |
| | ULTRAPERM 10 | 8.7 | 0.74 | 100 000 - 200 000 |
| 300 - 500 | PERMAX M | 8.25 | 1.5 | 50 000 |
| | PERMENORM 5000 H2 | 8.25 | 1.55 | 12 000 |
| 10 - 100 (release circuit with serial capacitance) | ULTRAPERM F60 | 8.7 | 0.74 | 125 000 |
| | VITROPERM 800 F | 7.35 | 1.2 | 145 000 |

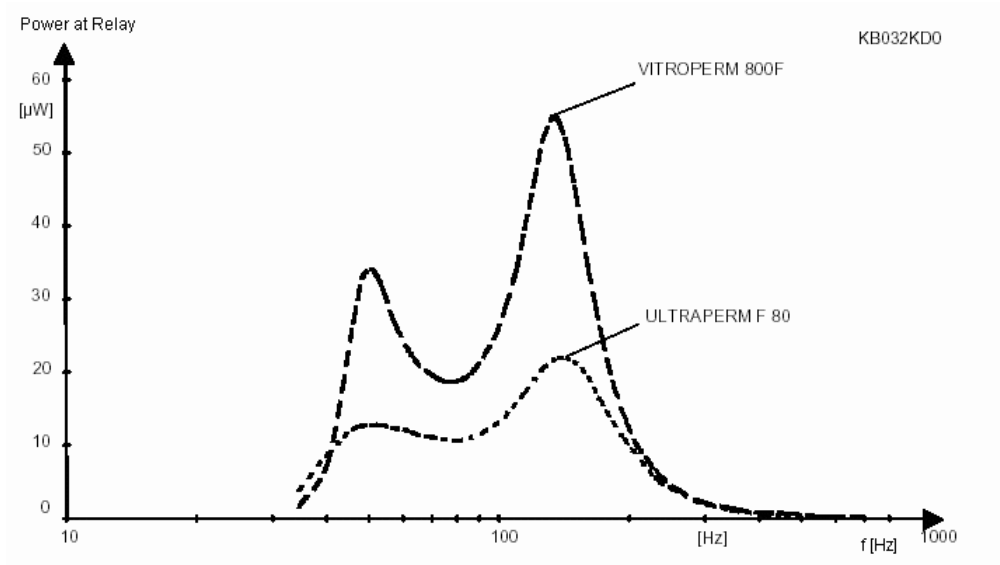
For circuit breakers which are only alternating current sensitive, materials with round hysteresis loops are usually used. By means of ULTRAPERM, PERMAX M, and PERMENORM 5000 H2 it will then be possible to generate very high induction voltages - depending on magnetization conditions, that is on the range of the nominal trip current $I_{\Delta N}$. As an alternative to the standard power adaptation, it is also possible to implement a series resonance close to mains frequency in the case of alternating current sensitive circuit breakers, especially for nominal differential currents ≤ 30 mA. Here, the permeability of the core is not necessarily a primary objective; the required increase in resonance is also decisively determined by the core losses. Materials such as VITROPERM 800 F and ULTRAPERM F60 are particularly suitable in this respect. In the case of circuit breakers which also have to detect pulsating direct differential currents, it is initially necessary that the core features a linear characteristic curve with a low remanence value and in connection

therewith a high induction stroke. For this case as well as for the requirement to achieve nominal differential currents with $I_{\Delta N} \leq 30$ mA, the "classic" material ULTRAPERM F80 is available. Recently, we were able to present VITROPERM 800 F; this is a material for this type of application which features a superior resonance behavior, which is above all due to its excellent dynamic properties - in addition to the highest starting permeabilities. When comparing the energy transferred to the relay the two materials, with both materials featuring the same core size and permeability values, the potential of VITROPERM becomes clear. Even in the market sector of switches with a nominal differential current ≤ 100 mA, the introduction of VITROPERM 500 F allows us to supply a material featuring a wide range of permeability setting options. Thus, in contrast to the classic materials ULTRAPERM F, PERMAX LGF, and PERMENORM 5050 LGF, here also there is an alternative material featuring significantly better magnetic properties.

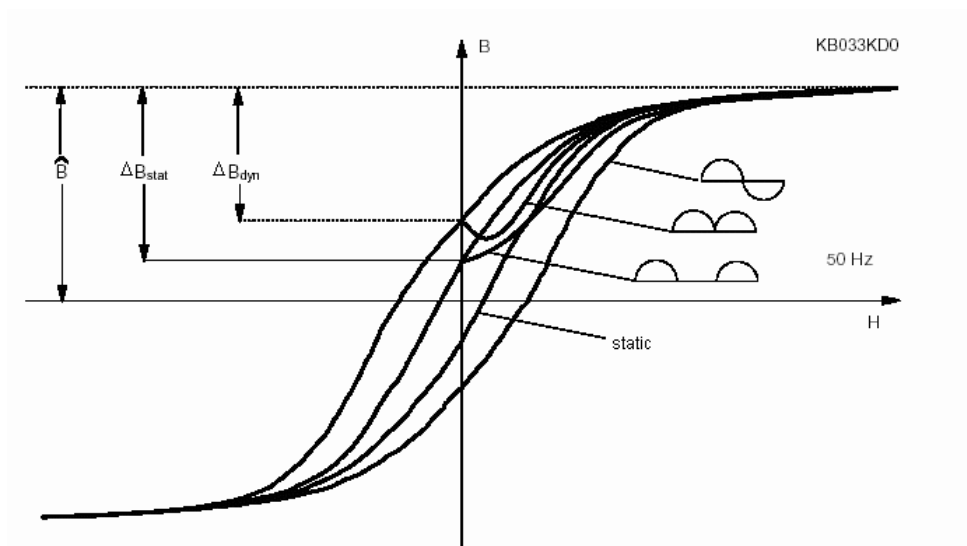
Application-related magnetic quantities

With circuit breakers that have been exclusively designed for sinus-shaped nominal differential currents, induction \hat{B} is an application-related term for describing the voltage effective on the relay. This also applies to pulse current sensitive switches; however, in addition these must also trip in the event of non-sinus-shaped differential currents occurring. As in most applications a unipolar holding magnet relay is used whose triggering behavior with regard to pulsating direct differential currents is dependent on their polarity, the actual trigger currents may assume very different values in spite of

the symmetrizing effect of the parallel-resonant circuit (blocking circuit). The connection between the pulsating differential current with "incorrect" polarity and the resulting secondary voltage on the holding magnet is best described by ΔB_{dyn} . This is contrasted by solutions with bipolar effective relay, for example restraining magnet relay or storage circuits with a full wave rectification in the secondary circuit. In this application segment ΔB_{stat} will appear as an application - related term, in addition to \hat{B} .



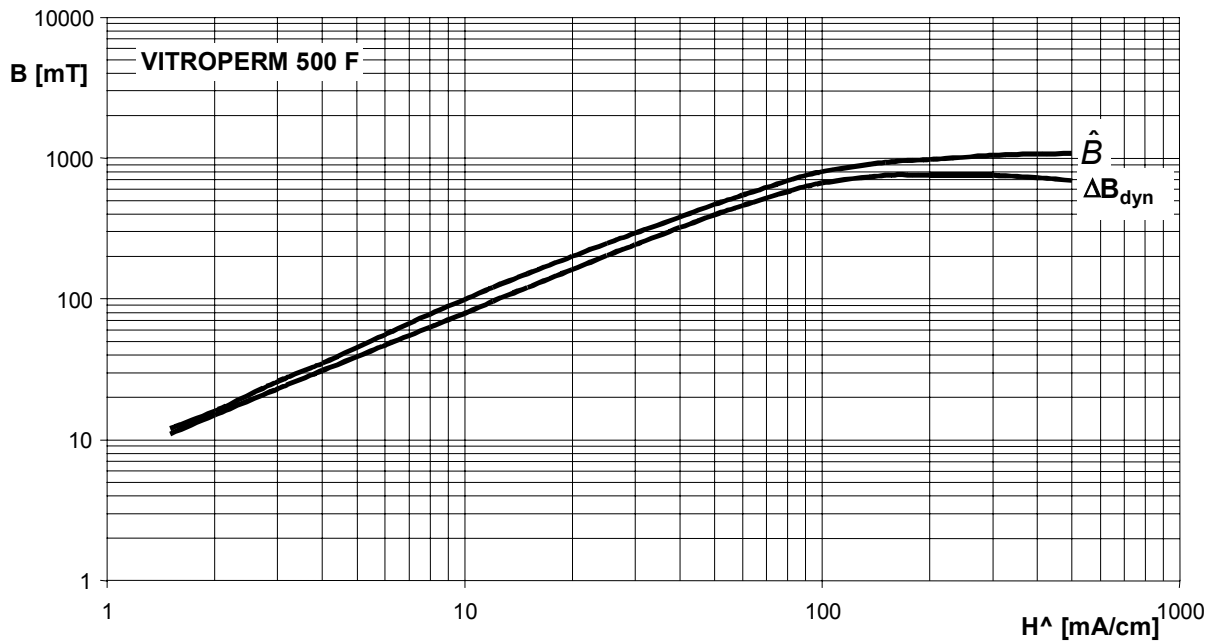
Trigger power at the relay of a pulse current sensitive circuit breaker with cores made of different materials



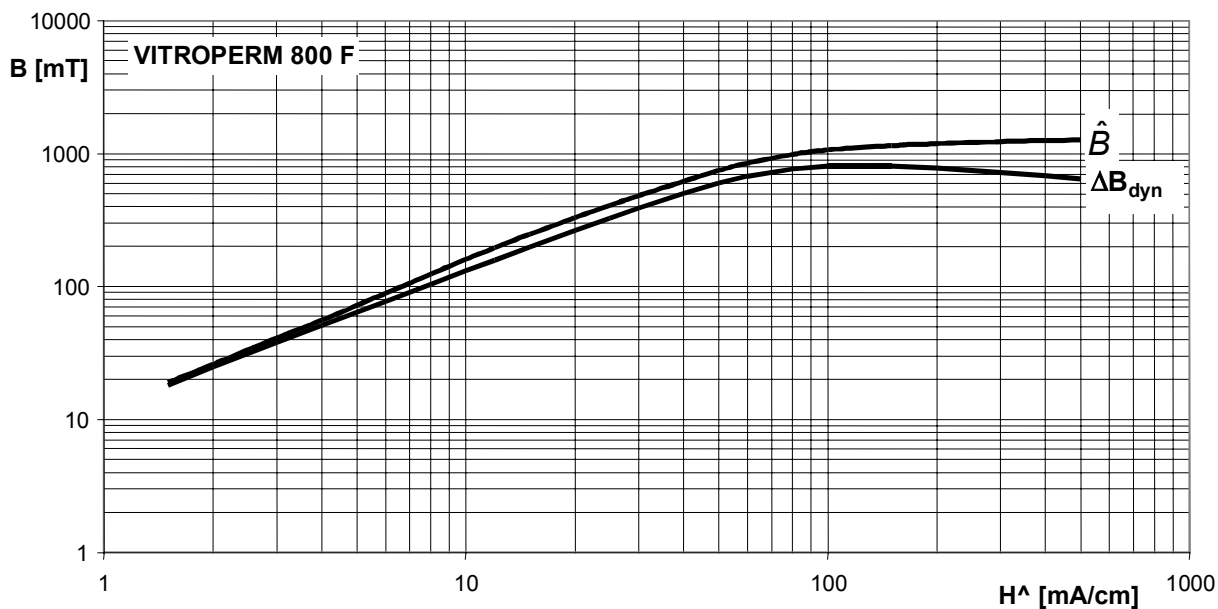
Definition of measurement quantities \hat{B} , ΔB_{stat} , ΔB_{dyn}

The **limit curves** for the materials specified in the materials table allow delivery agreements to be made for individual core types.

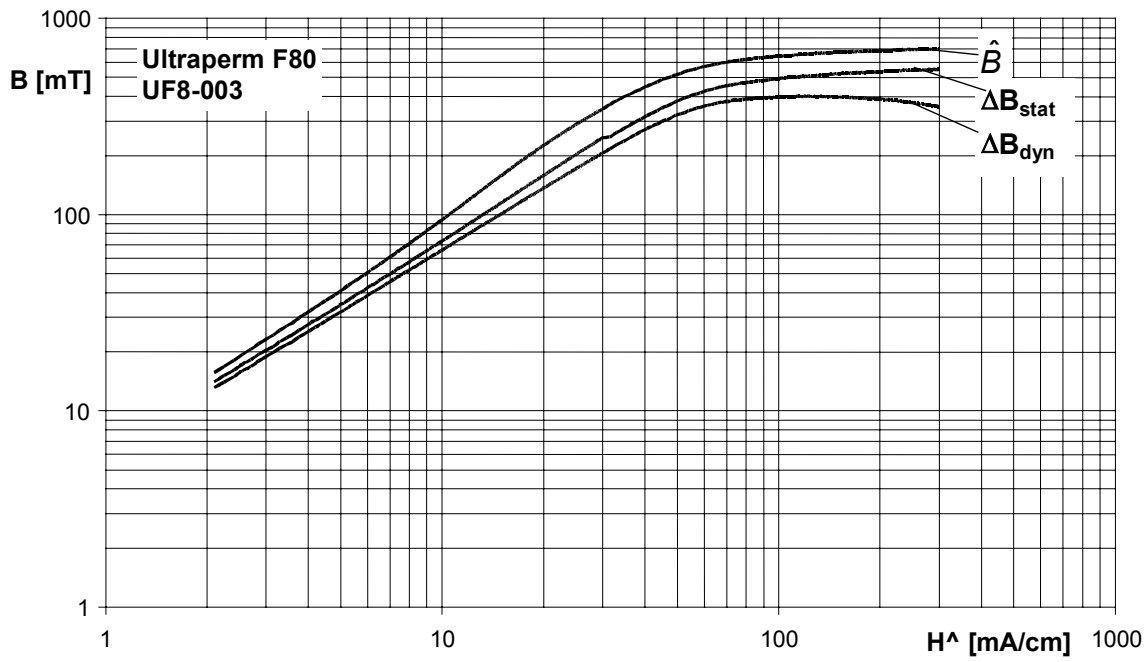
Note, however, that in line with the relevant specific application only individual points can be tested and agreed. The validity of the curves is limited to certain dimensional ranges:



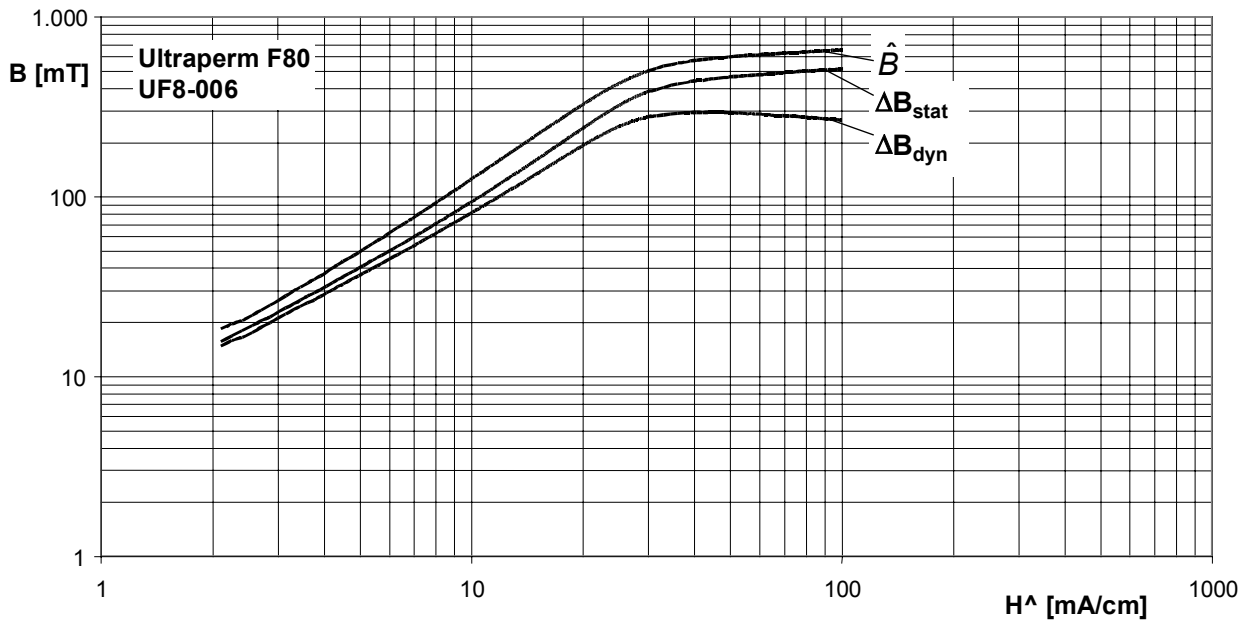
Induction field strength limit curves for **VITROPERM 500F**, magnet quality **LHF 580-01**
 $f = 50$ Hz



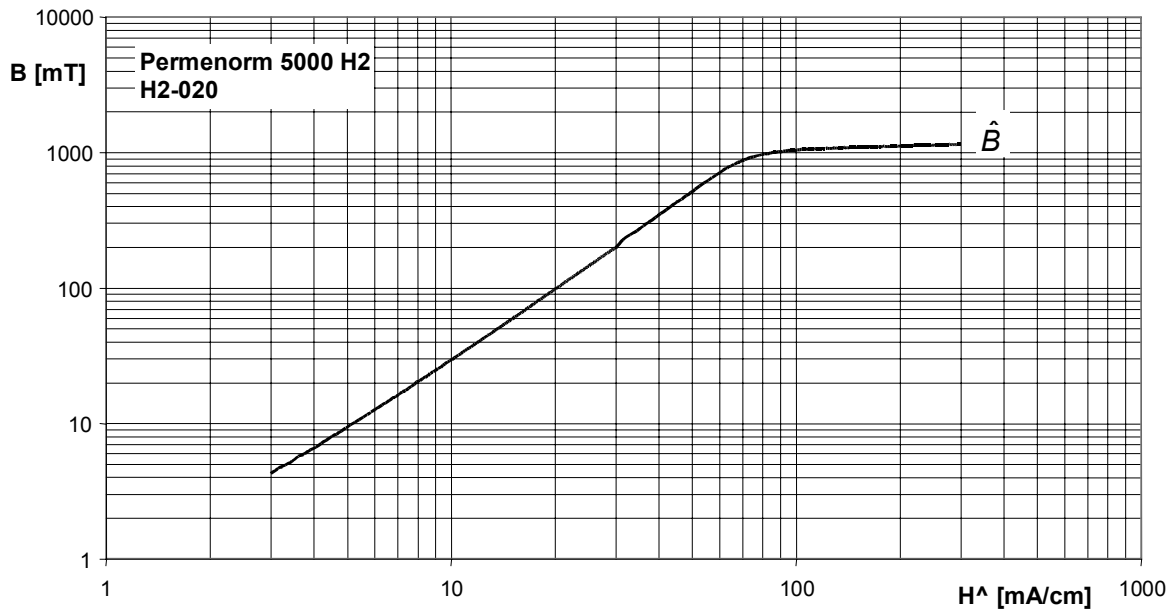
Induction field strength limit curves for **VITROPERM 800F**, magnet quality **LPF 585-01**
 $f = 50$ Hz



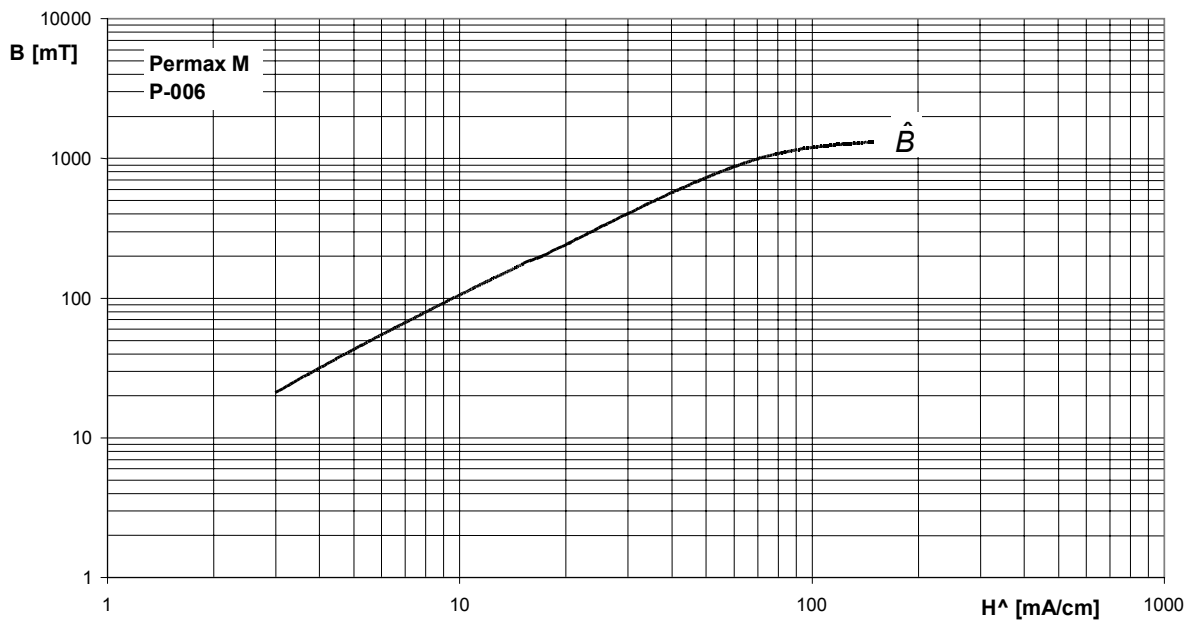
Induction field strength limit curves for **ULTRAPERME F80**, magnet quality **UF8-003**
 $f = 50$ Hz



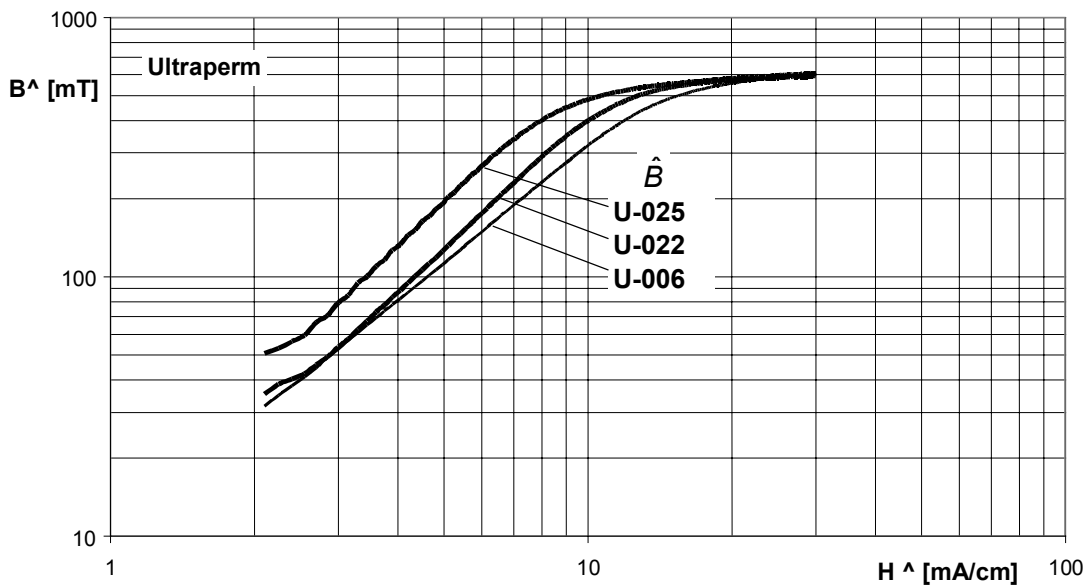
Induction field strength limit curves for **ULTRAPERME F80**, magnet quality **UF8-006**
 $f = 50$ Hz



Induction field strength limit curves for **PERMENORM 5000 H2**, magnet quality **H2-020**
 $f = 50$ Hz



Induction field strength limit curves for **PERMAX M**, magnet quality **P-006**
 $f = 50$ Hz

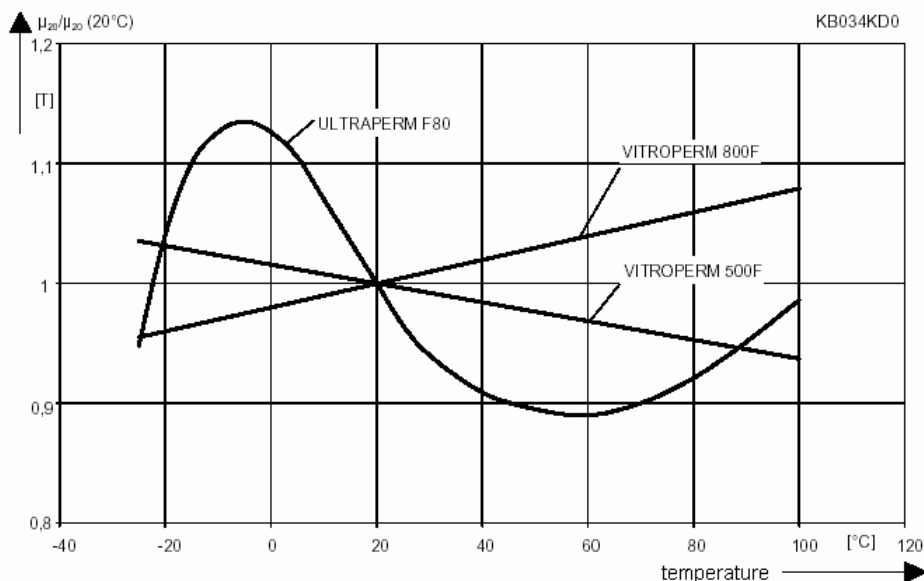


Induction field strength limit curves for **ULTRAPERM 10 / 200 / 250**, magnet quality **U-006, U-022, U-025**
 $f = 50$ Hz

Temperature behavior

The terms \hat{B} , ΔB_{stat} , ΔB_{dyn} as well as the permeability determined from these, which represent a measure for the application-oriented magnetic properties of the cores, are in part quite pronouncedly temperature and current-shape dependent in the case of crystalline materials and depend on actual magnetization field strength values. Temperature behavior can be influenced by variations during heat treatment, and it can be largely optimized for the typical limit values of the application temperature range between e.g. -25°C and 100°C . Here, as a rule, our tape wound cores will be adjusted such that a compromise between the required

properties at room temperature and those at limit temperatures is achieved. Dependencies in this form do not exist in the case of our nanocrystalline material VITROPERM; here, the temperature dependency of the terms \hat{B} , ΔB_{stat} , ΔB_{dyn} and thus also of the permeabilities is largely independent of the magnetization field strengths and current-shapes. An almost linear course of permeability across temperature appears whose increase is primarily dependent on the level of core permeability. The point of rotation in the curves lies at approximately 20°C ; for high permeabilities there is an increase towards 100°C ; at low permeability levels, the increase has a negative sign.



Comparison of the temperature dependency of the permeability values for crystalline and nanocrystalline F-materials

Design

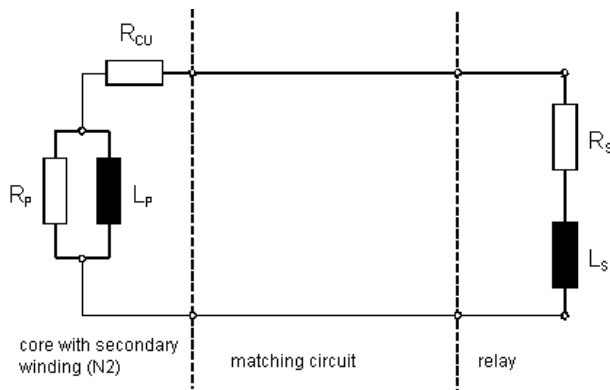
Usually, tape wound cores are supplied in a „fixed“ condition, meaning in the case of cores for circuit breakers that they are supplied inserted in plastic cases. The proper fixing of cores in the troughs is effected by the classic means of foam rings; as a production- optimized alternative, we also offer to glue in the cores by means of a special permanently elastic adhesive agent. For the cost-optimized processing of the case in our production, an adaptation of their design to our automatic encapsulating devices will be of decisive significance. The case used should be closed either by means of a cover or a half-shell which can be joined without positioning. In particular, a reversible snap mechanism is to be preferred. In cases where this is precluded by outside contours, it is possible to tie them up by means of heatresistant adhesive

tape. The form stability of the case parts is a further important influence parameter; here, material thickness and stiffness should allow a low deformation handling. We should like to draw attention to the option of using standardized VAC cases whose construction and material selection provide for a particularly rational production, and which are stocked in a range of sizes. For marking encapsulated cores, there is the option to provide a plain text print if there is a sufficiently large continuous surface area on the outside contour (cover / bottom); a further option is the use of case parts made of coloured synthetic material compounds. When using adhesive tapes, these can be used for marking purposes. If you have any queries with regard to case design or available tools/moulds, please feel free to contact us.

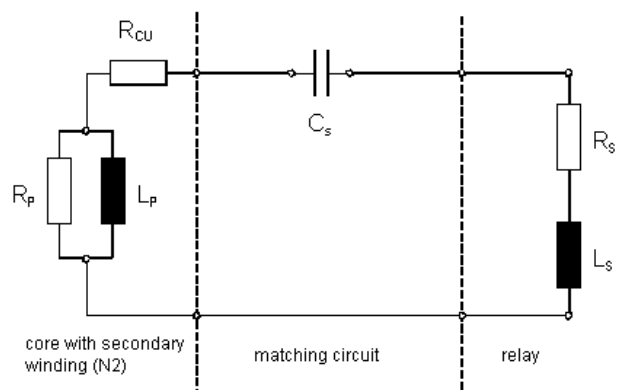
Application Notes / Types of circuit breaker designs

Due to the range of different design solutions and different relay types, there are, in the new construction and design of

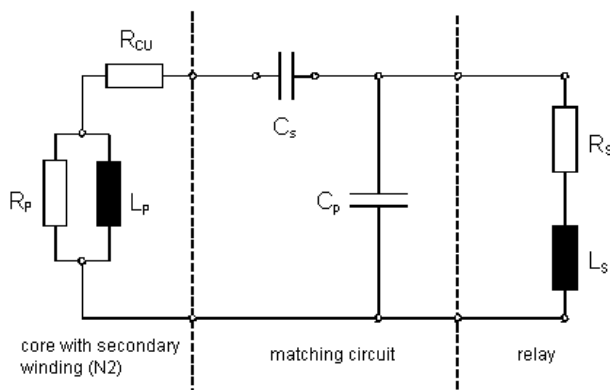
an circuit breaker, a large number of possible solutions for implementing the core used.



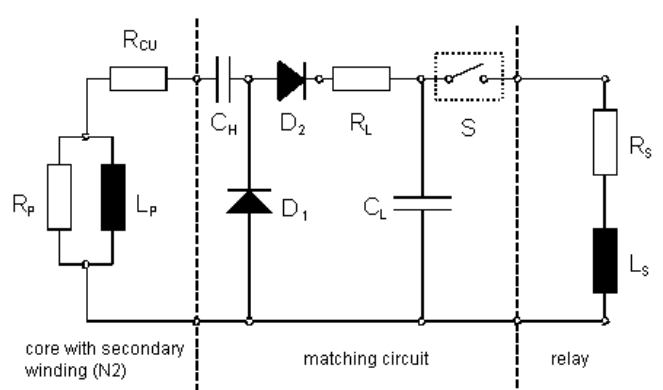
a. alternating current sensitive switch



b. alternating current sensitive switch with series resonance capacitor



c. pulse current sensitive switch



d. selective switch

L_p, R_p : inductance and loss resistance of the sumcurrent transformer in the parallel equivalent circuit

L_s, R_s : inductance and loss resistance of the trigger relay in the series equivalent circuit

R_{Cu} : direct current resistance in the secondary winding

R_L : load resistance

C_s : series resonance capacitor

C_p : parallel resonance capacitor

C_H : auxiliary capacitor for voltage doubling

C_L : filter capacitor

D_1, D_2 : semiconductor rectifier

S: electronic threshold value switch (schematic)

Due to the non-linear magnetic characteristic curves, there is no simple method for deriving the requirements in respect of the sum-current transformer from the specifications for the circuit breaker. Therefore, the design of a new circuit breaker will mostly be proceeded on an empirical basis. This route involves a great deal of costs, at ever shorter innovation cycles; the availability of an option for short-cutting this way of proceeding will allow a reduction in costs when projecting a new switch. We have therefore created a simulation option for circuit breakers of the types a, b, and c, which allows an approximate calculation of the behavior of a circuit breaker, complete with resonance circuit, by means of numeric simulation in the early development phase for cores made of our materials. By means of a suitable modeling of the various individual components, and using the calculation of the relay currents achieved in a specific construction, the optimum material as well as an adapted design can be determined. In this connection, it will be necessary that the framework conditions, e.g. circuit type, values for specified components, as well as the conditions of use, are known. In order to model the trigger behavior, an exact knowledge of the characteristics of the trigger relay used will be necessary. Data are available for the most important relays on the market. However, it is also possible to determine the necessary parameter set for other relays. With our application-specific competence and by means of our simulation program, we can offer a wide range of support services during development. Material, quality, and test specification should then be specified on the basis of the above-mentioned information, a simulation run (if necessary), and in consultation with our product marketing. The

introduction of VITROPERM has led to some interesting and innovative possibilities in circuit breaker design. With its excellent dynamic properties, whilst having high permeability values at the same time, constructions and designs can be implemented which are not possible with standard NiFe materials. Thus, for instance, when designing circuit breakers for nominal currents I_N up to approximately 63 A and a nominal differential current of $I_{\Delta N} \leq 30$ mA, the number of primary windings can be reduced to a single winding. For $N_1 = 1$, the working point of the core will be located within the initial permeability range. For this reason, the cores used should have an I_{Fe} value which is as low as possible in order to allow a magnetization field strength to be reached which is as high as possible for the nominal differential current specified. Here, core geometries as known from the rcd-ocb range are particularly advantageous here. On the other hand, it is possible to use extremely compact cores (involving the use of several primary windings) which give the circuit breaker / switch designer a free hand in design and construction and thus make possible innovative products such as an circuit breaker integrated into a standard protective contact mains socket. In future it is quite conceivable to have combinations of VITROPERM cores weighing just a few grams and fitted with a highly sensitive trigger relay. Such combinations will not only have a significantly lower space requirement than current solutions but also give the equipment manufacturer a cost position which will allow an expansion of business and ensure that the electromechanical circuit breaker will continue to be able to hold its own against other solutions.

Annex: Formulas

For calculating the magnetization field strength \hat{H} from the effective value of the current the following will hold for alternating magnetization (including full wave rectification):

$$\hat{H} = \frac{i_{RMS} \cdot \sqrt{2} \cdot N_1}{l_{Fe}}$$

for magnetization with sinus half-waves:

$$\hat{H} = \frac{i_{RMS} \cdot 2 \cdot N_1}{l_{Fe}}$$

Calculation of the induction amplitude \hat{B} from the rectification mean value of voltage \bar{u} , valid for all voltage shapes sinusoidal fundamental wave.

$$\hat{B} = \frac{\bar{u}}{4 \cdot f \cdot A_{Fe} \cdot N_2}$$

$$\Rightarrow \text{Unit equations } \left[\frac{Vs}{m^2} \right] = \frac{[V]}{\left[\frac{1}{s} \right] \cdot [m^2]}$$

For double wave rectification or half wave rectification the following holds:

$$\hat{B} = \frac{\bar{u}}{2 \cdot f \cdot A_{Fe} \cdot N_2}$$

Units

| | | |
|--|--|--|
| \hat{H} | $\left[\frac{A}{m} \right]$ | Magnetization field strength |
| \hat{B} ΔB_{dyn} ΔB_{stat} | [T] bzw. $\left[\frac{Vs}{m^2} \right]$ | Induction amplitude Induction swing |
| l_{Fe} | [m] | Mean iron path length |
| A_{Fe} | $[m^2]$ | Effective iron cross section |
| f | [Hz] bzw. $\left[\frac{1}{s} \right]$ | frequency |
| \bar{u} | [V] | voltage mean value |
| N_1 N_2 | | Primary no. of turns Secondary no. of turns |