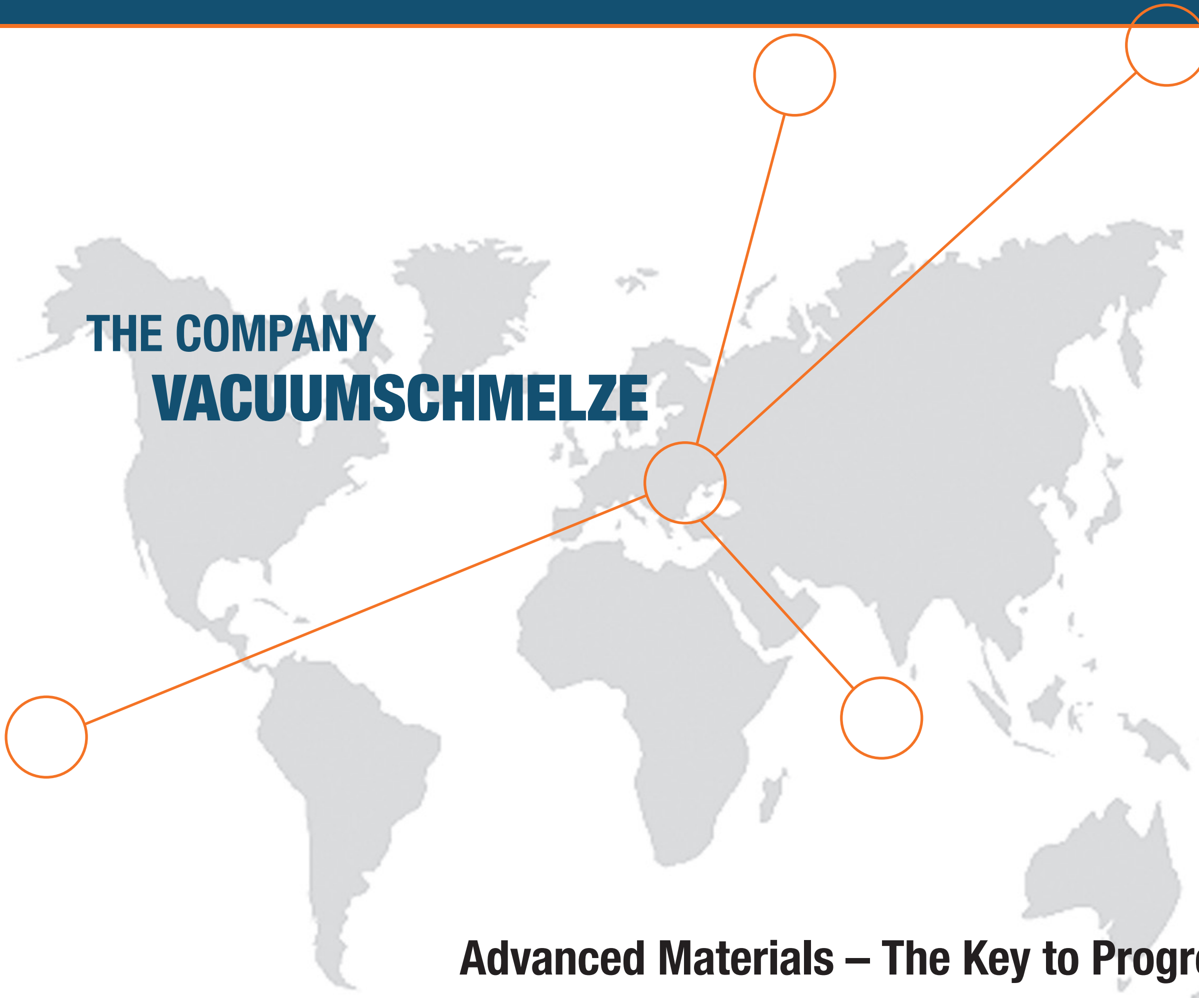
CURRENT TRANSFORMERS

FOR ELECTRONIC ELECTRICITY METERS, CURRENT MONITORING AND PROTECTION APPLICATIONS

ADVANCED MATERIALS – THE KEY TO PROGRESS

VAC® VACUUMSCHMELZE

THE COMPANY
VACUUMSCHMELZE



Advanced Materials – The Key to Progress

VACUUMSCHMELZE is one of world's leading producers of special metallic materials and related products. Our wide range of high quality semi-finished products, parts, components and systems are used in virtually every field of electrical and electronic engineering. This makes us one of the few global companies to offer its customers the complete range of magnetic technology products from a single source – from magnetically soft products to the most powerful permanent magnets in the world.

In all our activities, we benefit from our highly-developed material expertise and our decades of experience in magnetic technology. As early as 1923, we became the first company to introduce alloy smelting in a vacuum on an industrial scale and it was from this process that the name VACUUMSCHMELZE was derived.

One of our great strengths is our versatility. All the world's key industries rely on products and expertise from VACUUMSCHMELZE, with our principal customers active in drive and installation technology, medical technology, renewable energy, automation systems, process and control engineering, measurement technology, as well as the very important automotive and aerospace industries. VAC's dedicated solutions are developed in close cooperation with customers and reflect the highest levels of material and application expertise combined with the latest production technology.

THE COMPANY
VACUUMSCHMELZE

We are a global company with our headquarters in Hanau, Germany. We currently have approximately 4300 employees who are spread over production and sales locations in more than 50 countries on every continent, generating annual sales of approximately EUR 400 million.

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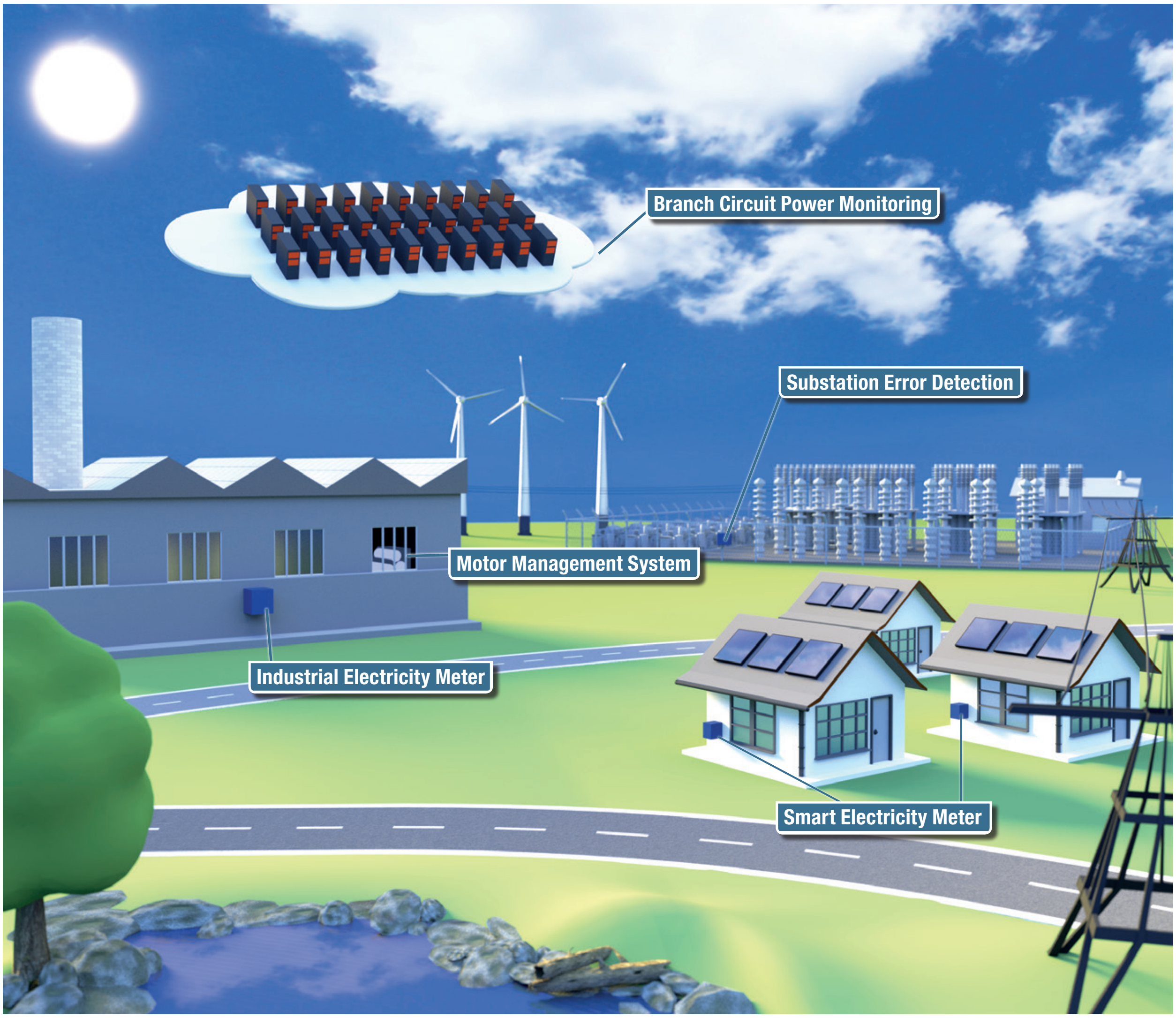
SECTION 1

APPLICATIONS

- **Branch Circuit Power Monitoring** – Multi-circuit monitoring to improve power distribution efficiency
- **Substation Error Detection** – High accuracy for utility network monitoring
- **Motor Management System** – Current measurement for motor protection
- **Industrial Electricity Meter** – Highest accuracy for critical power and large energy users
- **Smart Electricity Meter** – Precise measurement with or without DC immunity



New solutions for electric power generation and distribution have been driven by the transtition towards renewables and a general increase in the demand for electricity. In recent years, the production of electricity by conventional energy sources has seen a decline, while the share of energy from renewable sources has increased. This evolution leads to a complex electricity grid architecture, which must ensure safe electricity transmission and distribution and a sufficient supply for all application areas.

To guarantee both a resource efficient and energy efficient operation of the grid, so-called network management systems become necessary. Hence, Current Transformers (CTs) that enable a continuous monitoring of the electricity usage are needed. Modern materials and innovative engineering from VACUUMSCHMELZE provide a superior solution for fulfilling network monitoring demands. We offer various current detection options for monitoring, control and protection:

- Cores and Current Transformers for electronic energy meters
- Current Transformers for current monitoring
- Current Transformers for protection applications

MANUFACTURING OF VITROPERM AND VITROVAC

VAC pioneered the development of rapid solidification technology resulting in the production of thin tapes or ribbons approximately 20 µm thick. Based on this technology, amorphous VITROVAC® and nanocrystalline VITROPERM® material is produced in a technically advanced one-step process (Fig. 1). Special slitting and core winding machines produce tape-wound cores from the rapid-solidified material.

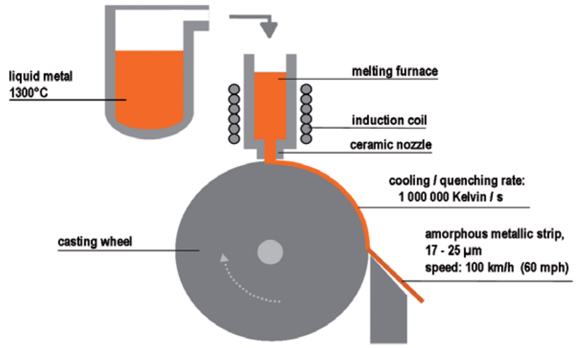


Fig. 1: Rapid solidification technology is used to produce thin metal tapes with an amorphous structure (metallic glass).

A subsequent heat treatment at around 500-600 °C induces the final magnetic properties into the material. VITROVAC remains amorphous during this annealing process whereas VITROPERM`s initially amorphous microstructure is transformed into the nanocrystalline state. This is a two-phase structure with fine crystalline grains (average grain diameter of 10-40 nm) embedded in an amorphous residual phase (Fig. 2).

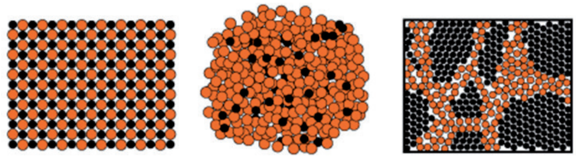


Fig. 2: Crystalline structure, amorphous structure, nanocrystalline microstructure

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ADVANTAGES OF VITROPERM AND VITROVAC FOR CT APPLICATIONS

For more than ten years we have focused on high-precision current transformers for use in electronic electricity meters. Developing and improving our own materials, namely VITROVAC and VITROPERM produced by rapid solidification technology, we are in a leading position to serve the metering and monitoring industry with high-performance current transformers.

Our R&D and Engineering departments can provide outstanding expertise in designing cores and components for the current measurement industry worldwide.

The key performance features for an efficient and accurate CT for electronic electricity meters are:

Performance features of a current transformer	Requirements for the core material
Low phase error φ	High permeability μ
Low amplitude error F(I)	High permeability μ; Low core losses tan σ
Large current range	High saturation flux density B_s
Constancy of the phase and amplitude error	High linearity, low and linear temperature dependence of μ
DC tolerance according to IEC 62053-21 and -23	Very good linearity of the hysteresis loop (F-loop); High saturation flux density B_s = small time constant τ

Table 1: Performance features of a CT vs. the requirements of the core material

For high precision electricity meters, only the materials with the highest permeability values like VITROPERM alloys are adequate. The permeability of VITROPERM F-loop can reach μ=300,000. According to Table 1 a CT made of this material has a very low phase error and low amplitude error.

If DC tolerance is required, the first choice is cores made of VITROVAC. This amorphous material has an excellent linearity, and due to the low permeability and low time constants, this results in a DC tolerance.

The high linearity of cores and CTs made of VITROVAC and VITROPERM allows our customers easy compensation of the remaining phase error. Dependent on the accuracy class and the material, no compensation may be necessary.

Further details are explained in the application note on pages 10 and 11.

PRINCIPLE OF CIRCUITRY

Phase and amplitude errors are critical for electricity measurement accuracy when current transformers are used. In meters of medium accuracy without DC tolerance, these phase and amplitude errors have very low absolute values, and can therefore be easily compensated by a simple correction in the circuit.

Current transformers with DC tolerance have the special feature of a relatively high and very constant absolute phase error value, whereas the amplitude error is negligibly small. This causes an energy measurement error which varies only slightly with the primary current and which results in unacceptable high error values with complex loads (e.g. inductive load with $\cos\varphi = 0.5$) if the phase error is not carefully compensated.

Since the specified scatter of the secondary inductance L cannot be reduced at will, the phase error of the individual current transformer is scattered to the same extent. An individual correction is therefore recommended to stay reliably within the error limits. This can be performed with a suitable digital signal processor (DSP) which is digitally adjusted to the implemented current transformer in a calibration run at a single current value (e.g. at I_b). Particularly high accuracy can be achieved when the phase error curve is measured at several currents and is approximated between these for correction.

This is often impossible, or only possible to a certain extent, in devices with DSPs of a simple internal structure. Here, correction is possible by means of an RC low-pass filter connected in series with the analogue current measuring input, whereby a C-value of typ. 150 to 300 nF is suitable for an R of approximately 1 kΩ. Because of the scatter of the L-values, adapted use of grouped C-values may be necessary.

If further modifications of the operating parameters are necessary, we offer recalculation of the error characteristics upon request.

TABLE 2: CTs WITH DC TOLERANCE ACCORDING TO IEC 62053-21 AND -23 – BASED ON VITROVAC

Order Code T60404-...	Phase- and Amplitude Error Curves	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max}	$\hat{I}_{peak}$	1 : [ ]	φ(I)	L	R_{DC}	R_B	U_B	Inner diameter Ø	Width D	Height H	Pin/ Wire
	[Fig./page]	[A_{rms}]	[A_{0p}]		[°]	[H]	[Ω]	[Ω]	[V_{rms}]	[mm]	[mm]	[mm]	
...E4622-X101	1/20	20	20	2500	3.62	4.6	54	37.50	0.3	5.0	28.5	14.5	Wire
...E4623-X101	2/20	40	40	2500	4.15	3.7	66	18.80	0.3	5.5	28.0	16.0	Wire
...E4624-X101	3/21	60	60	2500	4.06	3.0	55	12.50	0.3	8.0	30.5	15.0	Wire
...E4624-X501	3/21	60	60	2500	4.06	3.0	55	12.50	0.3	8.5	31.0	14.0	Pin
...E4625-X101	4/21	80	80	2500	5.15	2.4	59	9.40	0.3	8.0	30.5	15.0	Wire
...E4625-X501	4/21	80	80	2500	5.15	2.4	59	9.40	0.3	8.5	31.0	14.0	Pin
...E4626-X101	5/22	100	100	2500	4.48	2.1	44	7.50	0.3	9.5	35.0	15.0	Wire
...E4626-X501	5/22	100	100	2500	4.48	2.1	44	7.50	0.3	11.5	34.0	14.0	Pin
...E4627-X101	6/22	120	120	2500	4.07	1.8	34	6.25	0.3	12.0	39.0	18.0	Wire

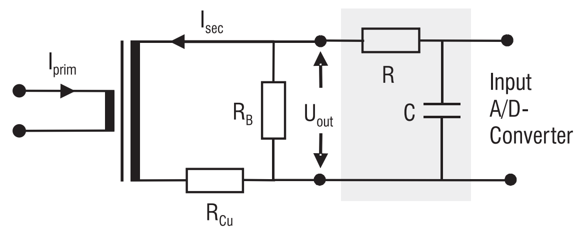
TABLE 3: CTs WITH DC TOLERANCE ACCORDING TO IEC 62053-21 AND -23 – BASED ON VITROPERM

Order Code T60404-...	Phase- and Amplitude Error Curves	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max}	$\hat{I}_{peak}$	1 : [ ]	φ(I)	L	R_{DC}	R_B	U_B	Inner diameter Ø	Width D	Height H	Pin/ Wire
	[Fig./page]	[A_{rms}]	[A_{0p}]		[°]	[H]	[Ω]	[Ω]	[V_{rms}]	[mm]	[mm]	[mm]	
...E4622-X121	7/23	20	20	2500	2.0	9.23	70.6	37.500	0.3	5.0	30.9	16.0	Wire
...E4623-X121	8/23	40	40	2500	2.1	6.50	60.0	18.750	0.3	7.0	33.8	16.9	Wire
...E4624-X121	9/24	60	60	2500	2.3	5.05	51.5	12.500	0.3	8.0	37.5	18.1	Wire
...E4624-X131	10/24	60	60	2500	3.5	3.80	71.5	12.500	0.3	8.0	32.7	16.3	Wire
...E4624-X531	10/24	60	60	2500	3.5	3.80	71.5	12.500	0.3	8.0	32.7	16.3	Pin
...E4625-X131	11/25	80	80	2500	3.4	3.33	62.0	9.375	0.3	9.0	36.8	17.4	Wire
...E4626-X121	12/25	100	100	2500	2.4	2.77	35.5	7.500	0.3	10.5	43.2	19.8	Wire
...E4626-X131	13/26	100	100	2500	3.3	3.10	49.0	7.500	0.3	9.0	38.1	17.7	Pin
...E4626-X531	13/26	100	100	2500	3.3	3.10	49.0	7.500	0.3	9.0	38.1	17.7	Pin
...E4627-X121	14/26	120	120	2500	4.1	3.10	37.0	6.250	0.3	12.5	45.5	19.0	Wire

APPLICATION NOTE

RC Components for Compensation of Phase Error

The excellent soft magnetic properties of the VAC core material for DC-tolerant CTs lead to a negligible small amplitude error, as well as to extremely low and linear temperature dependence. Due to the low permeability, a phase error of 4° to 5° is typical, which is easy to compensate considering its very stable value of typically within +/- 0.05°. Compensation can be effected digitally by appropriate correction in the microprocessor and in the analogue circuitry by an RC low-pass filter in front of the input of the A/D converter, see schematic circuit in Fig. 3. A number of major metering chip providers supply tailored solutions for optimum performance and accuracy in combination with these CT types.



$$C = (R_{CU} + R_B) / \omega^2 \cdot R \cdot L$$

Condition for value of R:

RB <<R<<IZI of converter

Typical R value = 1 kΩ

Typical C value: 150 ... 300 nF

Fig. 3: Schematic diagram

DC components and their influence on the accuracy of a Current Transformer for Electronic Energy Meters

During operation with DC currents high permeability cores tend strongly to gradual saturation. At each applied 50 Hz rectified pulse, the core becomes increasingly saturated until it reaches its maximum, B_{sat}. This behaviour is shown in Fig. 4. Driving the core into saturation results in incorrect measurement results.

To prevent this problem, amorphous VITROVAC or nanocrystalline VITROPERM based CTs can be used. The advantages of these materials are the small amplitude error and its very stable value. Furthermore, a smaller permeability causes a reduction of the time decay constant τ, which results in a faster degradation of the inner field ΔB_2 inside the core. This time constant defines whether a CT is DC tolerant or not. Only if $\Delta B_2 \geq \Delta B_1$ can the core be DC tolerant. So called

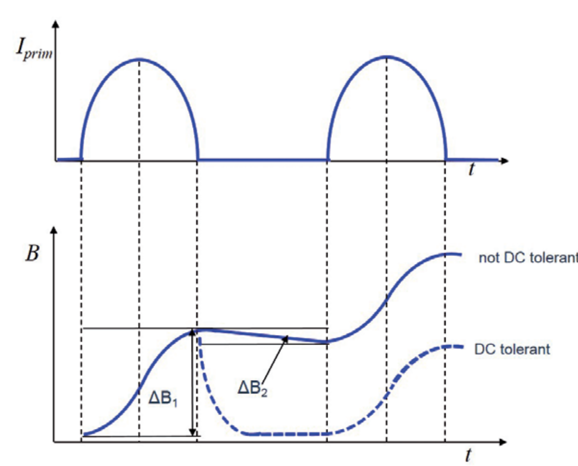


Fig. 4: Saturation of the core material

“combined cores” seem to be a low-cost alternative to low permeability VITROVAC or VITROPERM cores. It is claimed that CTs with those cores are DC-tolerant as well. A combined core is built up with two different materials. One high permeability material for operation under pure AC condition and a second low permeability material for operation when DC components are present in the AC current. The direct current will result in saturation of the high permeability material and the measurement is made by the low permeability material in that mode.

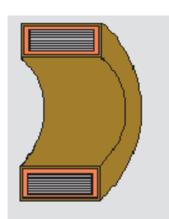
This is the reason for the significant disadvantage of combined cores compared to VITROVAC or VITROPERM cores.

The saturated part of the combined core induces the remaining magnetic flux into the low permeability part and consequently strongly influences the measurement result. This behaviour is shown in Fig. 5. The hysteresis loop of the VITROVAC or VITROPERM core is very linear over the whole range of the magnetic field strength whereas the combined core shows a strong non-linear behaviour.

Hence, the combined core does not measure the current correctly. In contrast, ultra-linear low permeability VITROVAC or VITROPERM CTs are able to measure current with a very high accuracy, even under DC conditions.

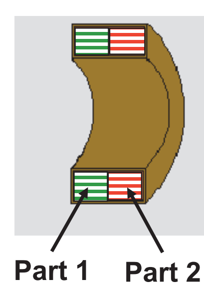
VAC core

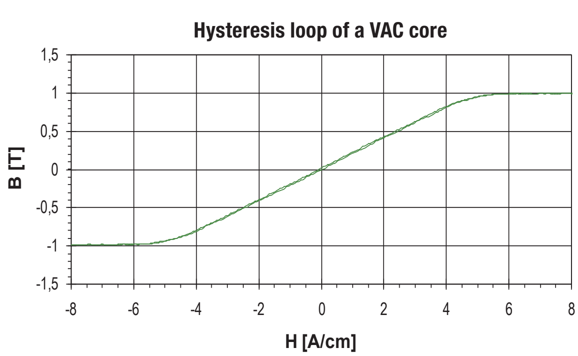
- low permeability
- amorphous or nanocrystalline core
- best linearity



Combined core

- two cores made of different alloys
- inhomogenous core





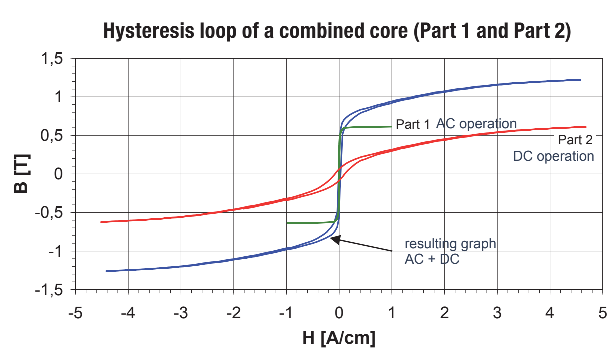


Fig. 5: Characteristics of a VAC core vs. a combined core

Power Factor

Usually, the shape of the current waveform in an electronic network is dependent on the kind of load (resistive, capacitive and inductive). Whereas resistive loads do not influence the sine wave phase, resistive and inductive loads strongly influence the phase shift between current and voltage. This can be quantified as a power factor cos φ. The power factor can also be defined as the ratio between true power and apparent power.

For resistive loads, e.g. light bulbs or electric heaters, cos φ is always 1. In this case both cores, combined cores and high performance VITROVAC, respectively VITROPERM cores, would measure accurately, whereas VITROVAC or VITROPERM would be much more linear.

In reality, typical loads in an electric network do not only consist of resistive loads. Every household and every company has capacitive loads like fluorescent lamps or inductive loads like vacuum cleaners. In every household or business, the use of vacuum cleaners, fluorescent lamps and other electric devices results in capacitive or inductive loads.

The left graph of Figure 6 shows the meter error behaviour of a VAC CT and the right one exhibits the combined core behaviour. Comparing VITROVAC and VITROPERM CTs and combined core CTs, the meter error of the combined core can differ by more than 40 %, dependent on cos φ, which is a significant disadvantage for the combined core CT.

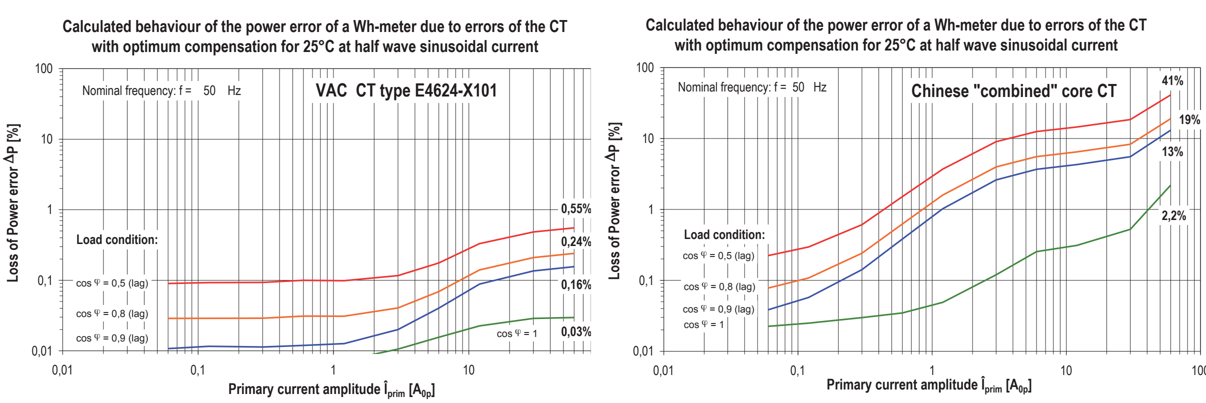


Fig. 6: Comparison of the power error of an electronic electricity meter. The left graph shows a VITROVAC based high accuracy meter which is nearly independent of the power factor. The right graph demonstrates the strong influence of the power factor and hence the inaccurate meter behaviour of a combined core based electronic electricity meter.

Whereas the power error of the meter is nearly constant over the whole power factor range for VITROVAC or VITROPERM cores, the power error of a combined core based meter has a strong dependence on the power factor cos φ (Fig. 7). Hence, it is not recommended to use these inaccurate combined cores in high precision electronic energy meters. Fig. 8 is an example on how relevant the measured energy consumption, and respectively the meter error, can be. Meter A, which is based on an amorphous VITROVAC core, measures as accurately at cosφ = 0.85 as at φ = 1.0. In comparison, Meter B using a combined core CT has a much larger error of 4.5 % at a superposed DC current of 2 amps. Those errors directly correlate to the cost of the energy consumption, which has to be paid by the end customer or the utility.

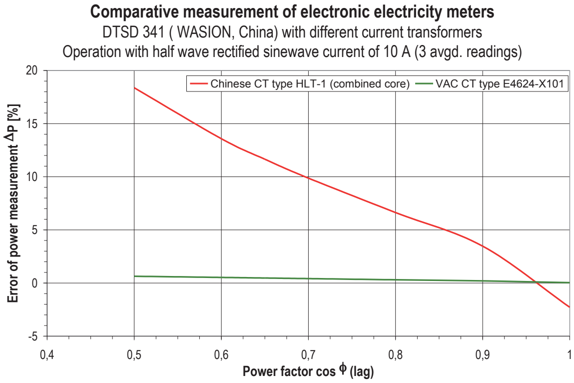


Fig. 7: Comparison of the dependence of power error with respect to the power factor. The VAC CT is very constant whereas the combined becomes increasingly inaccurate.

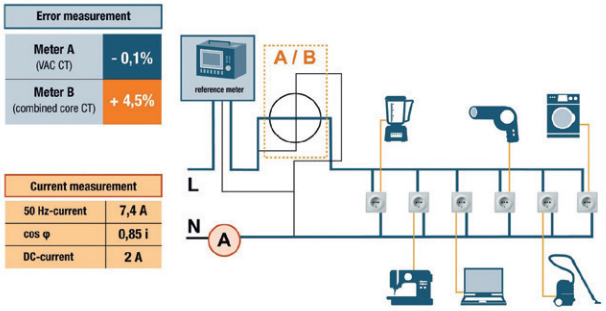


Fig. 8: Measurement example for a realistic cos φ in a typical household

DC TOLERANCE TEST ACCORDING TO IEC 62053-21, -23

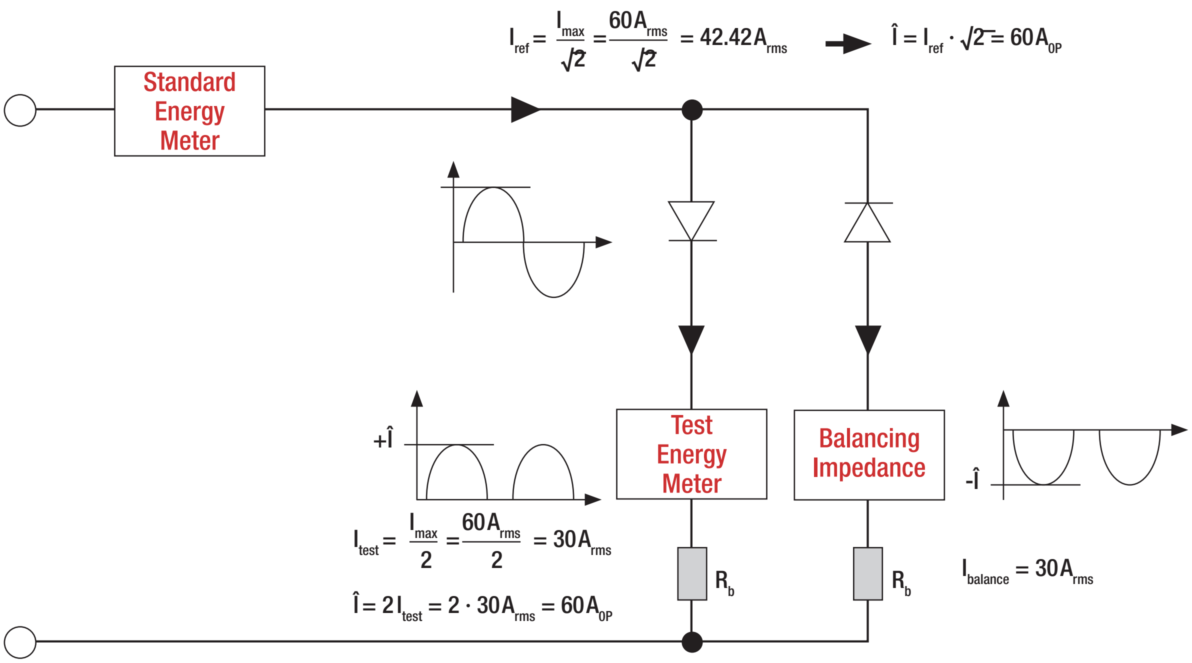


Fig. 9: Typical test circuitry

The diagram above shows a typical test configuration for the measurement of the DC tolerance of a 60 A electricity meter. The balancing impedance is a second meter of the same series. During this test, the meter shows 30 A_{rms}, which is equal to 60 A_{0P}, for only half-rectified sinusoidal currents.

Shielded CT s for Anti-Tampering

In special applications, if the sensitivity of the current transformer to external magnetic fields in special applications is still too high, we recommend shielded versions of CTs (see Table 4 on page 16). If required for anti-tampering issues, each CT can be encapsulated with a pair of deep drawn shielding caps.

For additional protection against manipulation by external fields from permanent magnets, a metal plate may be placed between the CT and the magnet (see Fig. 10 on page 15).

TYPICAL CHARACTERISTICS OF THE AMPLITUDE ERROR IN THE FIELD OF A PERMANENT MAGNET

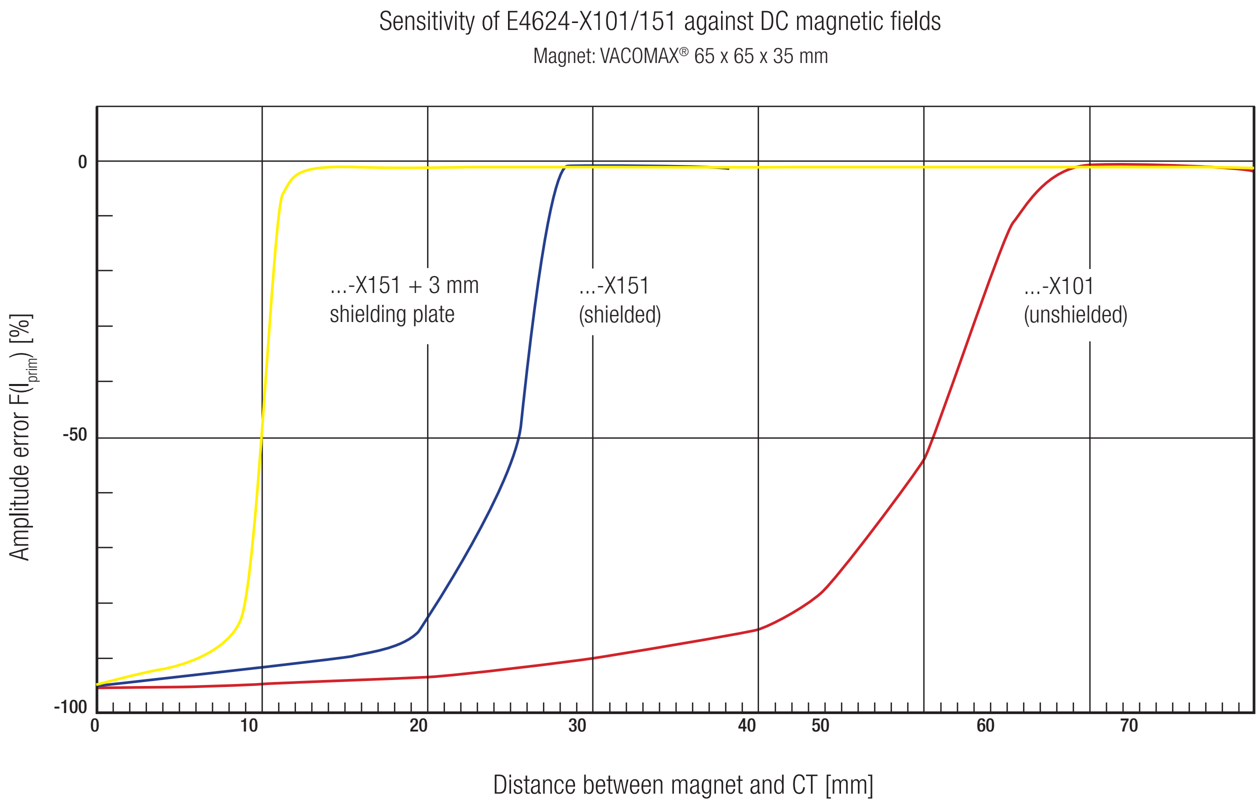


Fig. 10: Diagram above shows a comparison of different shielding configurations. For optimum protection against external magnetic fields, CTs from the …–X151 series and a 3 mm shielding plate are recommended.

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TABLE 4: SHIELDED CTs FOR ANTI-TAMPERING

Order Code T60404-...	Phase- and Amplitude Error Curves	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max}	$\hat{I}_{peak}$	1 : [ ]	φ(I)	L	R_{DC}	R_B	U_B	Inner diameter Ø	Width D	Height H	Pin/ Wire
	[Fig./page]	[A_{rms}]	[A_{0p}]		[°]	[H]	[Ω]	[Ω]	[V_{rms}]	[mm]	[mm]	[mm]	
...E4622-X011	19/29	6	–	2000	0.37	105.00	115.0	100.0	0.3	5.5	28.0	15.9	Wire
...E4622-X012	19/29	6	–	2000	0.17	238.00	115.0	100.0	0.3	5.5	28.0	15.9	Wire
...E4624-X151	3/21	60	60	2500	4.06	3.00	55.0	12.5	0.3	8.0	32.9	17.1	Wire
...E4624-X171	9/24	60	60	2500	3.5	3.80	71.5	12.5	0.3	8.0	36.9	19.2	Wire
...E4625-X151	4/21	80	80	2500	5.15	2.40	53.5	9.4	0.3	8.0	32.9	17.1	Wire
...E4626-X151	5/22	100	100	2500	4.48	1.97	55.0	7.5	0.3	9.5	35.8	17.2	Wire

TABLE 5: CTs WITHOUT TOLERANCE DC FOR DIRECT CONNECTION

Order Code T60404-...	Phase- and Amplitude Error Curves	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max}	$\hat{I}_{peak}$	1 : [ ]	φ(I)	L	R_{DC}	R_B	U_B	Inner diameter Ø	Width D	Height H	Pin/ Wire
	[Fig./page]	[A_{rms}]	[A_{0p}]		[°]	[H]	[Ω]	[Ω]	[V_{rms}]	[mm]	[mm]	[mm]	
...E4622-X002	15/27	20	–	2500	0.18	113	54	37.5	0.3	5.0	28.5	14.5	Wire
...E4623-X002	16/27	40	–	2500	0.12	155	61	18.8	0.3	5.5	28.0	16.0	Wire
...E4624-X002	17/28	60	–	2500	0.13	122	55	12.5	0.3	8.0	30.5	15.0	Wire
...E4624-X502	17/28	60	–	2500	0.13	122	55	12.5	0.3	8.5	31.0	14.0	Pin
...E4626-X002	18/28	100	–	2500	0.11	97	44	7.5	0.3	9.5	35.0	15.0	Wire
...E4626-X502	18/28	100	–	2500	0.11	97	44	7.5	0.3	11.5	34.0	14.0	Pin

TABLE 6: CTS WITHOUT TOLERANCE DC FOR INDIRECT CONNECTION

Order Code T60404-...	Phase- and Amplitude Error Curves	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max}	$\hat{I}_{peak}$	1 : [ ]	φ(I)	L	R_{DC}	R_B	U_B	Inner diameter Ø	Width D	Height H	Pin/ Wire
	[Fig./page]	[A_{rms}]	[A_{0p}]		[°]	[H]	[Ω]	[Ω]	[V_{rms}]	[mm]	[mm]	[mm]	
...E4629-X007	19/29	6	–	2000	0.37	105	112	100	0.3	7.0	23.0	11.0	Wire
...E4622-X501	19/29	6	–	2000	0.37	110	115	100	0.3	6.3	24.5	11.5	Pin
...E4629-X010	20/29	6	–	2000	0.17	238	114	30	0.3	7.0	23.0	11.0	Wire
...E4622-X503	20/29	6	–	2000	0.17	238	114	100	0.3	6.3	24.5	11.5	Pin
...E4658-X043	21/30	6	–	1500	0.40	35	46	75	0.3	5.0	16.8	9.0	Pin

TABLE 7: CTS FOR THE ANSI MARKET

Order Code T60404-...	Phase- and Amplitude Error Curves	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max}	$\hat{I}_{peak}$	1 : [ ]	φ(I)	L	R_{DC}	R_B	U_B	Inner diameter Ø	Width D	Height H	Pin/ Wire
	[Fig./page]	[A_{rms}]	[A_{0p}]		[°]	[H]	[Ω]	[Ω]	[V_{rms}]	[mm]	[mm]	[mm]	
...E4629-X007	19/29	20	–	2000	0.21	105.0	112.0	30.00	0.3	7.0	23.0	11.0	Wire
...E4622-X501	19/29	20	–	2000	0.21	110.0	115.0	30.00	0.3	6.3	24.5	11.5	Pin
...E4629-X010	20/29	20	–	2000	0.17	238.0	114.0	30.00	0.3	7.0	23.0	11.0	Wire
...E4627-X001	24/31	200	–	1000	0.11	24.6	13.5	1.50	0.3	8.5	30.0	17.5	Wire
...E4628-X001	25/32	320	–	1000	0.10	22.0	12.7	0.94	0.3	11.0	35.0	18.5	Wire

TABLE 8: CTs FOR MONITORING / PROTECTION AND MEASUREMENT APPLICATIONS

Order Code T60404-...	Phase- and Amplitude Error Curves	Primary Current Range I_{max}	Ratio 1 : [ ]	Characteristic Values L	R_{DC}	R_B	U_B	Dimensions Inner diameter Ø	Width D	Height H	Pin/ Wire
	[Fig./page]	[A_{rms}]		[H]	[Ω]	[Ω]	[V_{rms}]	[mm]	[mm]	[mm]	
...E4658-X039	26/32	6*	1500	8.0	44	75	0.3	5.0	16.8	19.0	Pin
...A4185-X037	27/33	8	300	≥70	50	20	0.5	–	27.6	15.0	Pin
...A4658-X034	28/33	10	1500	≥20	100	100	0.7	5.0	16.8	19.0	Pin
...A4658-X037	29/34	10	1000	12.8	50	30	0.3	5.0	16.8	19.0	Pin
...S4658-X051	30/34	100	2000	≥63	51	10	0.5	10.8	27.0	29.5	Pin

* with $\hat{I}_{peak} = 4.2\ A_{0p}$

Key to tables 2 to 8:

Noted values are typical at room temperature (25 °C)

All types are designed to have one primary turn ($N_1 = 1$), ideally, a bus-bar

I_{max} = maximum AC primary current with defined errors

$\hat{I}_{peak}$ = max. half wave rectified AC amplitude without saturation (for class 1 meter (IEC 62053 -21, -23): $F(\hat{I}_{max}) < 3\,\%$)

φ (I) = max. phase error for $I < I_{max}$

F(I) = max. amplitude error for $I < I_{max}$

N_2 = number of secondary turns

L = inductance at moderate excitation level ($I < I_{max}$)

R_{DC} = winding resistance

R_B = burden resistor

U_B = output voltage across burden resistor R_B at I_{max}

∅ = diameter of centre hole

D = maximum width of component in mm

H = maximum heigth of component in mm

For further details please see the datasheets which are provided at www.vacuumschmelze.com

CURRENT TRANSFORMER DESIGNS

The VAC standard product spectrum offers more than 50 current transformer components for the whole range of current measurement applications. These types can be ordered directly from VAC. Please see our separate standard product tables.

EXAMPLES FOR VAC STANDARD CURRENT TRANSFORMER DESIGNS

Despite the large range of standard products, sometimes custom versions are the best solution. It is one of VAC's core competences to engage our experienced product development engineers for the benefit of achieving the best and most efficient solution. A prerequisite for this must be an economic production volume.

EXAMPLES OF CUSTOMIZED VAC CURRENT TRANSFORMER DESIGNS

SECTION 2

TYPICAL TEMPERATURE DEPENDENCE OF PHASE AND AMPLITUDE ERRORS

Fig. 1: 20 A with DC Tolerance, T60404-E4622-X101

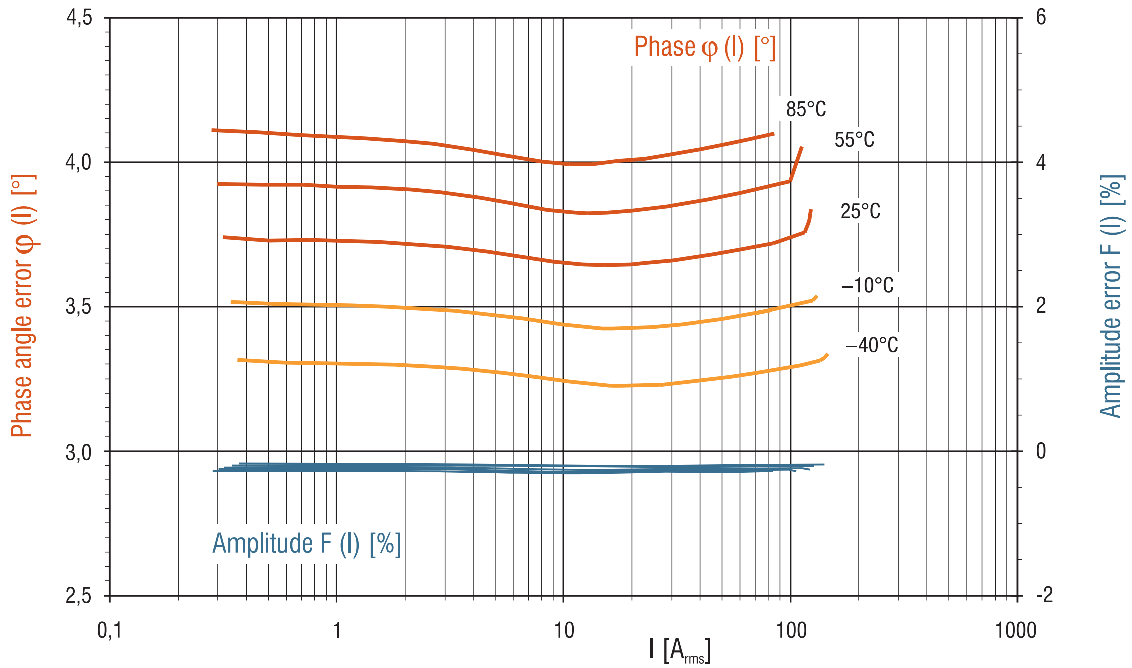


Fig. 2: 40 A with DC Tolerance, T60404-E4623-X101

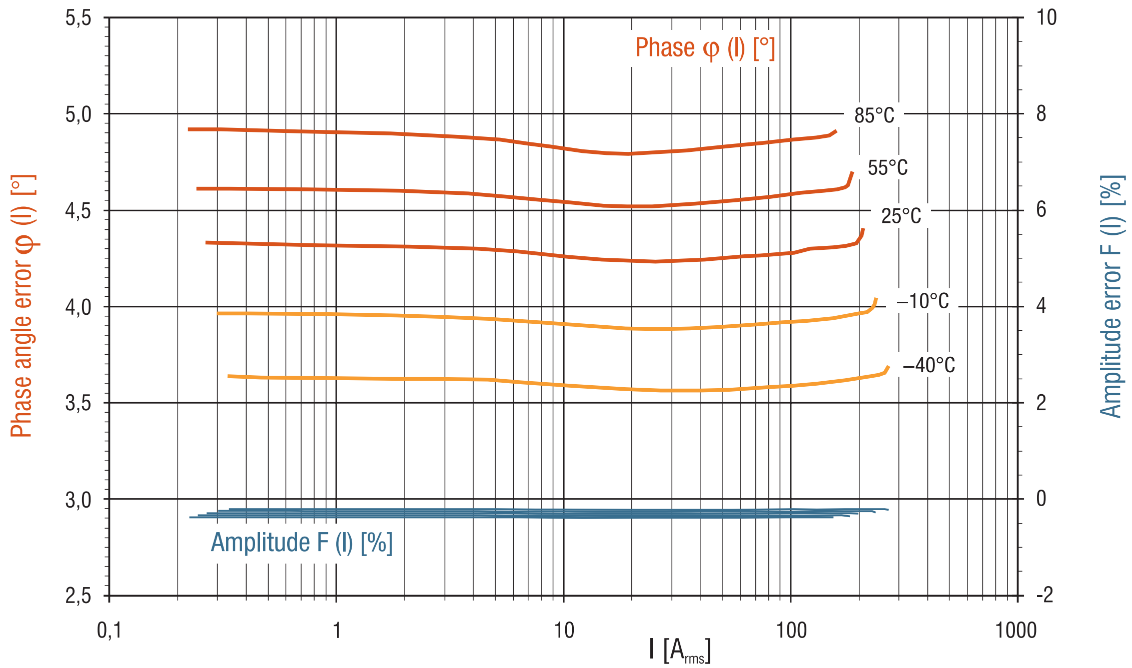


Fig. 3: 60 A with DC Tolerance, T60404-E4624-X101/-X501/-X151

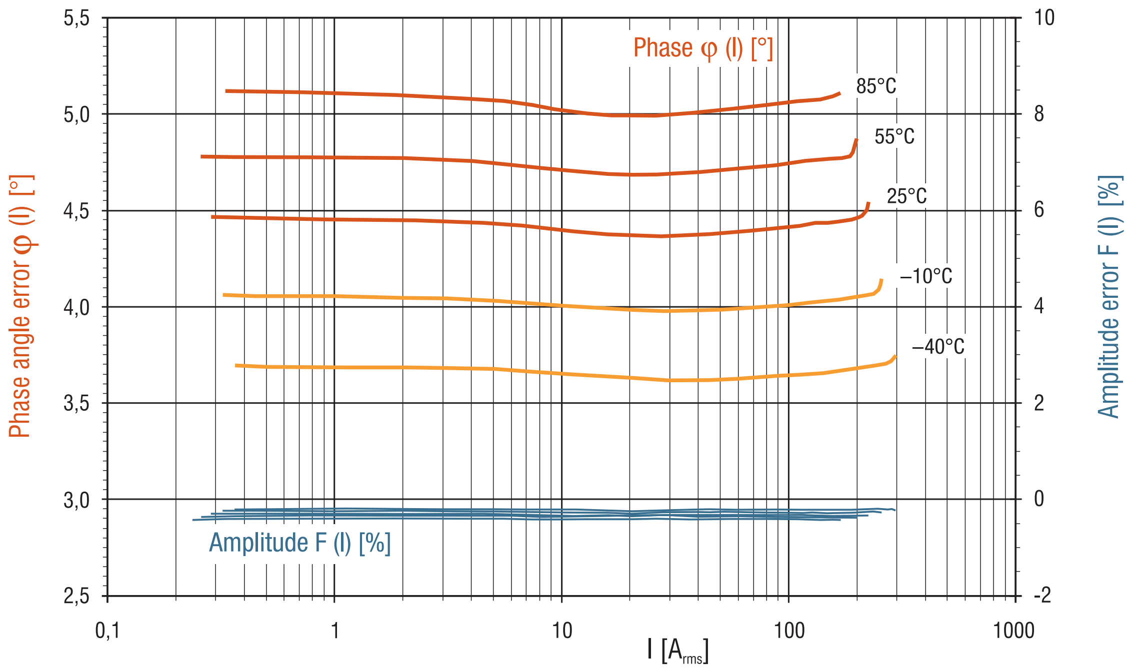


Fig. 4: 80 A with DC Tolerance, T60404-E4625-X101/-X501/-X151

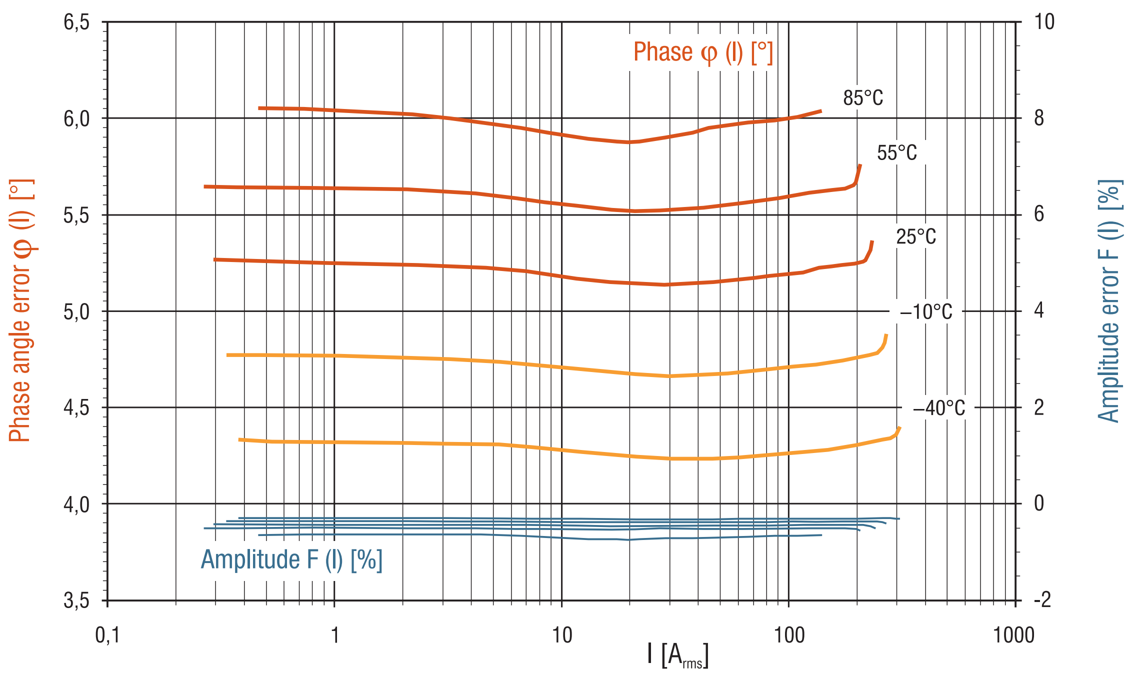


Fig. 5: 100 A with DC Tolerance, T60404-E4626-X101/-X501/-X151

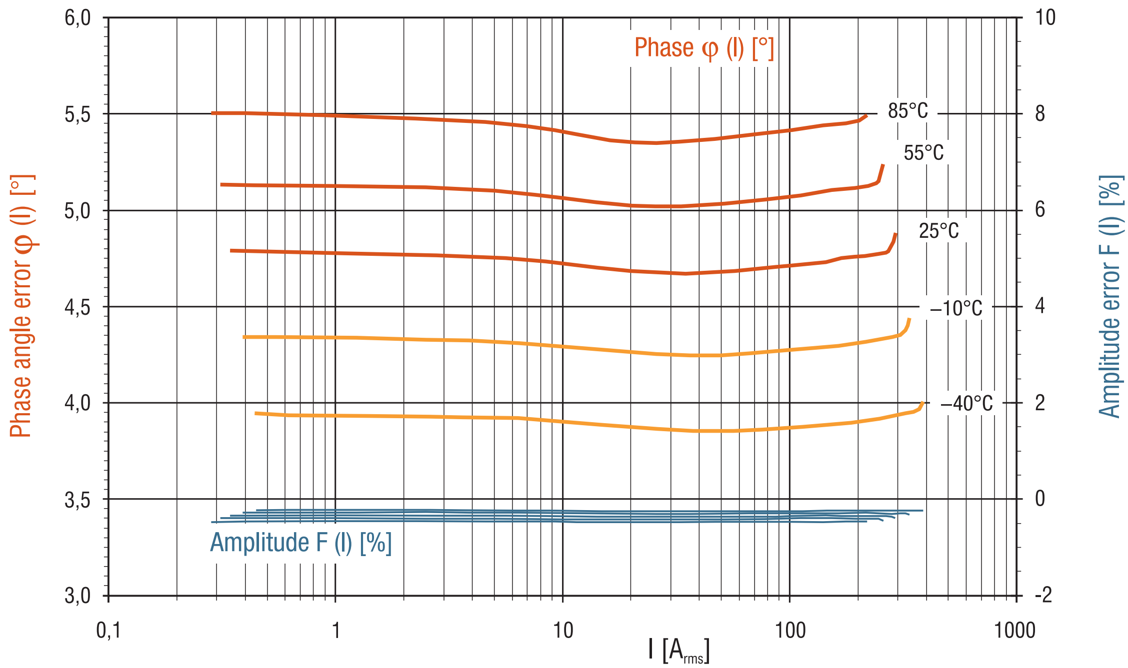


Fig. 6: 120 A with DC Tolerance, T60404-E4627-X101

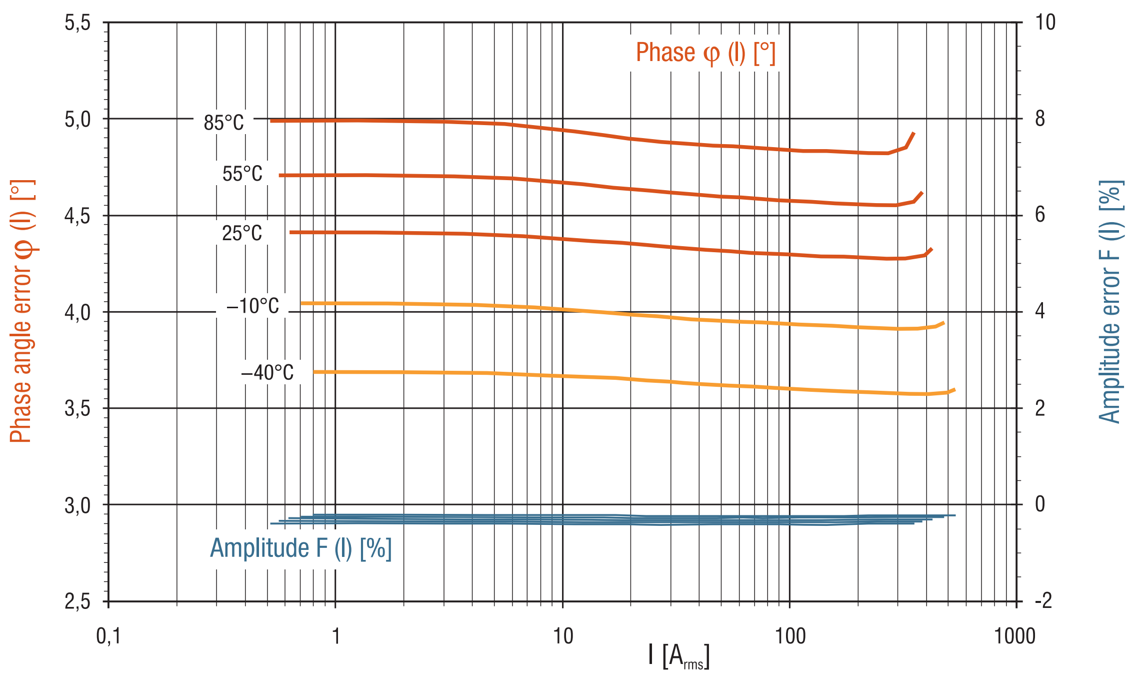


Fig. 7: 20 A with DC Tolerance, T60404-E4622-X121

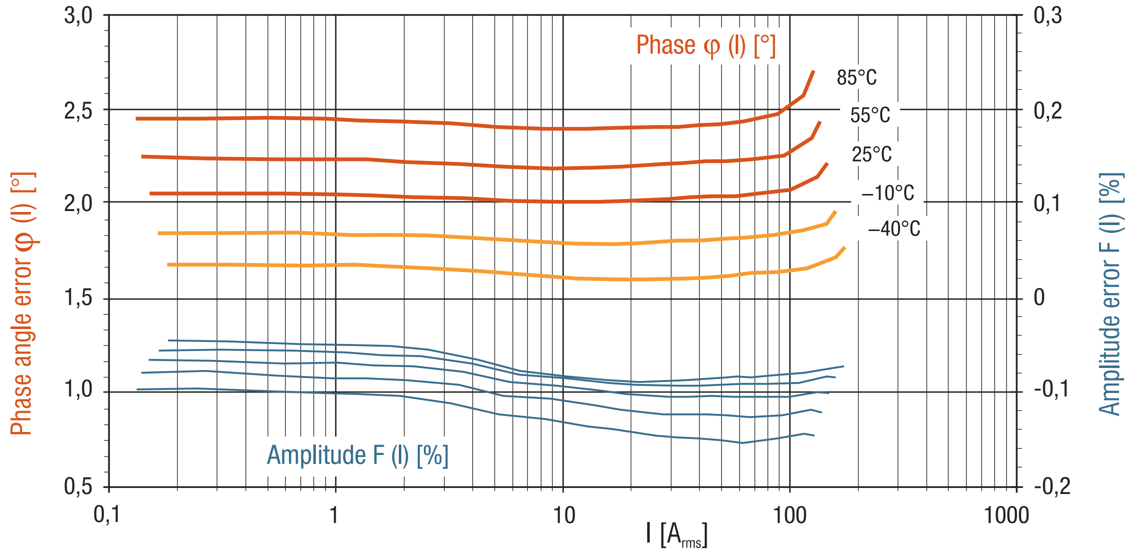


Fig. 8: 40 A with DC Tolerance, T60404-E4623-X121

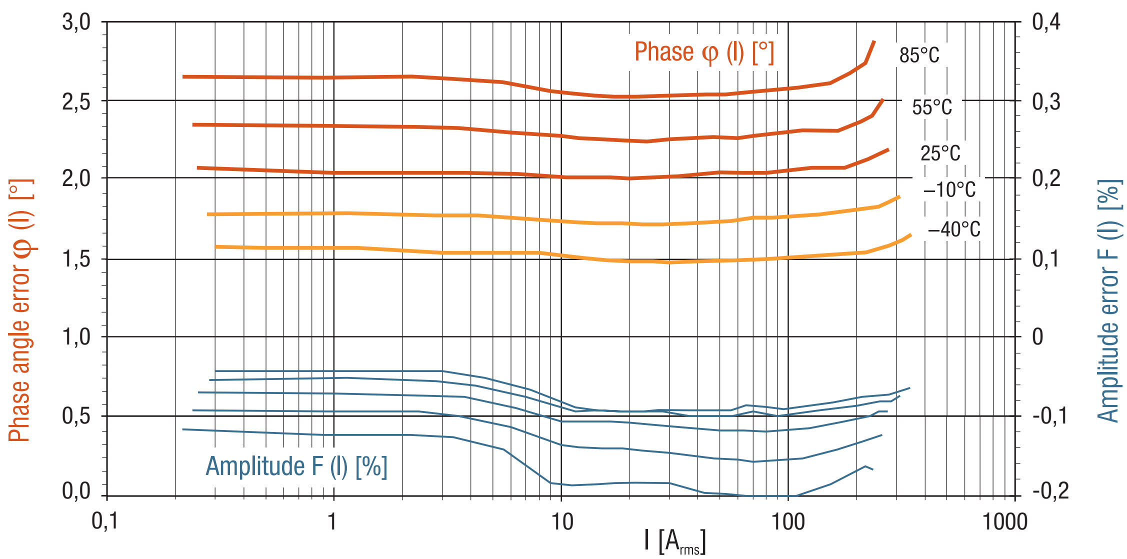


Fig. 9: 60 A with DC Tolerance, T60404-E4624-X121

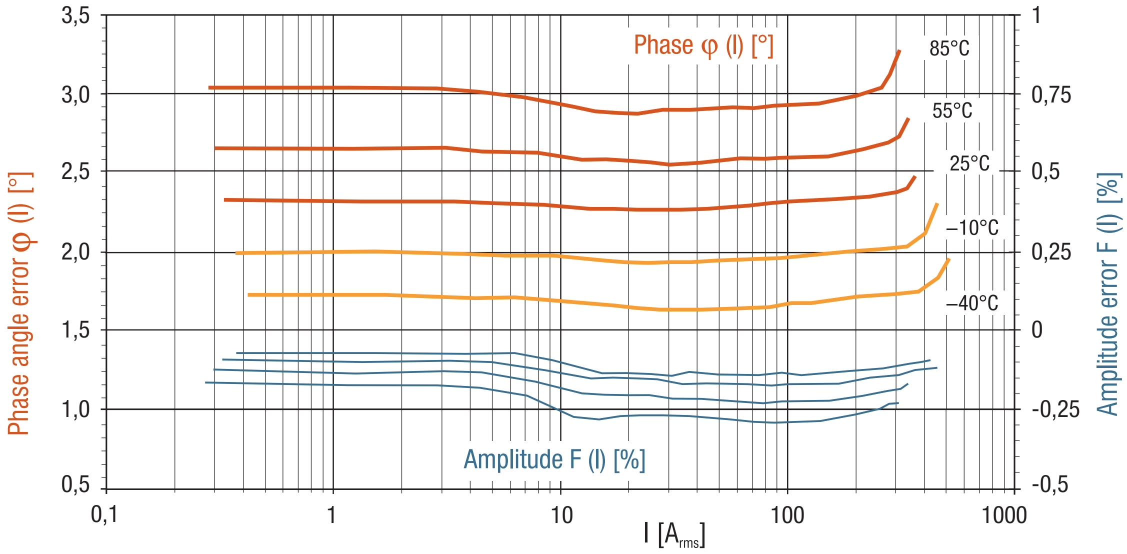


Fig. 10: 60 A with DC Tolerance, T60404-E4624-X131/-X531

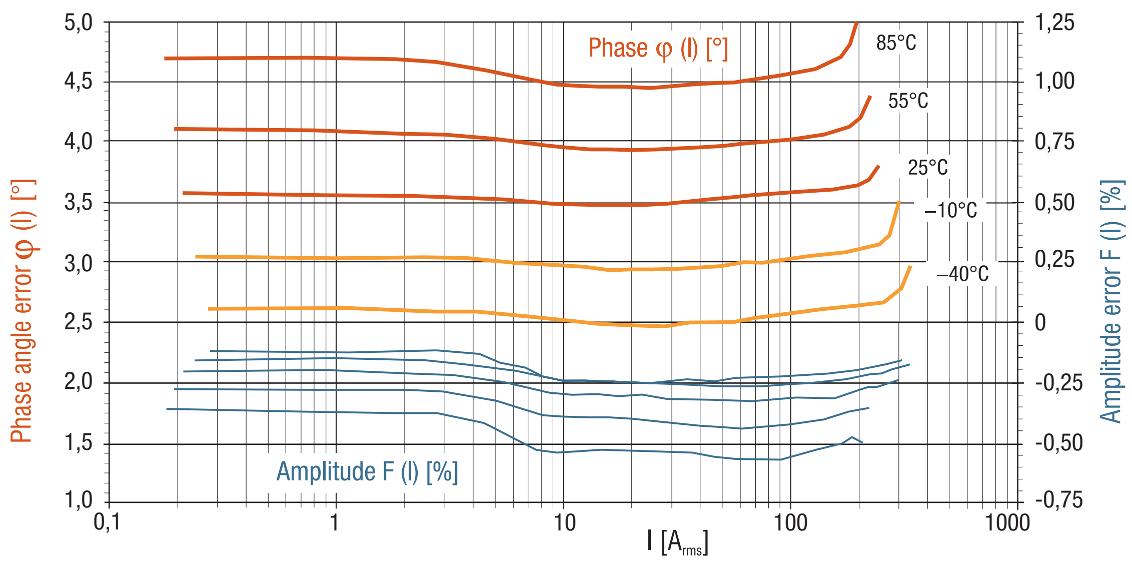


Fig. 11: 80 A with DC Tolerance, T60404-E4625-X131

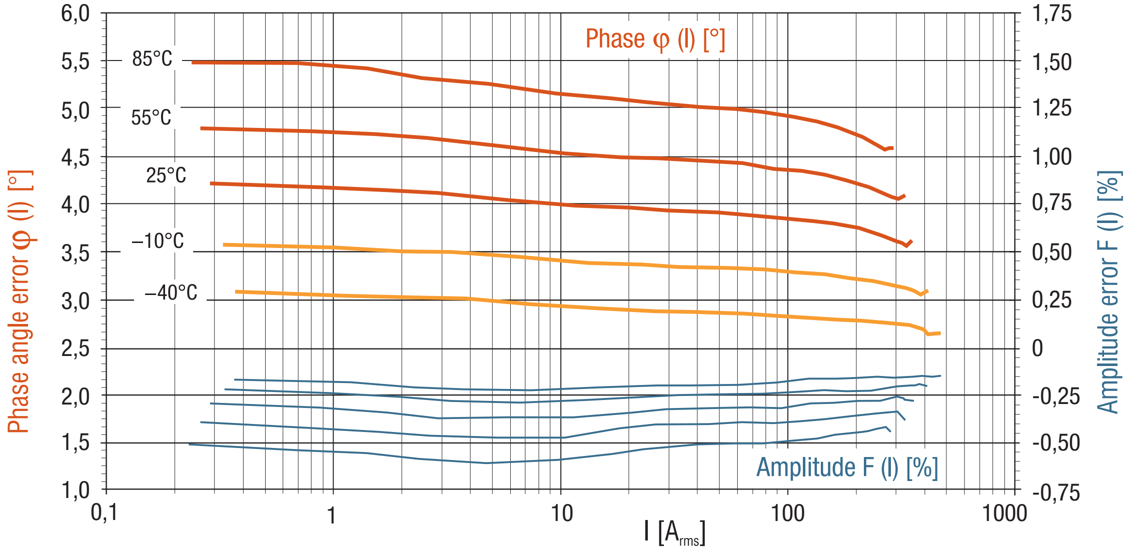


Fig. 12: 100 A with DC Tolerance, T60404-E4626-X121

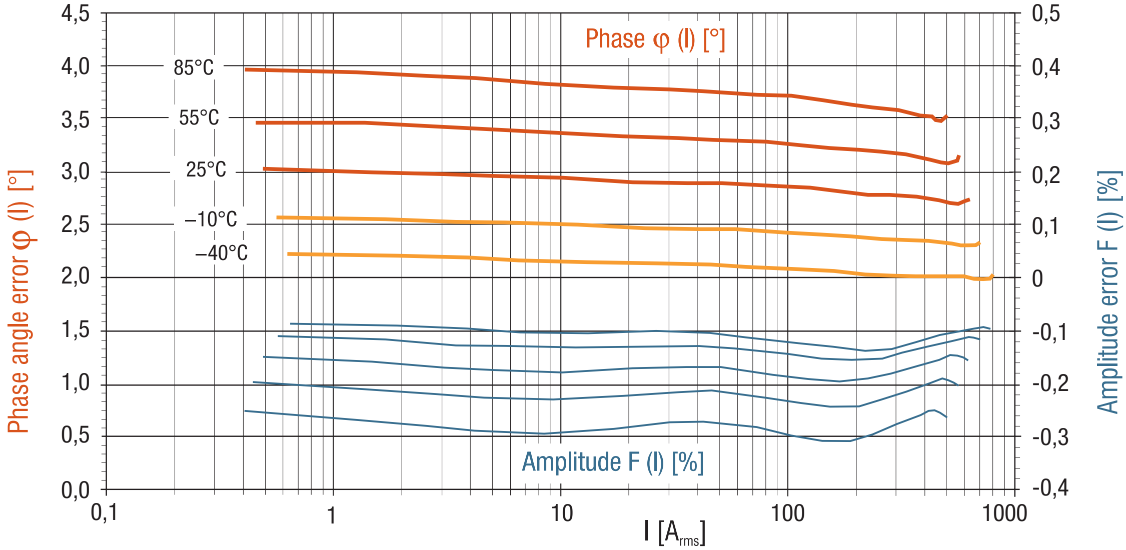


Fig. 13: 100 A with DC Tolerance, T60404-E4626-X131/-X531

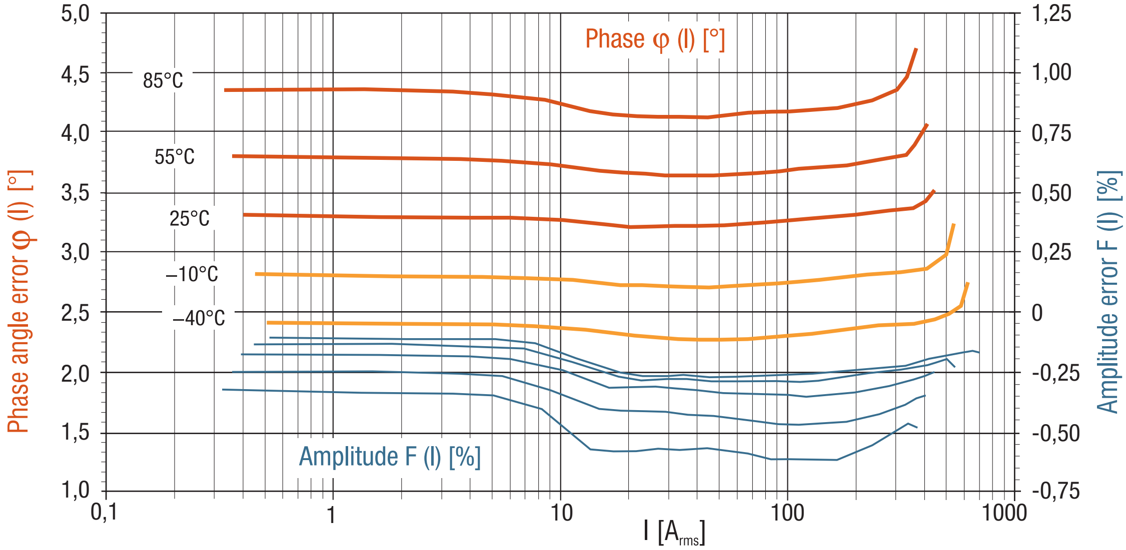


Fig. 14: 120 A with DC Tolerance, T60404-E4627-X121

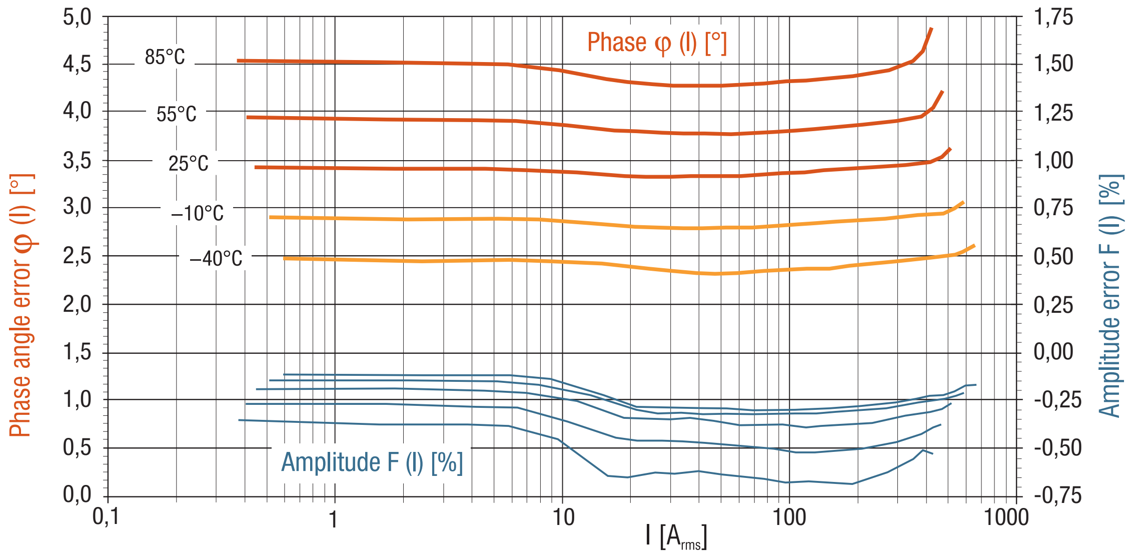


Fig. 15: 20 A, T60404-E4622-X002

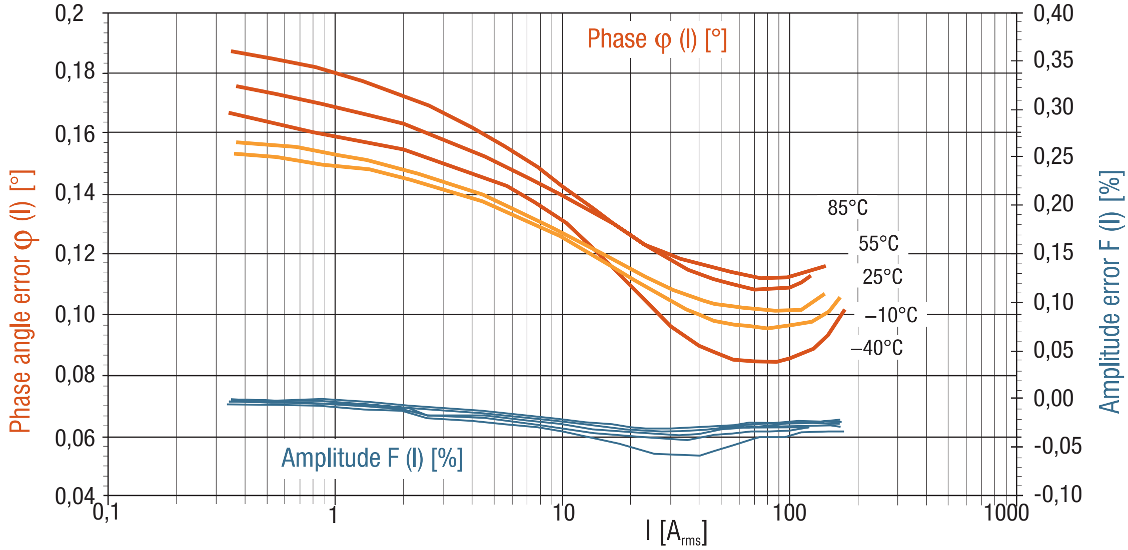


Fig. 16: 40 A, T60404-E4623-X002

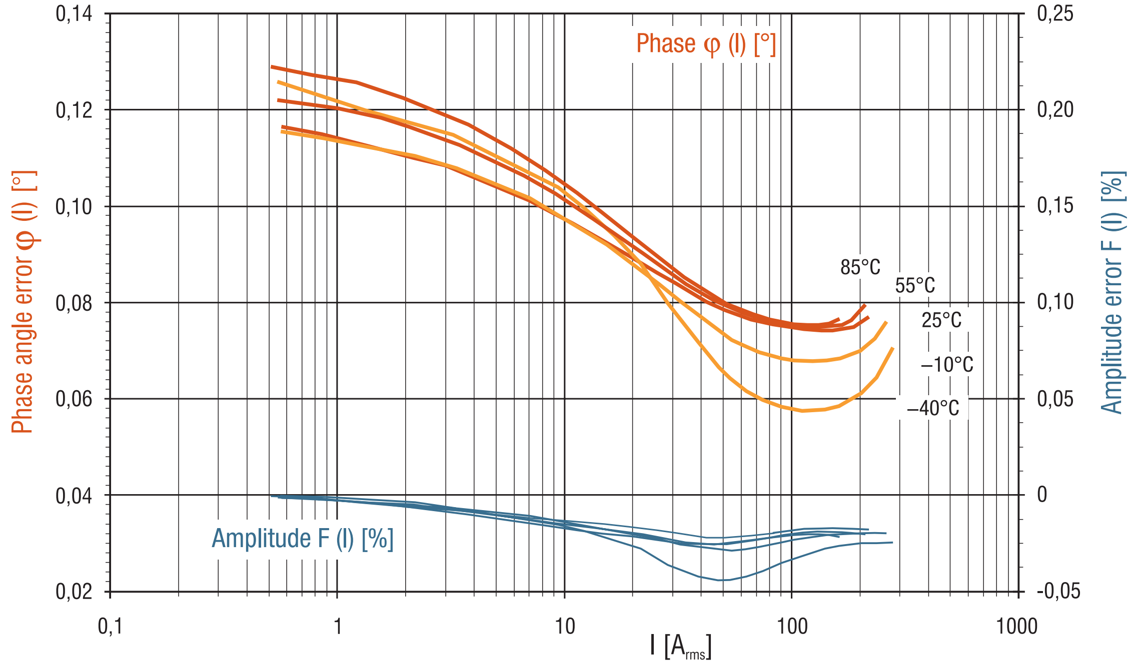


Fig. 17: 60 A, T60404-E4624-X002/-X502

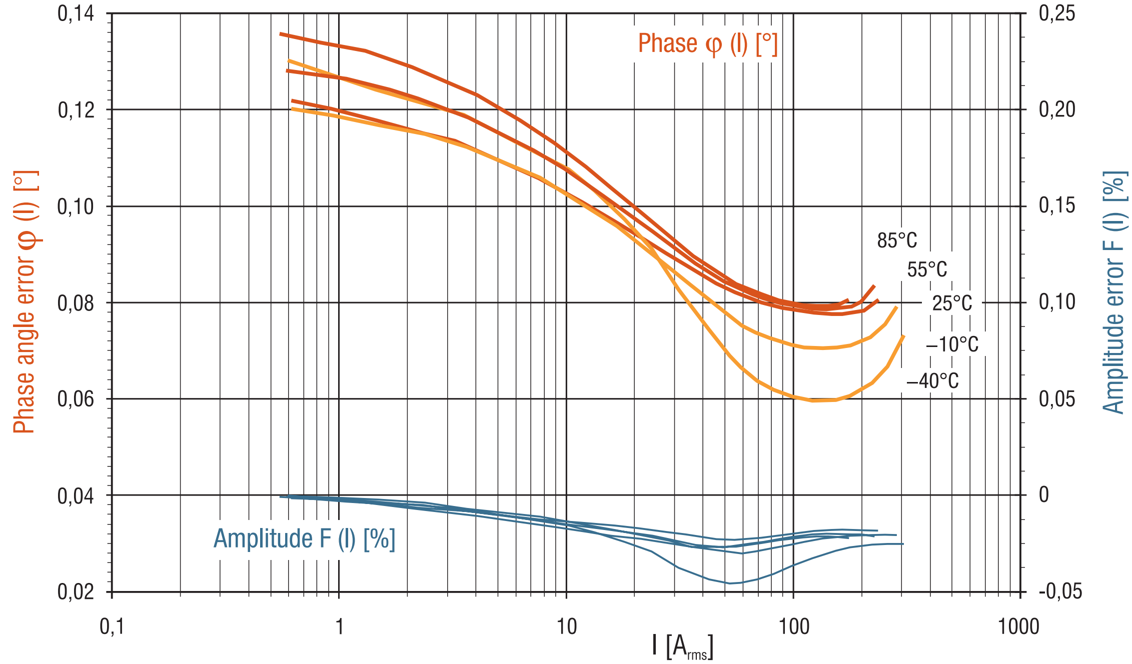


Fig. 18: 100 A, T60404-E4626-X002/-X502

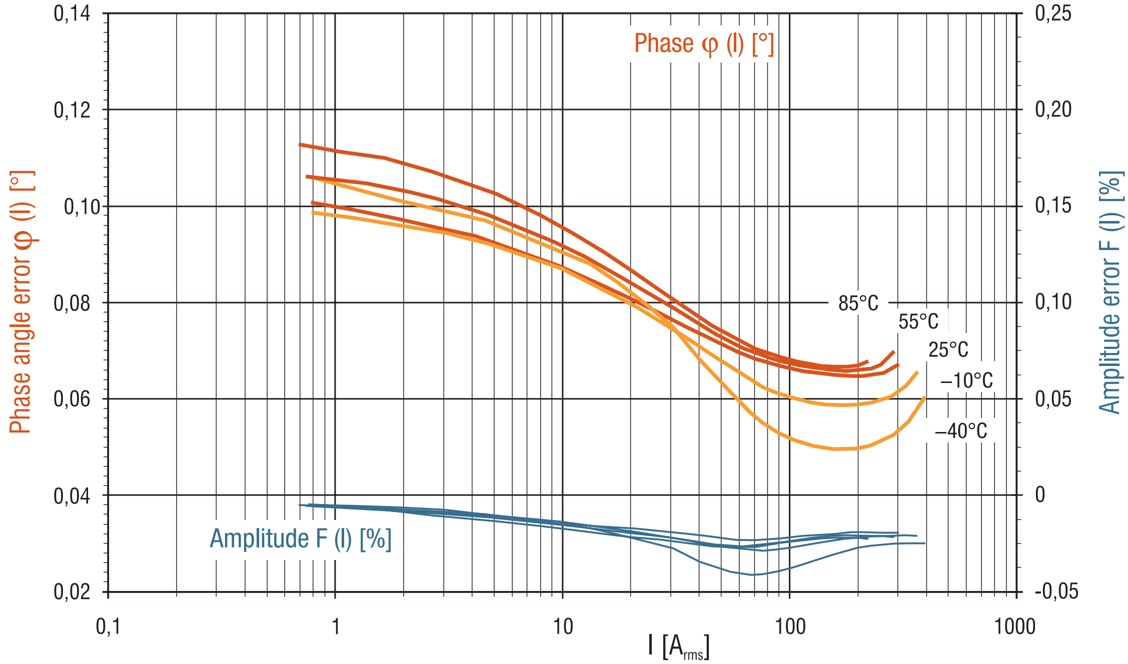


Fig. 19: 6 A, T60404-E4629-X007, 4622-X501, 4622-X011, 4622-X012

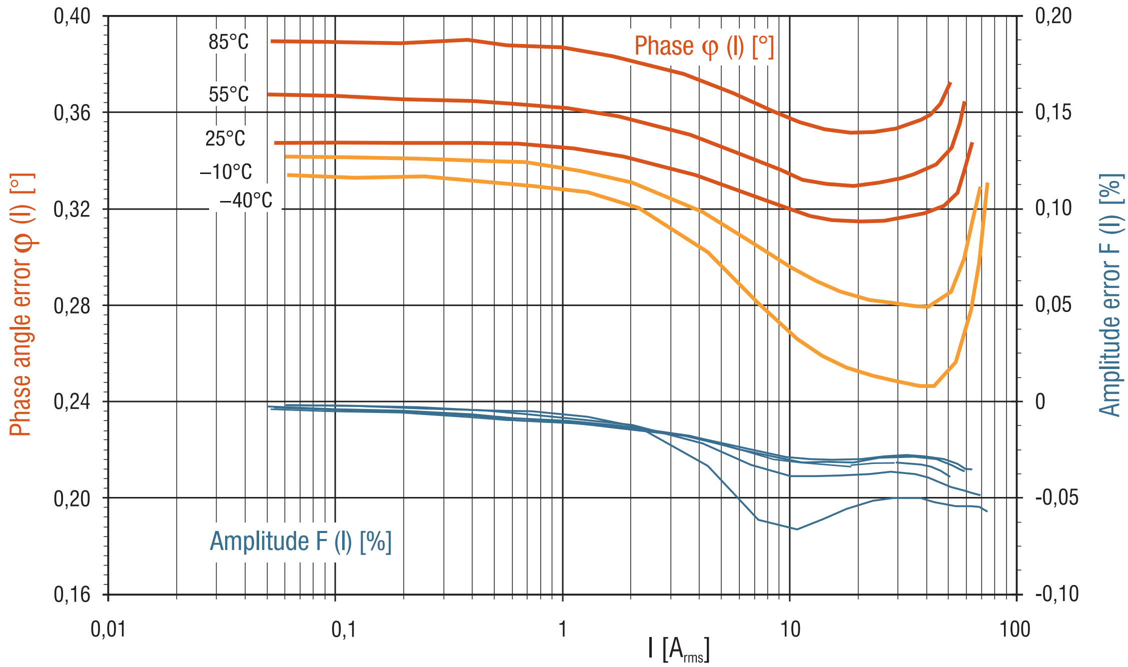


Fig. 20: 6 A, T60404-E4629-X010, 4622-X503

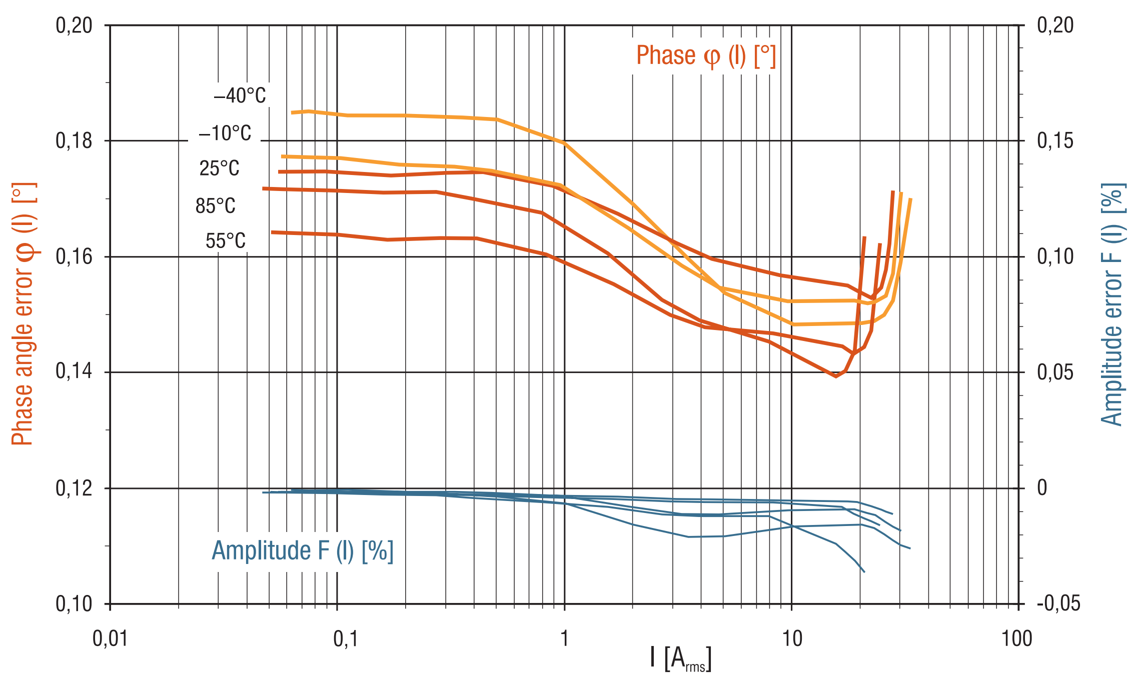


Fig. 21: 6 A, T60404-E4658-X043

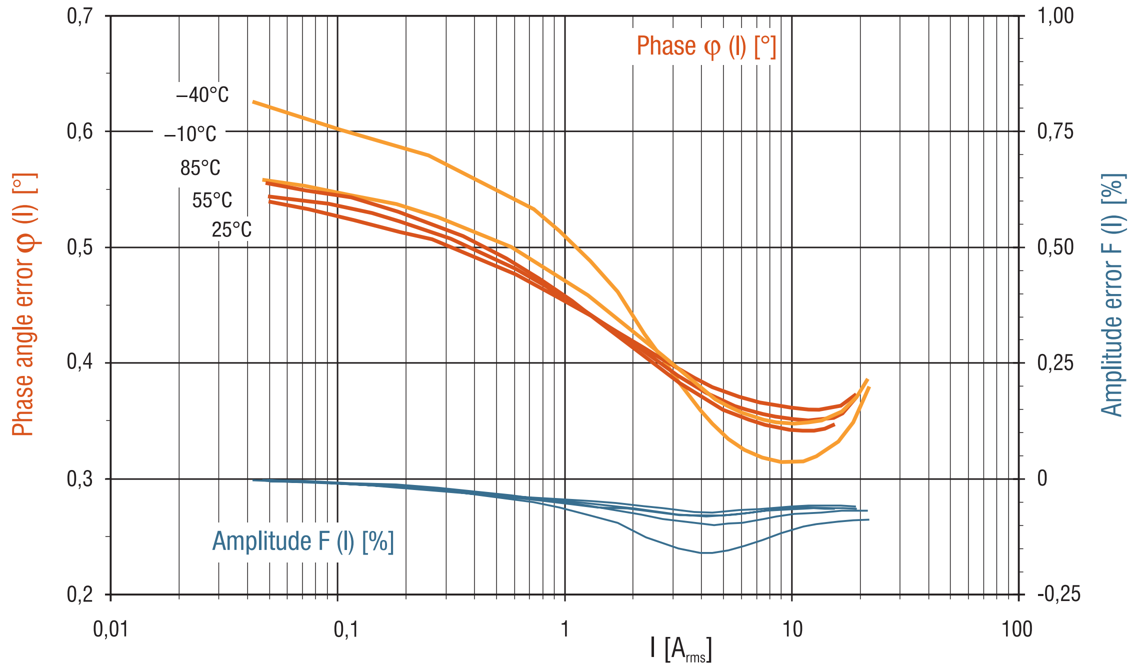


Fig. 22: 20 A, T60404-E4629-X007, 4622-X501

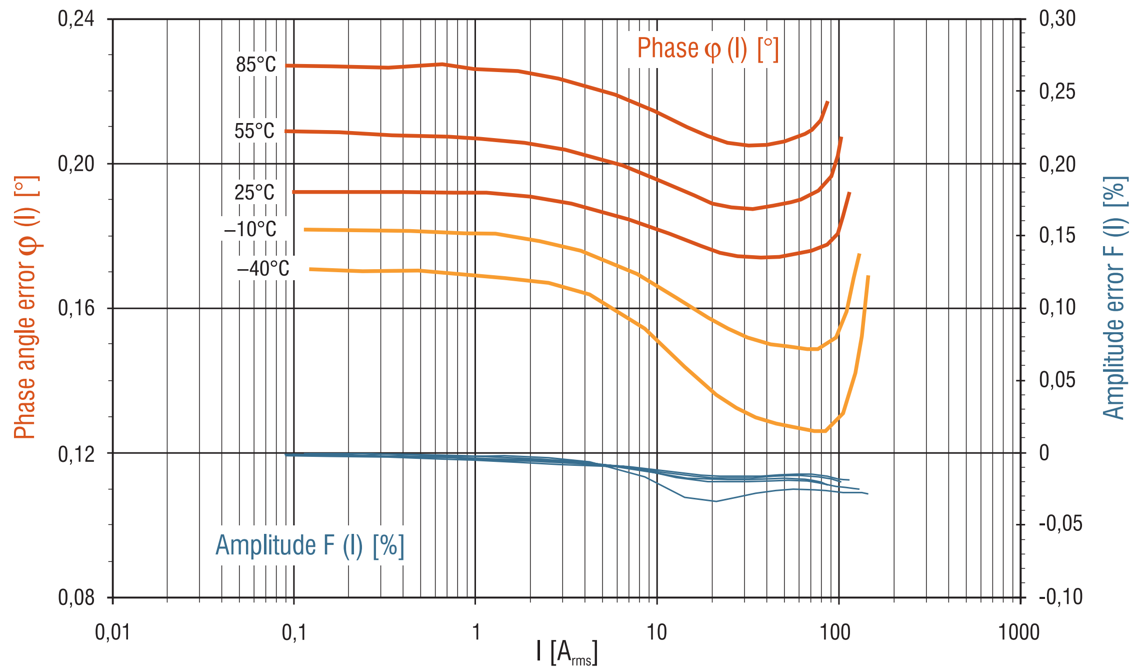


Fig. 23: 20 A, T60404-E4629-X010, 4622-X503

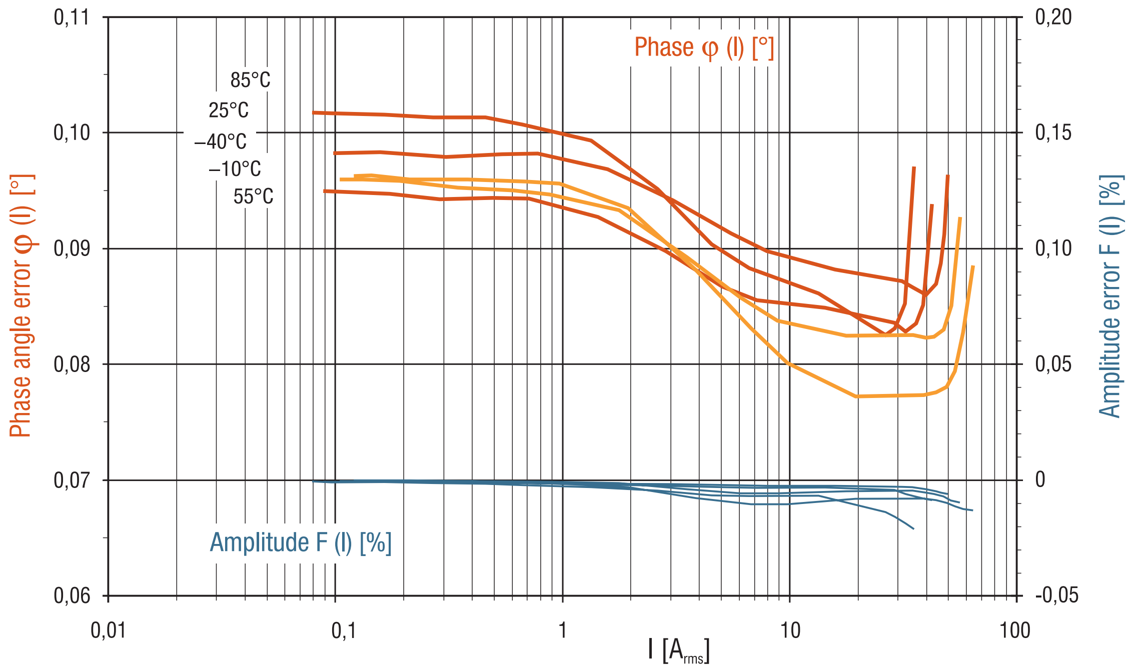


Fig. 24: 200 A, T60404-E4627-X001

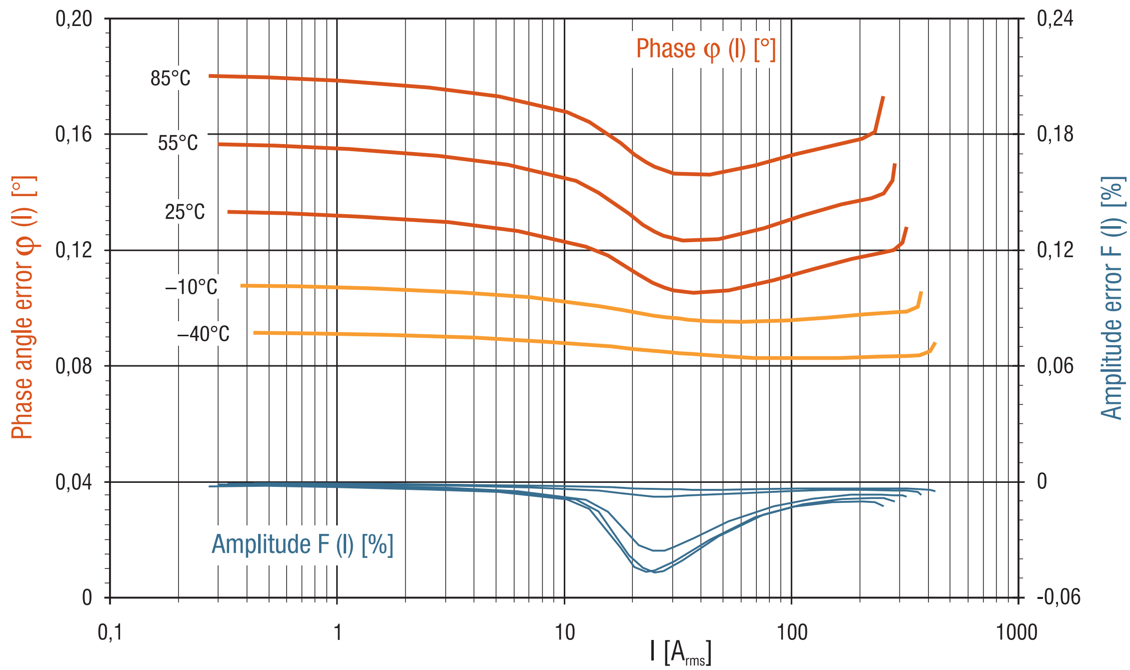


Fig. 25: 320 A, T60404-E4628-X001

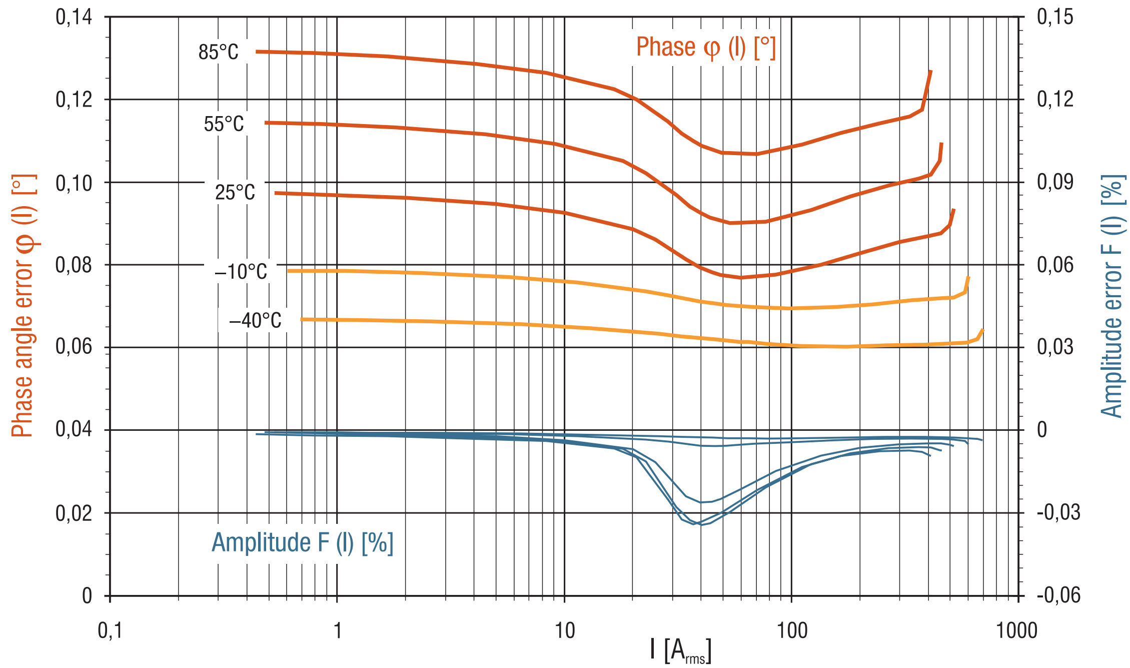


Fig. 26: 6 A, T60404-E4658-X039

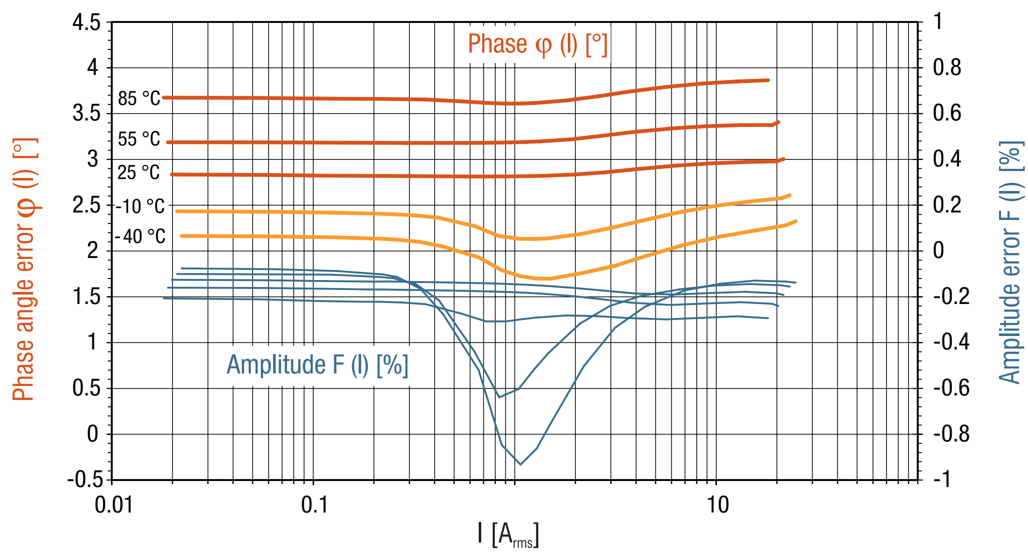


Fig. 27: 6 A, T60404-A4185-X037

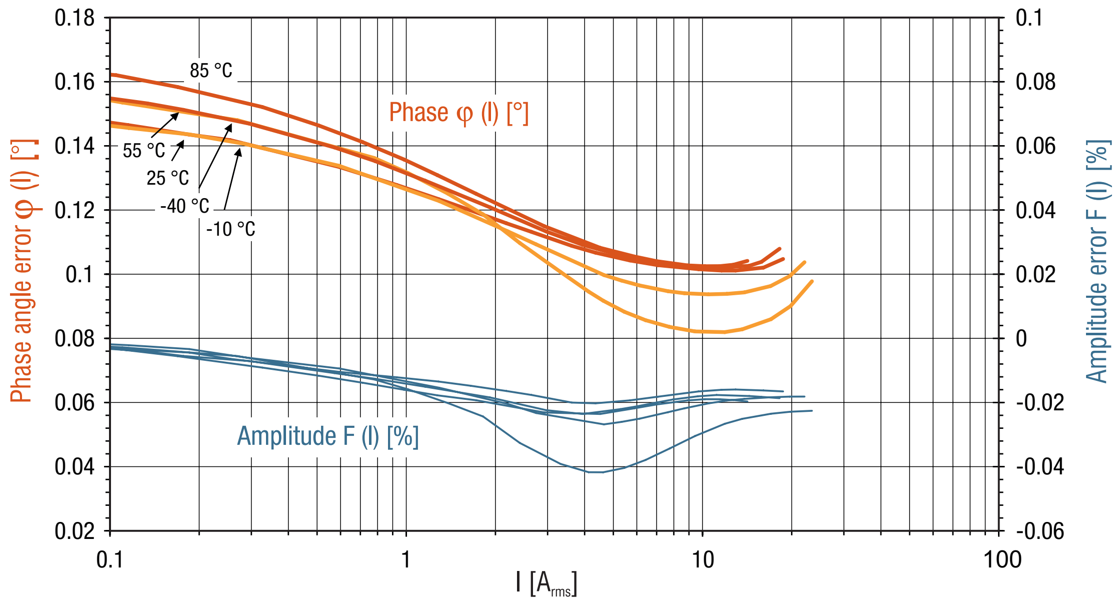


Fig. 28: 100 A, T60404-A4658-X034

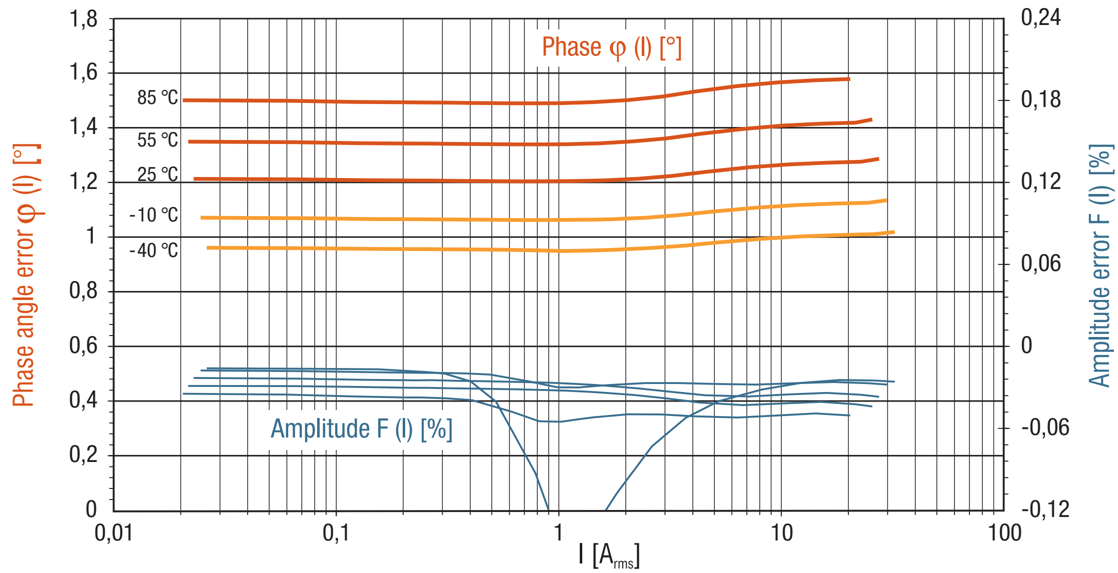


Fig. 29: 10 A, T60404-A4658-X037

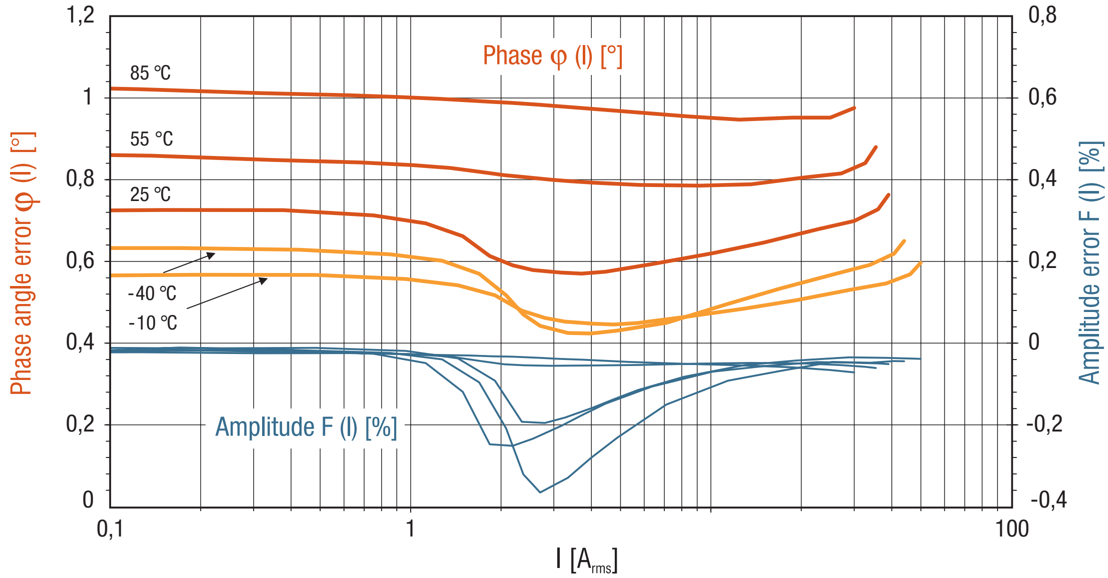
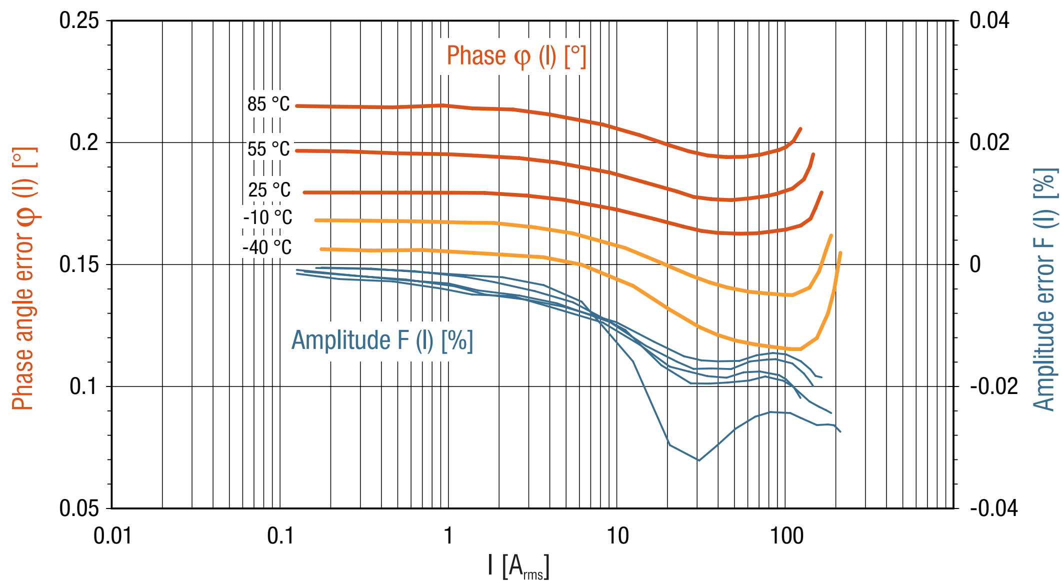
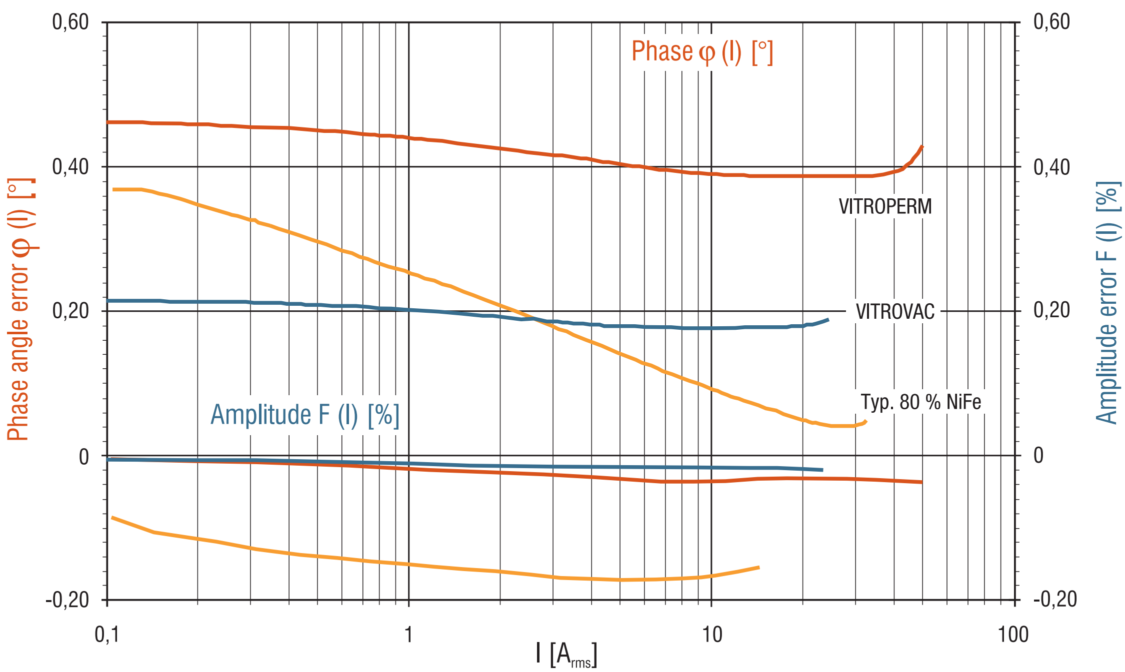


Fig. 30: 10 A, T60404-S4658-X051



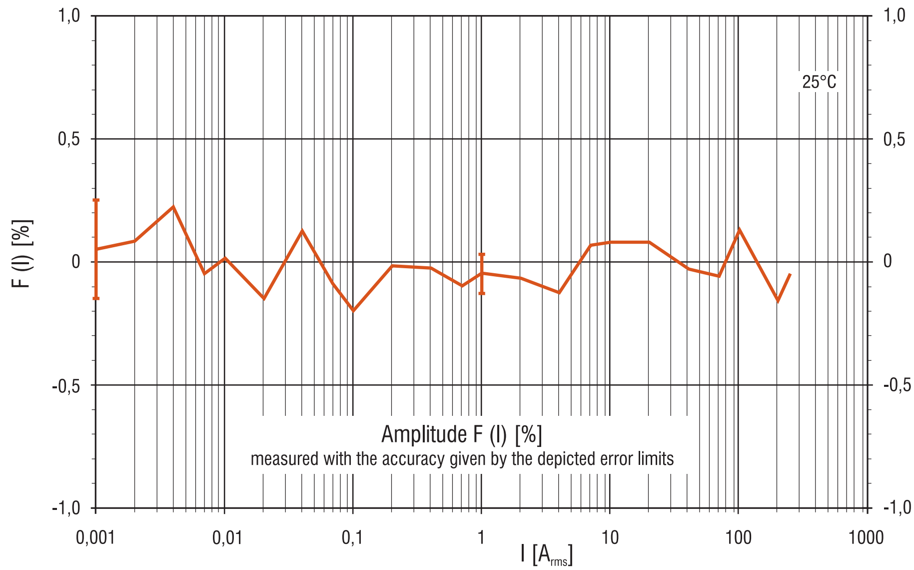
TYPICAL LINEARITY BEHAVIOUR OF DIFFERENT VAC CORE MATERIALS

Indirect connected / 6 A application



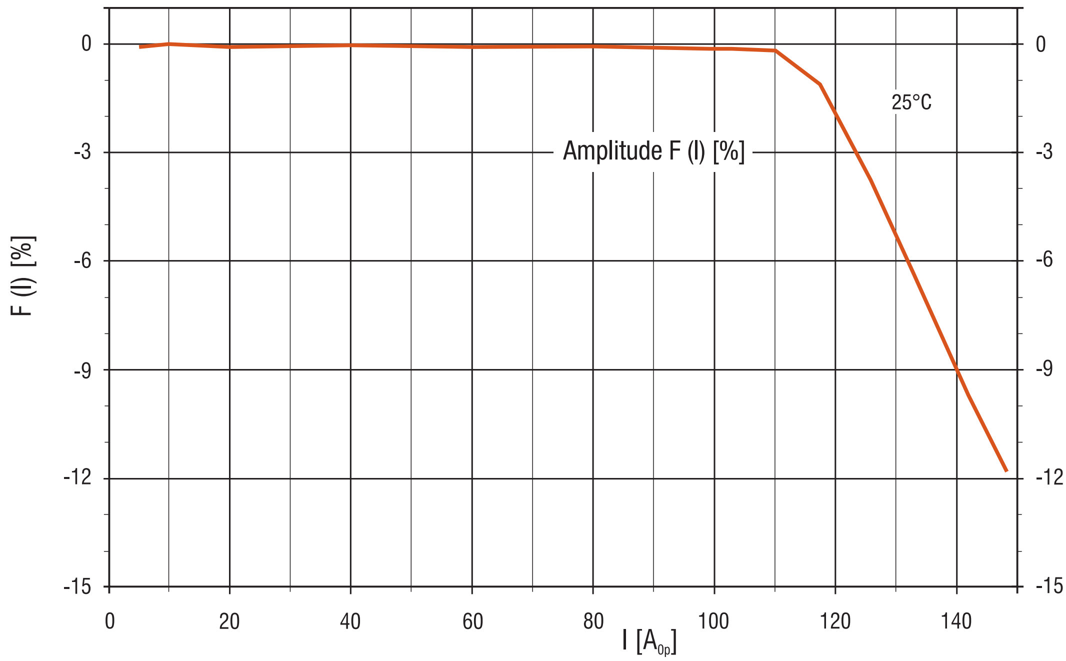
TYPICAL CHARACTERISTIC OF AMPLITUDE ERROR VS. PRIMARY CURRENT

100 A, T60404-E4626-X101



TYPICAL CHARACTERISTIC OF AMPLITUDE ERROR VS. UNIPOLAR (HALF-WAVE RECTIFIED) PRIMARY CURRENT

100 A, T60404-E4626-X101



APPENDIX

RECOMMENDATION: ENSURING THE MEASURING ACCURACY OF ELECTRICITY METERS

1. MEASURING SENSITIVITY FOR LOW LOADS

According to Table 6 of IEC 62053-21, the percentage error limits for meters of class 1 (balanced loads) are specified as follows:

Value of current for direct connected meters	Percentage error limits for meters of class 1
$0.05\, I_b <= I <= 0.1\, I_b$	+/-1.5 %
$0.1\, I_b <= I <= I_{max}$	+/-1.0 %

There are no limits specified in the low load range below $0.05\, I_b$ (e.g. for accurate metering of stand-by modes of electronic devices, low energy lamps…).

For the specification of meters with I_b=5 A and balanced loads (IEC) we therefore recommend supplementing these requirements by low load conditions as follows:

Current	Value of current for direct connected meters	Percentage error limits for meters of class 1
$0.05\,A <= I < 0.25\,A$	$0.01\, I_b <= I <= 0.05\, I_b$	+/-1.5 %
$0.25\,A <= I <= I_{max}$	$0.05\, I_b <= I <= I_{max}$	+/-1.0 %

This condition will ensure fair measuring accuracy in the low load range.

2. DC IN THE AC CURRENT CIRCUIT

According to Table 8 of IEC 62053-21 with respect to DC components, the limits of variation in percentage error shall be as follows:

Influence quantity	Value of current for direct connected meters	Power factor	Limits of variation in percentage error for meters of class	
			1	2
DC and even harmonics in the AC current circuit	$\frac{I_{max}}{\sqrt{2}}$	1	3.0	6.0

This condition does not represent realistic loading where very often an inductive load condition (power factor <<1) occurs simultaneously with the DC-content of the current waveform (e.g. hair-dryers, vacuum cleaners …).

We therefore recommend supplementing the DC tolerance requirements by inductive load conditions as follows:

Influence quantity	Value of current for direct connected meters	Power factor	Limits of variation in percentage error for meters of class	
			1	2
DC and even harmonics in the AC current circuit	$\frac{I_{max}}{\sqrt{2}}$	1 0.5 inductive	3.0	6.0

This condition will ensure reliable measuring accuracy independent from power factor and DC components.

3. IMMUNITY AGAINST EXTERNAL MAGNETIC FIELDS

According to Table 8 of IEC 62053-21, the immunity of meters against external magnetic fields shall be as follows:

Influence quantity	Value of current		Power factor	Limits of variation in percentage error for meters of class	
	for direct connected meters	for transformer operated meters		1	2
Continuous magnetic induction of external origin	I_b	I_n	1	2.0	3.0
Magnetic induction of external origin 0.5 mT	I_b	I_n	1	2.0	3.0

The conditions specified are adequate for normal environmental conditions.

In recent years years, the requirements concerning much stronger fields have been discussed by metering regulators to also consider potential tampering with meters. These requirements led to considerable efforts by meter manufacturers, e.g. encapsulation of the meter's susceptible components using magnetic shielding to minimise the effects of strong rare earth magnets.

However, it must be realised that not only permanent magnets, but also coils creating AC magnetic fields can potentially be used for tampering, and that ultimately any measurement principle, including the Ferraris meter, can be manipulated in one way or the other. Of course, counter-measures such as magnetic shielding are also available for each measurement method. In the long run, the competition between factors such as increasing magnet dimensions and increasing shielding efforts cannot be won by either of the parties involved, with the only real outcome being to increase meter costs significantly.

We therefore recommend introducing electronic means to detect tampering attempts and taking corresponding measures inside the meter's electronics and communication system, while retaining the specifications cited above for field immunity requirements.

For example, external magnetic influences of extreme field strengths, clearly indicating tampering attempts, could be detected by cost-effective electronic sensors and generate an alarm signal at the front panel. Additionally, the alarm status should be stored within the meter's data memory and, if a data exchange module is installed, communicated via the data interface to the data collection and evaluation site of the energy supplier.

VACUUMSCHMELZE GMBH & CO. KG
GRÜNER WEG 37
D 63450 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC MAGNETICS LLC
2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1 270 769 1333
FAX +1 270 769 3118
INFO-USA@VACMAGNETICS.COM

VACUUMSCHMELZE SINGAPORE PTE LTD
1 TAMPINES CENTRAL 5, #06-09
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS
SHANGHAI SALES OFFICE
ROOM 06, 19F
ZHONGRONG HENGRUI INTERNATIONAL PLAZA
620 ZHANGYANG ROAD, PUDONG DISTRICT
SHANGHAI, PRC 200122
PHONE +86 21 58 31 98 37
FAX +86 21 58 31 99 37
VAC_CHINA@VACUUMSCHMELZE.COM

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