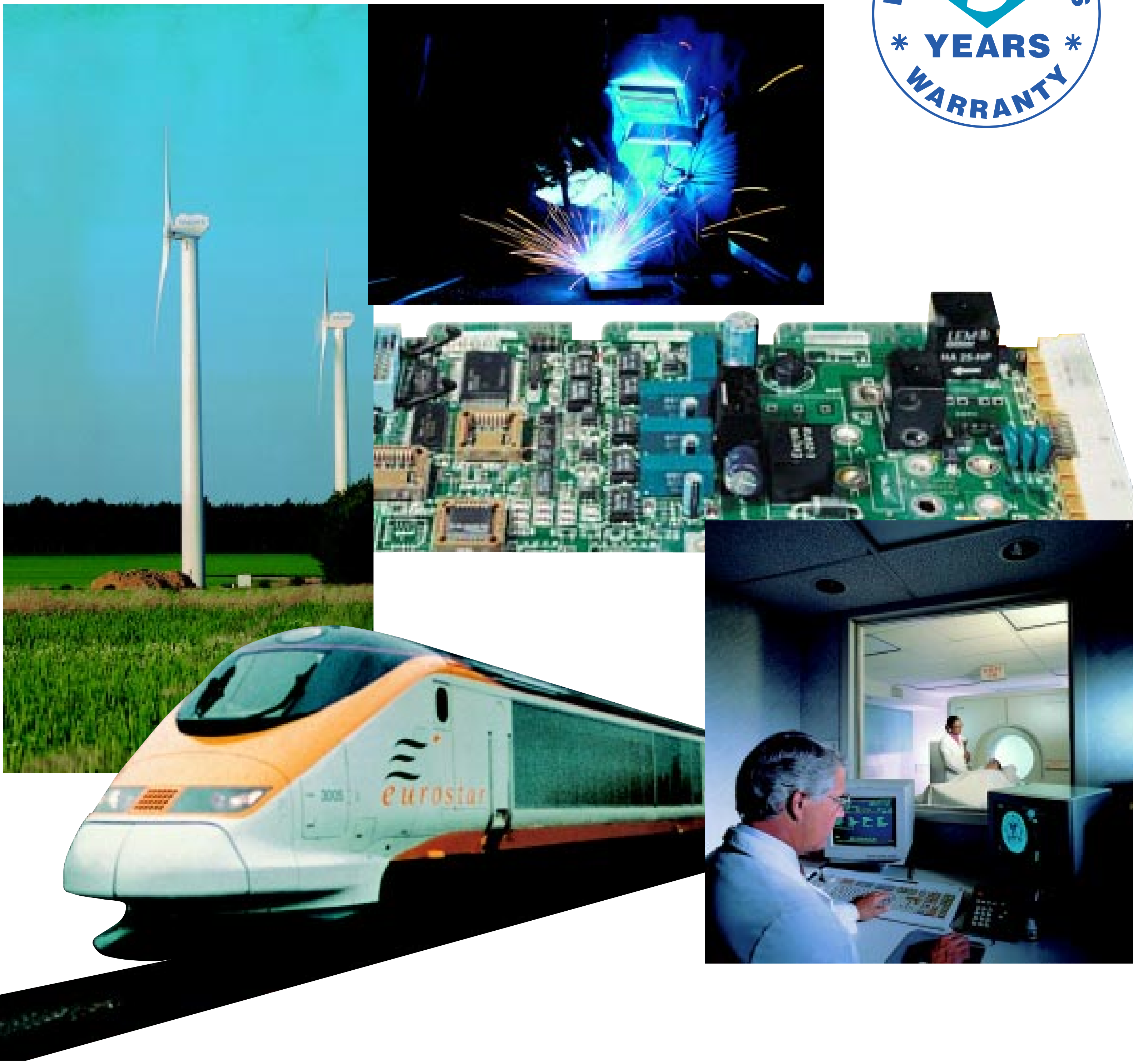
Isolated Current and Voltage Transducers

Characteristics - Applications
Calculations

LEM

LEM TRANSDUCERS 5 YEARS WARRANTY



The LEM Group today provides multidisciplinary know-how and solutions for power electronic measurements and tasks in key economic segments like Energy, Transportation, Industry, R&D, Engineering, Medical, Environment, Test Facilities, etc.

A total commitment to the quality of our products and services is a priority. Together with the best combination of understanding and competence, is this the only way to gain customer confidence and to guarantee long term partnership success.

Summary

Isolated Current and Voltage Transducers
Characteristics - Applications - Calculations

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1 Optimal solutions with 5 different technologies of LEM transducers

During its 25 years of existence (1972-1997), LEM has been able to respond to a number of specific demands, thus creating a wide range of galvanically isolated current and voltage transducers, which have become standards in the measurement field and the characteristics of which are clearly shown in the catalogue. The user may select from numerous models divided into 5 main groups for the measurement of current and voltage (Table 1):

- Open-loop Hall effect transducers
- Closed-loop Hall effect transducers
- C-type closed-loop transducers
- IT-type closed-loop transducers
- LEM-flex, flexible transducers for AC current.

The summary table hereafter and the detailed description of the typical characteristics of these technologies, make it easier to choose the most suitable transducer for each application.

Even though most of the applications will find their best solution with a standard transducer selected out of one of the 5 technologies mentioned, please contact your LEM specialist if your needs are not totally met. He will then propose a transducer, specific for your application.

Table 1. Overview of the various LEM transducer technologies with their corresponding main characteristics

Current measurement		**Hall effect open loop transducers**	**Hall effect closed loop transducers**	**C-type closed loop transducers**	**IT-type closed loop transducers**	**LEM-flex, flexible transducers for AC current**
Measuring range	I_P	0 - 18000 A	0 - 15000 A	0 - 150 A	0 - 600 A	0 - 60000 A
Bandwidth	f	0 - 25 kHz	0 - 200 kHz	0 - 250/500 kHz	0 - 100 kHz	8 Hz - 100 kHz
Typ. accuracy at 25 °C	X	±1 %	±0.5 %	±0.1 %	2 ppm	±1 %
Linearity		±0.5 %	±0.1 %	±0.05 %	1 ppm	±0.05 %
Response time	t_r	<3 - 7 µs	<1 µs	0.3...0.4 µs	0.3 µs	<50 µs
Operating temperature	T_A	-25 - +70 °C	-40 - +85 °C	-25 - +70 °C	-10 - +50 °C	-20 - +85 °C

Voltage measurement			**Hall effect closed loop transducers**	**C-type closed loop transducers**
Measuring range	V_P		0 - 9500 V	0 - 7000 V
Bandwidth	f		several kHz	0 - 400/700 kHz
Typ. accuracy at 25 °C	X		±1 %	±0.2 %
Linearity			±1 %	±0.05 %
Response time	t_r		10...100 µs	0,6 µs
Operating temperature	T_A		-25 - +70 °C	-25 - +70 °C

2 Determining parameters for transducer selection

The wide variety of the LEM transducer range is the direct result of our know-how and many years of experience. This enables us to respond to the specific problems of our customers within the greatly diversified application fields of power electronics.

2.1 Which parameters need to be considered?

The selection of a transducer is linked to parameters which are both technical as well as economic.

All aspects of an application must therefore be globally envisioned and taken into account. Among the technical parameters the following must be mentioned in particular:

- The electrical constraints
- The mechanical constraints
- The thermal constraints
- The environmental conditions

In the development phase of a product, when it has to be characterised, each parameter is tested, usually individually, without being combined with several others. As regards production control, a quality plan is set up, which indicates the tests to be carried out on each product so as to check its compliance. These tests, which are termed routine tests, are, unless otherwise specified, generally carried out at nominal current and within a laboratory environment, without constraints.

When the practical application is considered, it often is the case of a combination of several factors which must be evaluated in their totality, so as to select the appropriate product.

For example, the current to be measured is not the nominal current, the environment combines with magnetic, thermal and mechanical constraints, there are phenomena of transient overloads, etc..., thus an assembly of parameters which may influence the correct operation and the quality of the measurement.

2.2 Main selection criteria

For a simple application, namely in an environment which can be qualified as "clean", electrically, climatically and mechanically, one must first of all refer to the general catalogue of LEM transducers, which shows the various ranges of available products with their main characteristics in tabular form. The individual data sheet of each product will then inform you in greater detail of its characteristics.

The following parameters will guide you to a first sample of products which, among the various existing technologies, may prove satisfactory for you.

2.3 Additional selection criteria

For an application of higher complexity, involving a combination of various environmental elements, such as:

- Disturbed magnetic environment;
- Electro-magnetic interference;
- Fast transitory fronts generating important common mode voltage variations (dv/dt);
- Disturbances of mechanical origin (vibrations, shocks, etc..)
- Specific requests relative to a desired level of partial discharges;
- Compliance with specific standards;
- Others...

Additional information may be necessary to carry out your definitive selection.

It is therefore generally useful to supply us with a set-up diagram of your installation and the most detailed possible description of the operating conditions of your application (e. g. graph of the waveform of the signal to be measured, nearby disturbing elements such as inductances, other current carrying conductors, or other environmental conditions).

In this instance we have a standard specification sheet (see page 31), which you should fill out as well as other necessary information which would allow us to analyse your needs in greater detail.

Current transducers

Electrical parameters	Selection criteria
• Type of current to be measured: DC, AC or complex waveform current	• Adapted technology (see table 1) • Define the thermal or r.m.s. I_{PN} current to be measured
• Range of current to be measured	• Define the permanent peak current to be measured: Ip • Transient overloads to be measured: - Maximum peak value - Duration
• Required output signal	• Type: current, voltage • Value at I_{PN} , at $I_{pk\ max}$: define the necessary measuring resistor (for current output).
• Measurement accuracy	• Required accuracy at 25 °C Take into account the offset current or voltage (DC) + the non-linearity. • Global accuracy within the operating temperature range. Take into account the accuracy at 25 °C + the offset drift + the gain variation (if applicable).
• Available power supply	• Power supply voltage • Maximum allowable current consumption
• Isolation voltage	• Working voltage • Applicable standards defining either: - The necessary dielectric test voltage; - The rated voltage according to the specified pollution class.

Dynamic operating parameters	Selection criteria
• Frequency range	• Define the operating frequency range - Fundamental operating frequency - Superimposed switching frequency (if applicable) • Decide on the appropriate transducer technology
• di/dt correctly followed	• Define the response time and rise time in relation to the applied current slope (di/dt) • Define the di/dt overloads applied but not measurable which the transducer has to withstand. • Decide on the appropriate transducer technology

Environmental parameters	Selection criteria
• Operating, storage temperatures	• Define the effective temperature range for which the specified performances are applicable. • Define the storage temperature range

Mechanical parameters	Selection criteria
• Electrical connection of the primary circuit	• With through-hole: define the appropriate aperture depending on the conductor dimensions. • Bus bar dimensions • Other connections (screw terminals, etc..)
• Electrical connection of the secondary circuit	• Type of secondary circuit connection
• External dimensions	• Define the maximum dimensions required
• Fastening	• Type of appropriate fastening (printed circuit, on front panel)

Voltage transducers

Closed loop Hall effect transducers

Selection criteria are in their great majority identical to current transducers. Two types of design are available:

Without built-in resistor R_1

- These models are chosen when response time is the fundamental criteria to consider. Indeed the primary winding shall be designed with a minimum number of turns in order to reduce its primary inductance. On the other hand in order to obtain an optimum accuracy, the primary current will be higher in order to keep the nominal primary ampere-turns ($I_P \bullet N_P$) as specified for the model. For instance, LV100 model has 100 ampere-turns and LV 200 model has 200 ampere-turns.
- Adjustment of the output signal value: Calibration of the output signal value can either be carried out via the external resistor R_1 or by adjusting the measuring resistor.

With built-in primary resistor R_1

The transducer is composed of a complete unit together with R_1 + transducer:

Choice is made according to the nominal voltage to be measured and the measuring range which, for these devices of generally is 1.5 times the specified nominal voltage.

Electrical parameters	Selection criteria
● Measurement accuracy	● Consider value of the primary winding resistance and its variation with temperature, relative to the value of resistance R_1 (built-in or external).
● Maximum power allowed to dissipate in R_1	● Related to resistance R_1 and the primary current to be supplied to the primary winding.

Dynamic operating parameters	Selection criteria
● Frequency bandwidth or response time	● Depends on the L/R time constant of the primary circuit (Primary winding L_P and Primary resistance R_1).

Voltage transducers, C type

By principle the construction integrates the primary resistor. The number of primary amperes-turns is lower than for Hall effect closed loop transducers (for example: CV3 - .... means 3 ampere-turns).

Criteria leading to the choice of these transducers are:

- Higher frequency bandwidth or faster time.
- The low sensitivity to common mode voltage variations.
- Higher accuracy of measurement.
- The low power dissipation in the primary circuit.
- The low sensitivity to external magnetic fields.

3.1 Introduction to the Hall effect

Both the open loop and the closed loop transducers use the Hall effect, which was discovered in 1879 by the American physicist Edwin Herbert Hall, at the John Hopkins University in Baltimore. The Hall effect is caused by the Lorentz force, which acts on the mobile electrical charge carriers in the conductor, when they are exposed to a magnetic field that is perpendicular to the current direction.

A thin sheet of semiconductor material is traversed lengthwise by a control current I_C (Fig. 1). The magnetic flux B generates a Lorentz force F_L perpendicular to the direction of the mobile charge carriers composing the current. This causes a change of the number of charge carriers at both edges of the sheet, thus creating a potential difference referred to as Hall voltage V_H.

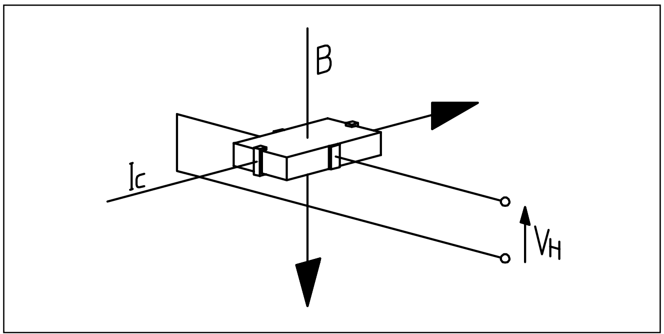

Fig. 1 Representation of the electrical parameters of the Hall effect

For the arrangement, described above, with a magnetic field perpendicular to the current, we obtain:

$V_H = (K/d) \bullet I_C \bullet B$

where K is the Hall constant for the material used, and d the thickness of the thin sheet. Such an arrangement is referred to as Hall generator.

The Hall effect generators show a certain dependence of the Hall sensitivity and the offset voltage V_{OT} on temperature, which can, however, be greatly compensated by the electronic circuit of the current transducer.

3.2 Hall effect open loop current transducers

3.2.1 Construction and principle of operation

The open loop transducers use the Hall effect. The magnetic induction B, contributing to the rise of the Hall voltage, is generated by the primary current I_P to be measured. The control current I_C is supplied by a constant current source (Fig. 2).

Within the linear region of the hysteresis cycle, B is proportional to I_P ($B_{air\ gap}$ = constant (a) $\bullet$ I_P).

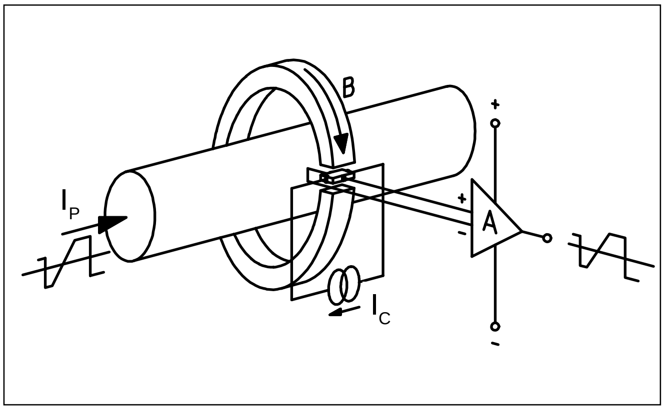

Fig 2 Conversion of the primary current into an output voltage

The Hall voltage is thus expressed by:
$V_H = (K/d) \bullet I_C \bullet \text{constant (a)} \bullet I_P$

Except for I_P, all terms of this equation are constant.
Therefore: $V_H = \text{constant (b)} \bullet I_P$
The measurement signal V_H is amplified to supply the user output voltage or current.

Current ranges
The LEM transducer range permits measurement of nominal currents I_{PN} reaching from several Amperes to several tens of kA with an overall accuracy of a few percent.

Advantages and limitations
The open loop transducers are capable of measuring DC, AC and complex waveform currents with galvanic isolation. They stand out by their low power consumption and their reduced size, as well as low weight, in particular for the high current range. They involve no insertion losses in the circuit to be measured and they are particularly resistant to current overloads. They are relatively low priced and, in general, well suited to industrial applications.

3.2.2 Characteristics and features

Measurable current range
It is defined by the linear region of the magnetisation curve of the magnetic circuit (Fig. 3)
Generally, the measurement range varies, according to the type, from 1 to 3 times the nominal current.

Output signal
This voltage is directly proportional to the measured current. The available voltage level depends on the supply voltage. Generally the output voltage V_{out} is 4 V at the nominal current I_{PN}. Current output versions are also available.

Measurement accuracy
Accuracy depends on various factors such as electrical parameters or parameters linked to the environment conditions (ambient temperature, etc.).

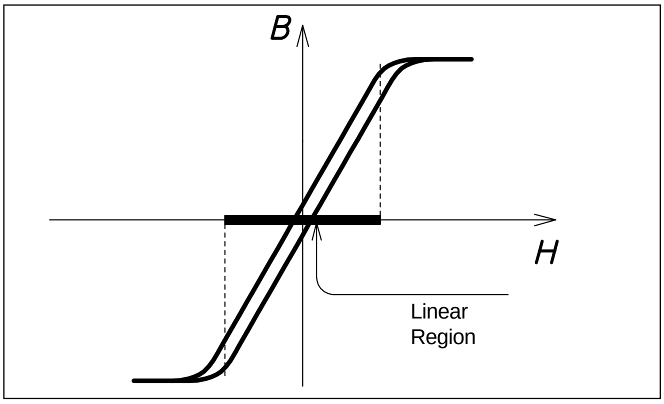

Fig. 3 Magnetisation curve

Factors determining the accuracy

at ambient temperature:
- Offset voltage DC at $I_P = 0$
- Loop gain
- Linearity

depending on the operating temperature:
- Offset drift
- Gain variation

Note: The transducers are factory-calibrated at an ambient temperature of 25 °C and at nominal current.
The accuracy at ambient temperature shown in our data sheets thus takes these adjustments into account.

Dynamic behaviour

Frequency response
The limitations are mainly due to two factors:
a) Electronic circuit bandwidth which depends on the type of amplifier used and the internal compensation circuits.
b) Core heating is due to eddy current and hysteresis losses at higher frequencies.

The losses due to eddy current depend on:
e^2 (thickness of the metal sheets), B^2 (peak magnetic induction), f^2 (frequency).

The losses by hysteresis are proportional to f (frequency) and to B^2 (peak magnetic induction). The energy dissipated by hysteresis corresponds to the surface of the B-H cycle of the material.

For a troublefree operation of the open loop current transducers it is therefore necessary to limit the temperature rise, in order to avoid an overheating of components used in the transducer.

To define the operating limits in a simple way, we have considered the «current x frequency» product. In practice this is the product:

$I_P \cdot N_P \cdot f$
with
I_P = primary current in A
N_P = number of primary turns
f = signal frequency in Hz

For "through-hole" types of open loop transducers $N_P = 1$ and the product:

$I_P \cdot f$ is usually ≤ 400 000

within the temperature limits indicated in the data sheet, using this value does not cause any unacceptable temperature rise.

For the series HA.. and HY.., where the primary conductor is already integrated in the transducer, the current in this conductor also generates an additional temperature increase.

Our product characterisation file provide derating curves, which takes into account the combined phenomena (Eddy current and heating of the primary coil) at a given operating temperature.

Hereafter is an abstract of data coming from tests results obtained with the transducer HY10-P

The product $I_P \cdot f$ is the following

at T_A = 25 °C

I_P	$I_P \cdot f$	f_{max}
10 A	130 000	13 kHz
6 A	198 000	33 kHz
2 A	680 000	340 kHz

at T_A = 70 °C

I_P	$I_P \cdot f$	f_{max}
10 A	59 000	5.9 kHz
6 A	72 000	12 kHz
2 A	180 000	90 kHz

Note: In practice the frequency bandwidth of the amplifier must of course also be taken into consideration to actually measure the current at the given frequency.

Dynamic behaviour

Response time and di/dt behaviour
LEM defines the response time by the delay between the instant the primary current reaches 90 % of its final value and the moment the output signal reaches 90 % of its final amplitude (Fig. 4).

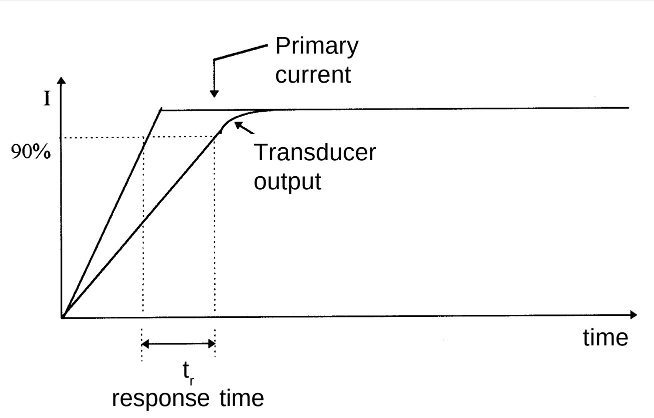

Fig. 4 Definition of the response time

For the open loop transducers the response time and the di/dt correctly followed depend on the slew rate of the amplifier used. The assembly configuration of the transducer within the circuit to be measured can also influence the dynamic behaviour.

The dynamic behaviour of the current transducers has been measured in the laboratory with a digital oscilloscope, for a nominal primary current and a di/dt of 50 A/µs.
The response time obtained is < 3 µs. Figure 5 shows the result obtained with the HAL 600-S transducer.

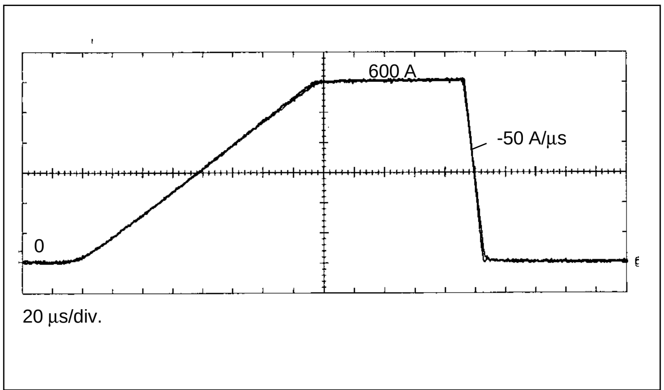

Fig. 5 Dynamic behaviour of the HAL 600-S transducer at 600 A and a -di/dt of 50 A/µs

3.2.3 Typical applications

The open loop current transducers are used in numerous industrial applications, where they provide display, regulation and control of the currents.

Among the typical applications we find:

- Frequency converters and 3-phase drives for current control of the output phases.
- Electric welding equipment, for the control of the welding current.
- UPS and other equipment operating with batteries for the control of charge and discharge current.
- Electric vehicles, in traction converters and battery current control.
- Electric traction systems, trackside circuit breaker and rectifier protection, rolling stock traction converters and auxiliaries.
- Other applications include energy management systems, switching power supplies, electrolysis equipment.

3.2.4 Calculation of the measurement accuracy

As indicated previously, the accuracy indicated in the data sheets applies to the nominal current I_{PN} at an ambient temperature of 25 °C.

The total error to be considered for the application comprises the offset voltage, the non-linearity and the temperature effects.

The theoretical maximum corresponds to the sum of the individual maximum errors, but in practice it is rare that all the errors are additive.

In the examples that follow and in order to simplify the calculations, we take for granted that the power supplies are perfectly stabilised and that the residual magnetism (see below) is negligible.

Example: Current transducer HAL 200-S

A current of 200 A has to be measured at an ambient temperature of +70 °C. The data sheet indicates the output voltage is 4 V at the nominal current of 200 A.

Current to be measured I_P = 200 A
Value (V) / Accuracy in %

At an ambient temperature of 25 °C:		
a) offset voltage DC at I_P = 0	10 mV max	
b) gain adjustment	factory adjusted	
c) non-linearity	at 25 °C	
Total error at 25 °C (includes a+b+c)	±40 mV	±1 %
Depending on operating temperature (from 25 °C to +70 °C)		
d) offset drift: 1 mV/K max.	±45 mV	±1.13 %
e) gain drift: 0.05 % of reading/K	±90 mV	±2.25 %
Maximum global error	**±175 mV**	**±4.38 %**

Considerations on the magnetic offset
Depending on the type of transducer and the magnetic material used, an error could be added to the ones mentioned above. It is due to the residual magnetism (remanence) which induces an offset that we may qualify as magnetic offset, the value of which depends on the magnetisation state of the magnetic circuit. This error is maximum when the magnetic circuit has been saturated. This might happen in case of high current overload conditions.

As an example, measurements carried out on the HAL, HAK and HTA types of transducers give the following results. After a cycle of current varying from 0 to 3 • I_{PN} then back to zero, the magnetic offset is 2.5 mV for HAL transducers and 3 mV for HAK and HTA transducers (<0.1 % of I_{PN}).

3.3 Hall effect closed loop current transducers

The closed loop transducers (also called compensation or zero flux transducers) have an integrated compensation circuit by which the performance of the current transducers using the Hall effect can be markedly improved.

3.3.1 Construction and principle of operation

Whereas the open loop current transducers give a V_{OUT} output voltage proportional to the amplified V_H Hall voltage, the closed loop transducers supply a secondary current I_S proportional to V_H which acts as counter-reaction signal in order to compensate the induction created by the primary current B_P by an opposed secondary induction B_S.

The secondary current I_S, reduced by the turns ratio, is much lower than I_P, because a winding with N_S turns is used to generate the same magnetic flux (ampere-turns). One thus selects:

$N_P \bullet I_P = N_S \bullet I_S$

The B_S induction is thus equivalent to B_P and their respective ampere-turns counter-balance each other (compensate). The system thus operates at zero magnetic flux (fig. 6).

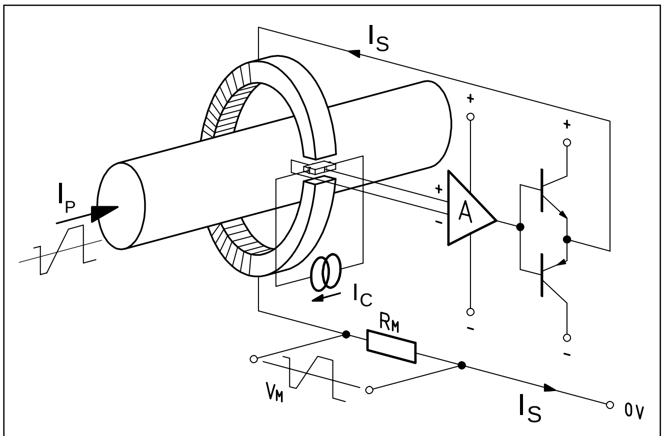

Fig. 6 Operating principle of the closed loop transducer

Let us take as an example the measurement of a DC current of 100 A. The number of turns N_P = 1, because the conductor leads directly into the magnetic circuit, thereby constituting a single turn. The secondary winding has N_S = 1000 turns. The turns ratio is thus 1:1000.

As soon as I_P takes a positive value a B_P induction appears in the air gap of the magnetic core, producing a V_H voltage in the Hall element. This voltage is transformed into a current by way of a current generator the amplifier stage of which supplies the I_S current flowing through the secondary winding. The B_S induction is thus created which compensates the B_P induction.

The resulting secondary current is thus:

$$I_S = \frac{N_P \bullet I_P}{N_S} = \frac{1 \bullet 100}{1000} = 100 \text{ mA}$$

I_S is thus the exact image of I_P. This is the measurement current intended for the user.

Current ranges
The range of the closed loop LEM transducers permits measurement of I_{PN} nominal currents from a few amperes to several tens of kA, with an accuracy of about 1 %.

With the devices produced by our LEM DynAmp subsidiary, which use the same technology, it is possible to measure very high currents up to 500 000 A.

Advantages and limitations
The closed loop transducers are capable of measuring DC, AC and complex waveform currents with galvanic isolation. They stand out by their:

- Excellent accuracy.
- Very good linearity.
- Low temperature drift.
- Very fast response time and wide frequency bandwidth.
- They do not produce any insertion losses in the circuit to be measured.
- Their current output is specially useful for applications in a noisy environment. Furthermore, if necessary it is very easy to convert the signal into a voltage.
- They withstand current overloads without damage.

These transducers are particularly well suited for industrial applications which require high accuracy and wide frequency bandwidth performance. The main limitations of this technology involve mainly the consumption of the power supplies which must provide the compensation current. Furthermore, for the high current ranges, they are more expensive and bulkier than their open loop technology equivalents.

Nevertheless, because of the use of modern production means and due to LEM's expertise in this field, these transducers are now quite cheap, particularly for the range of low currents.

3.3.2 Characteristics and features

Measurable current range:
As they operate with a practically zero flux (in practice low leakage magnetic flux exists), these transducers have an excellent linearity over a wide measuring range. The latter is defined by the capacity of the power supply voltage to provide the secondary current, taking into account the internal voltage drops of the transducer and in the measuring resistor.

Furthermore, this type of transducer can in fact measure a higher current value than the one limited by the parameters indicated above which define the normal measuring range. The high transient currents, which however must (for thermal reasons) be of short duration, can indeed be measured. The transducer operates in this case like a current transformer. Considerations, such as a good magnetic primary/secondary coupling, must of course be taken into account when mounting the transducer, in order to obtain satisfactory results. This is why the data sheets do not show a value in this respect, because every application must be studied specifically; it is therefore advisable to consult us in order to carry out the necessary tests.

Output signal - Load resistance
At the output, the transducer supplies a secondary current which is the counter-reaction current. This current can be transformed into a voltage thanks to a load resistance called the measuring resistance.

The value of the measuring resistance must be situated within the range shown in the catalogue; meaning: comprised between the $R_{M\ min}$ resistance (defined in order to respect an adequate power dissipation of the electronic circuit) and the $R_{M\ max}$ resistance (defined to avoid the electronic saturation of the circuit, taking into account the minimum available supply voltage and which determines the maximum measuring range).

It must be noted that in the data sheet we have indicated the R_M values corresponding to the permanent nominal rating and a given measuring range. Other conditions can be determined, of which you will find some examples in the § 3.3.4.

Measurement accuracy
Accuracy depends on several factors to be taken into account, depending on the type of measurement to be carried out. Whether they are the electric parameters (AC, DC, industrial frequency or complex waveform with high frequency currents, etc...) or the parameters linked to the environment conditions (ambient temperature, etc...).

Factors determining the accuracy:

At ambient temperature:
- the DC offset current at $I_P = 0$
- the non-linearity.

Depending on the operating temperature:
- the offset drift.

Dynamic behaviour

Frequency operation
The measurements carried out on the closed loop transducers show an excellent frequency response. This bandwidth is due to two phenomena. For the DC current and the low frequencies, the electronics with the Hall-element is determining. In the high frequency regions the transducer operates as a current transformer (Fig. 7). The minimum high frequency limit for most of current transducers is equal to 100 kHz. Some models even reach a bandwidth of 150 to 200 kHz.

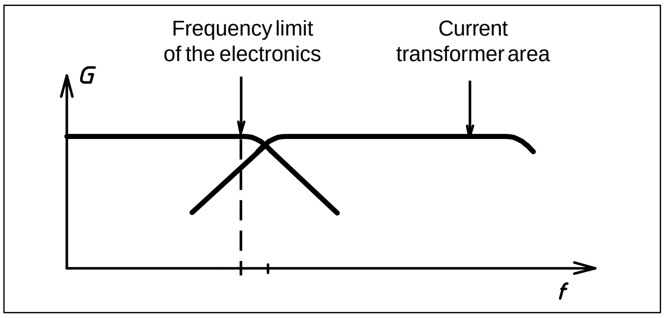

Fig. 7 If the frequency is increased, the closed loop transducer then operates as a current transformer.

Thanks to the combined optimisation of the bandwidth of the electronic circuit and the frequency bandwidth of the current transformer it is possible to cover these two frequency regions, providing high accuracy over the product's whole frequency bandwidth. LEM has thus created a special product range, the principle of which is patented, the LB transducer series. Their frequency bandwidth has been linearised and extended to over 300 kHz.

Response time and di/dt behaviour
The response time to a current step is defined by several parameters among which are the reaction time, the rise time and the delay time (see glossary in chapter 9). The response time (see Fig. 4) is comparable to the delay time which also characterises the correct following of the transducer with the di/dt to be measured.

For the closed loop transducers the reaction time is below 1 µs. The correct following of di/dt depends on the intrinsic construction of each product and of the assembly configuration of the transducer within the circuit to be measured. The closed loop transducers are capable, according to the models, of measuring di/dt's of some 50 A/µs up to several hundreds of A/µs. This is why they are also used for the protection of semiconductors in the case of short-circuits in power equipment.

3.3.3 Typical applications

Closed loop current transducers are used in a number of industrial applications, where they provide the measurement, display and control of currents.

Among typical applications are the following:

- Frequency converters and three-phase drives for the current control in the phases and in the DC bus, for protection in case of short-circuits.
- Converters for servo-motors frequently used in robotics.
- Electric welding equipment for the control of the welding current.
- UPS and other equipment operating with batteries, for the control of charge and discharge currents.
- Electric vehicles, in the traction converters and the control of the battery current.
- Electric traction systems, whether in traction converters and auxiliaries or in the sub-stations.
- Converters for windmills.
- Special power supplies for radars.

Other applications can also be named, such as

- energy management systems, switching power supplies, lasers, rectifiers for electrolysis.
- There are also many applications for laboratories or for test and control benches.

3.3.4 Examples of calculation and dimensioning

The following examples are intended to help the user to estimate, according to his application, the limits of operating values of the closed loop current transducers and to calculate the adequate measuring resistor to be used.

1st example: Closed loop transducer LA 55-P

a) Which maximum measuring voltage can be obtained with the following parameters?
$\hat{I}_P = 70$ A, $T_A = 70$ °C, $V_C = \pm 15$ V

The turns ratio of 1:1000 determines the secondary current
$\hat{I}_S = 70$ mA

The catalogue/data sheet indicates
$R_M = R_M$ max = 90 Ω. Where from results a maximum measuring voltage of:
$V_M = R_M \bullet \hat{I}_S = 90\ \Omega \bullet 70\ \text{mA} = \mathbf{6.3\ V}$

b) Which load resistance must be selected for the following parameters in order to obtain a measuring voltage of 3.3 V for the nominal primary current?
$I_P = 50$ A, $T_A = 85$ °C, $V_C = \pm 12$ V; $I_S = 50$ mA

For the given parameters the data sheet recommends a measuring resistance comprised between
R_M min. = 60 Ω and R_M max. = 95 Ω

$R_M = V_M/I_S = 3.3\ \text{V}/50\ \text{mA} = \mathbf{66\ \Omega}$
This value can thus be used.

c) For the same parameters as in b), can one obtain a measuring voltage of 6 V?

$R_M = V_M/I_S = 6\ \text{V}/50\ \text{mA} = 120\ \Omega$

As the measuring resistance exceeds the acceptable R_M max. value, when using the calculated resistance the 50 A current will not be measured. The acceptable R_M max. resistance of 95 Ω supplies a maximum measuring voltage of **4.75 V.**

d) What is the available voltage at the amplifier output which will allow to supply the maximum secondary current**,** thus determining the measurable current range?

The indications in the data sheet take into account the internal voltage drop, which is constituted by one of the final electronic stage $V_{CE(sat)}$ and the one on the resistance of the secondary winding R_S (Fig. 8).
The tolerance of the supply voltage must also be considered, in order to ensure that the secondary current will be supplied in all cases.

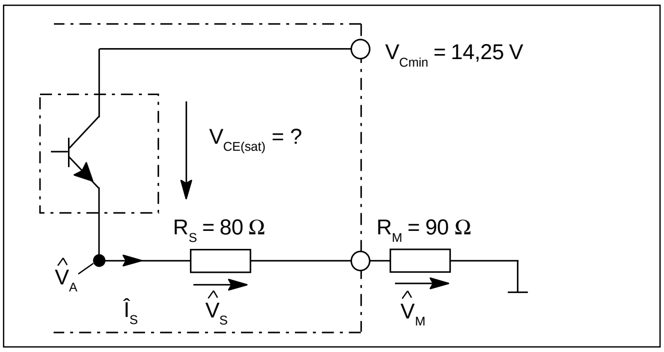

Fig. 8 Equivalent diagram for calculation of the available voltage V_A on the final stage of the amplifier.

The voltage available at the amplifier output (V_A) must first of all be determined, which will allow to calculate the voltage drop in the secondary winding and in the measuring resistance. $\hat{V}_A = (R_S + R_M\ \text{max.}) \bullet \hat{I}_S$

For this calculation the indications of the data sheet will be used, which are given for the specified operating conditions.

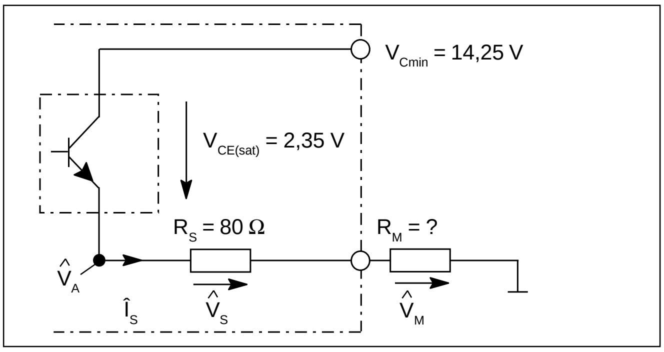

Fig. 9 Equivalent diagram to calculate the measuring resistance R_M

The data sheet of the LA 55-P transducer indicates:

- on the line noted: Measuring resistance
  With ±15 V, at 70 A max. and at +70 °C: $R_{M\ Max}$. = 90 Ω
- on the line noted: Secondary internal resistance
  R_S = 80 Ω (at +70 °C)

One concludes that: $\hat{V}_A = (80\ \Omega + 90\ \Omega) \bullet 70\ \text{mA} = \mathbf{11.9\ V}$

e) Which is the voltage and the maximum measuring resistance (Fig. 9) to be defined for the following parameters?

$\hat{I}_P$ = 60 A, T_A = +70 °C, V_C = ±15 V (±5 %); $\hat{I}_S$ = 60 mA.

$\hat{\mathbf{V}}_{\mathbf{M}} = \hat{V}_A - (R_S \bullet \hat{I}_S)$
$\hat{\mathbf{V}}_{\mathbf{M}}$ = 11.9 V - (80 Ω • 60 mA) = **7.1 V**
$\mathbf{R}_{\mathbf{Mmax}} = \hat{V}_M/\hat{I}_S$ = 7.1 V/60 mA = **118 Ω**

2nd example: Can one measure a current range higher than the one indicated on the data sheet?

For every transducer LEM indicate the operating conditions for a measuring range which generally is 1.5 to 2 • I_N. If one wishes to determine a measuring range above the one indicated, the following two parameters must be considered:

- The limits given by $R_{M\,min}$ which conditions the maximum authorised power for the electronic circuit. $R_{M\,min}$ can, as the case may be, be different or equal to zero.
- The primary conductor maximum temperature, which must not exceed the values specified in the data sheet (e. g. 100 °C) so as not to damage the plastic materials used.

a) Case where R_{Mmin} is different from zero.
Let us take once more the example of the LA 55-P.

Which maximum current can be measured with the measuring resistance $R_{M\,min}$?

V_C = 15 V ±5 %; T_A = +70 °C; R_S = 80 Ω
$R_{M\,min}$ = 50 Ω

$\hat{I}_S = \hat{V}_A/(R_S + R_{M\,min})$
$\hat{I}_S$ = 11.9 V/(80 + 50) Ω = 91.5 mA
Namely a maximum primary current of 91.5 A

b) Case where R_{Mmin} is equal to zero
Example of the LA 305-S transducer

V_C = 15 V ±5 %; T_A = +70 °C; R_S = 35 Ω (at +70 °C)
$R_{M\,min}$ = 0 Ω; turns ratio = 1: 2500

If R_M is indeed equal to zero, the transducer output will deliver directly a current. If one wishes a voltage output, the appropriate R_M value shall be connected. For example 5 Ω.

Let us first of all determine the available voltage at the amplifier output, $\hat{V}_A$:

$\hat{V}_A = (R_S + R_{Mmax}) \bullet \hat{I}_S$

$R_{M\,max}$ = 75 Ω at 300 A with V_C = 15 V
$\hat{I}_S$ = 300 A/2500 = 120 mA

$\hat{V}_A$ = (35 + 75) Ω • 120 mA = 13.2 V

$\hat{I}_S = \hat{V}_A/(R_S + R_{Mmin})$
$\hat{I}_S$ = 13.2 V/(35 +5) Ω = 330 mA
Thus a measurable primary current range of
330 mA • 2500 = 825 A. This corresponds to a measuring range of 2.75 • I_N

In this case the measuring voltage will be
$\hat{V}_M$ = 330 mA • 5 Ω = 1.65 V

Important!
One must in addition ascertain that the condition of the primary conductor temperature is well respected.

3.3.5 Calculation of the measurement accuracy

The maximum error is calculated as follows:

Current transducer LA 55-P
A DC current of 50 A is measured with the current transducer LA 55-P. The supply voltage of the transducer is ±15 V.

The data sheet gives a value of 0.65 % of I_{PN} for the accuracy at 25 °C. With a turns ratio of 1:1000 the output current will be 50 mA. The offset drift with temperature is ±0.6 mA/110 K max. (-25 to +85 °C).

The value of the individual errors is therefore:

Accuracy at 25 °C	±0.65 % of I_N =	±0.65 %
Offset drift with temperature	±0.6 mA/50 mA	±1.2 %
Maximum error		**±1.85 %**

It represents the maximum deviation, expressed in percentage of the nominal value.

Observations on the magnetic offset
When the I_P current strongly exceeds its nominal value and the ampere-turns can no longer be compensated by the secondary circuit, the magnetic induction B leaves the point 0 and begins a hysteresis cycle. The core is magnetised and the Hall generator supplies a non-zero V_H voltage for I_P = 0. The same effect can occur when one of the two supply voltages is missing. In this case the electronic circuit is unable to supply a sufficient compensation current and the core becomes magnetised. This is remedied by demagnetising the magnetic core with an AC current progressively decreasing to zero, taking care to previously turn off the transducer's power supply or by opening the measuring output circuit.

3.3.6 Unipolar power supply

Most of the LEM transducers can also be supplied by an unipolar voltage for measurement of unidirectional currents. In this case the following must be taken into consideration:

1. The supply voltage is the sum of the positive and negative voltages indicated in the data sheet.

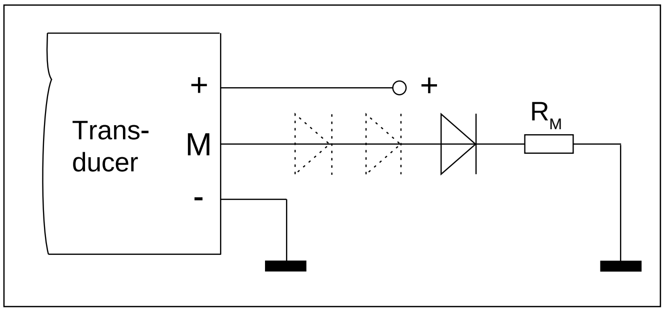

Fig. 10 Disposition of diode(s) with an unipolar power supply

2. The load resistance shall be calculated separately, in order not to exceed the acceptable dissipated power of the amplifier's final stage. As a first approximation this calculation is not necessary if one does not exceed half of the nominal primary current. In other cases please consult us.
3. As the amplifier circuit is designed for a bipolar power supply and is used here as unipolar, diodes must be inserted into the measuring circuit, as shown in Fig. 10. This is in order to compensate the residual voltage across the unused output transistor which could generate a current comparable to an offset in the measuring circuit.

   Furthermore, variants specially adapted for unipolar operation are available as a standard device.

3.4 Hall effect closed loop voltage transducers

3.4.1 Construction and principle of operation

The Hall effect voltage transducers are based on the same principle as their current transducer counterpart. They are in fact constituted by a current transducer assembly where the main difference is in the primary circuit which is made with a winding having a high number of turns. This permits realisation of the necessary ampere-turns for the creation of the primary induction, while having a low primary current, thus permitting a minimal consumption in the circuit to be measured.

To measure a voltage it is therefore sufficient to shunt from this voltage the equivalent primary current which will supply the transducer. This is carried out with the help of a resistance connected in series with the primary winding.

The Hall effect voltage transducers are therefore constituted by a current transducer assembly and a primary resistance named R_1. This resistance can be external or integrated into the transducer construction.

3.4.2 Voltage transducer without incorporated resistor R_1

As this voltage transducer applies the same operation principle as the current transducer described above, the same rules apply for the values of the voltages and the measuring resistor. In addition the value of R_1 must be calculated (Fig. 11).

Example 1 with transducer LV 100:
What must be the external resistance value R_1, in order to measure a voltage of V_{PN} = 230 V nominal, with a peak measuring range of 500 V and what is the measurement accuracy?

a) Dimensioning the primary resistance R_1:

Nominal current	I_{PN} = 10 mA
Measuring range	I_P = 20 mA
Internal primary resistance	R_P = 1900 Ω (at +70 °C)

$R_1 = V_{PN}/I_{PN} - R_P = (230/10 \cdot 10^{-3}) - 1900 = 21\,100\ \Omega$
R_1 = 21.1 Ω

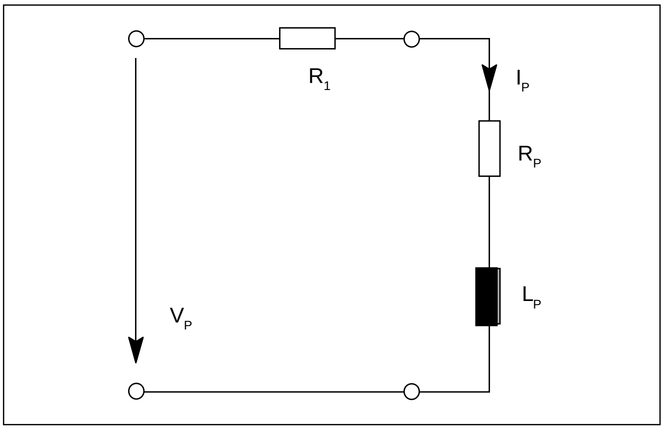

Fig. 11 Equivalent diagram for calculation of primary resistance R_1

Nominal power P_N dissipated in R_1

$P_N/I_{PN}^2 \cdot R_1 = 10^2$ mA • 21.1 kΩ = 2.11 W

In order to avoid excessive thermal drifts of the R_1 value and for the sake of reliability, the user will generally select an installed power 3 to 4 times above the calculated nominal power. In our case:

R_1 = 21.2 kΩ/8 W

Total resistance R_{Ptot} of the primary circuit will be:

$R_{Ptot} = R_P + R_1$ = 23 kΩ.

b) Can one measure the max. voltage of 500 V?
Measurement of 500 V is possible in transient operation, provided that the mean r.m.s. value (thus the heating dissipation) of the current is kept to 10 mA.

If this rule cannot be adhered to, R_1 must be redimentioned with a lower permanent current, e. g. 9 mA.

In our case we will presuppose that the mean r.m.s. value is respected and we calculate the parameters.

$\hat{I}_P = (\hat{V}_P/R_{Ptot})$ = 500 V/23 kΩ = 21.7 mA or 2.17 • I_{PN}.

We are therefore beyond the specified measuring range, but having admitted that the primary thermal conditions were correct, let us check on the secondary side whether the transient measurement is possible.

The turns ratio is 10'000/2'000, wherefrom $\hat{I}_S$ = 108.5 mA. In a fashion similar to the calculation of the current transducers (example 2), R_{Mmax}. is determined as follows:

Calculation of $\hat{V}_A$, according to the values of the data sheet

$\hat{V}_A = (R_S + R_{Mmax}) \cdot \hat{I}_S$
$= (60 + 150)\ \Omega \cdot 50$ mA = 10.5 V

Calculation of R_{Mmax} effective in this case:
$R_{Mmax} = (\hat{V}_A/\hat{I}_S) - R_S$
$= (10.5\ V/108.5\ mA) - 60\ \Omega = 36.8\ \Omega$

Conclusion: measurement is possible.

c) Influence on the accuracy of the R_1 selection and the variation of R_P depending on the operating temperature.

Every variation of R_1 and R_P influences the stability of the primary current and thus the image of the voltage to be measured.

Note: The resistance value of a winding executed in copper wire depending on the temperature is given by the relation:
$R_{Pf} = R_{Pi}\ (1 + a \bullet \Delta t)$ where
R_{Pf}: resistance value at the final temperature
R_{Pi}: resistance value at the initial temperature
a: temperature coefficient of copper = 0.004 Ω/K
Δt: final temperature - initial temperature

One considers for instance an operating ambient temperature of +70 °C.

- Selection of R_1: the user selects for instance a value of R_1 with an accuracy of 0.5 % and a temperature drift of 50 ppm/K.
- The R_P value is 1900 Ω at +70 °C and 1550 Ω at +25 °C

Maximum errors due to R_1

E1: intrinsic error of R_1 = ±0.5 %
E2: temperature drift: 50 ppm/K • (70 °C - 25 °C) = 0.225 %

Error due to the temperature variation of R_P:

E3 = [(R_P at +70 °C - R_P at +25 °C) / R_{Ptot}] • 100
= [(1900 - 1550) / 23000] • 100 = 1.52 %

Total maximum error of R_{Ptot}:

E = E1+ E2 + E3 = **2.25 %**

d) Calculation of the accuracy without R_1

In the example, R_1 has been calculated so that the primary current I_{PN} is 10 mA.

According to the data sheet the accuracy at +25 °C is ±0.7 % of I_{PN}. The temperature drift of the offset current is ±0.3 mA max. With a turns ratio of 10000:2000 the input current of 10 mA must generate an output current of 50 mA.

The values of the individual errors are then:

Accuracy at 25 °C, ± 0.7 % of I_{PN}	± 0.7 %
Temperature offset drift, ± 0.3 mA/50 mA	± 0.6 %
Maximum error of the transducer:	**±1.3 %**

e) Global measurement error

The total measurement error of a nominal 230 V voltage in the range of operating temperature is
2.25 % + 1.3 % = **3.55 %**.

Example 2:
What must be the value of the external primary resistance R_1 in order to measure a continuous voltage of V_{PN} = 1000 V nominal and what is the measuring accuracy?

a) Calculation of the primary resistance

The data sheet indicates:

Nominal current:	I_{PN} = 10 mA
Measuring range:	I_P = 20 mA or 2 • I_{PN}
Internal primary resistance:	R_P = 1900 Ω (at +70 °C)

$R_1 = (V_{PN}/I_{PN}) - R_P = (1000/10 \bullet 10^{-3}) - 1900 = 98100\ \Omega = 98.1\ k\Omega$

Nominal power P_{1N} dissipated in R_1
$P_{1N} = I_{PN}^2 \bullet R_1 = 10^2\ mA \bullet 98.1\ k\Omega = 9.8\ W$
One selects a power rating of 40 W

Total resistance (R_{Ptot}) of the primary circuit will be:
$R_{Ptot} = R_P + R_1 = 100\ k\Omega$

b) Influence on the accuracy of the selection of R_1 and the variation of R_P depending on the operating temperature.

One considers for instance an operating environment temperature of +70 °C.

- Selection of R_1: the user chooses for instance a value of R_1 with an accuracy of 0.5 % and a temperature drift of: 50 ppm/K
- The value of R_P is 1900 Ω at +70 °C and 1550 Ω at +25 °C

Maximum errors due to R_1:

E1: intrinsic error of R_1 = ±0.5 %
E2: temperature drift: 50 ppm/K • (70 °C - 25 °C) = 0.225 %

Error due to the variation of R_P with temperature:

E3 = [(R_P at +70 °C - R_P at +25 °C) / R_{Ptot}] • 100
= [(1900 - 1550) / 100000] • 100 = 0.35 %

Total maximum error of R_{Ptot}:

E = E1+ E2 + E3 = 1.08 %

c) Accuracy of the transducer (without R_1)

It is identical to the preceding calculation, namely 1.3 %.

d) Global measurement error

The total measurement error of a nominal 1000 V voltage is 2.38 % within the operating temperature range.

Note:
Between a measurement of 230 V and the one of 1000 V we note that the accuracy is strongly influenced by the variation of the winding's resistance depending on the temperature.

In order to obtain a better accuracy for the measurement of low voltages, we advise to select transducers with primary windings having a lesser number of turns. Even though the power dissipated in the primary circuit and the consumption on the voltage line to be measured will be higher, these transducers give a better response in frequency (see chapter 2), which may be an advantage in some applications.

3.4.3 Voltage transducer with incorporated resistor R_1

For the series LV 100-voltage, LEM has selected an installed power at R_1 of 10 W at the nominal voltage and the accuracy is identical for all its transducers.

They have the advantage of being factory-calibrated at the specified nominal voltage. However their measuring dynamic is limited to 1.5 times their nominal value. Nevertheless, as for the transducers with external primary resistance R_1, the same principles apply. One can measure transient voltages over 1.5 times the nominal voltage, providing the permanent power of 10 W installed in the primary and the calculation conditions indicated on R_{Mmax} for the secondary circuit are respected.

3.4.4 Typical applications

The closed loop Hall effect voltage transducers are used in many industrial applications to detect, monitor and regulate voltages.

One of the typical applications is, for example, the monitoring of input, output and DC filter voltages of frequency inverters.

4 Closed loop transducers, C type

With the LEM patented closed loop transducers of the C type it is possible to measure currents, differential currents and voltages. They have been developed in co-operation with Dan Otto, professor at the University of New Zealand, Auckland. These high accuracy transducers with a wide bandwidth have a very reduced temperature drift. They are designed with an original Ampere-turns compensation system, using an internal electronically controlled oscillator.

4.1 Construction and principle of operation

The C type transducers incorporate two cores T1 and T2 made of soft magnetic material (Fig. 12), each of them having a secondary winding N_S with an equal number of turns. The primary winding N_P is a winding common to the two cores.

The two secondary windings are connected in series. A square-wave generator of controlled frequency (1) supplies the compensation current I_S to the secondary winding of the core T1 (point A) as well as a magnetising current I_μ.

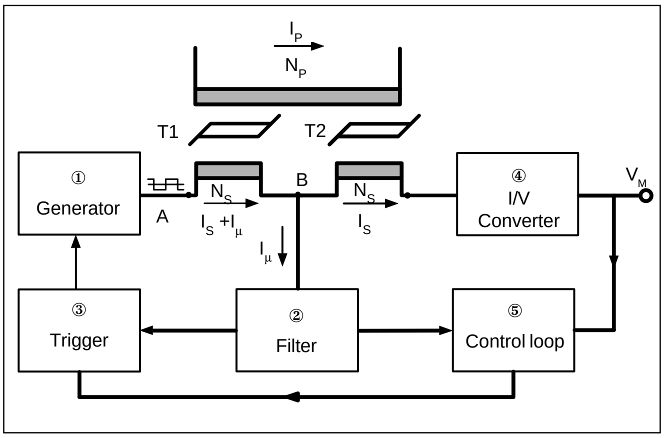

Fig. 12 Block diagram of C transducers

The common point B of the two secondaries is connected to the input of an active filter ② which absorbs the magnetising current I_μ of the T1 core (Fig. 13). This I_μ current is used in the circuit (to trigger the voltage polarity change of the square-wave generator) as soon as a beginning of saturation is detected.

The hysteresis curve obtained is symmetrical and the mean number of the secondary Ampere-turns is exactly the same as the primary Ampere-turns.

$(I_S + I_\mu) \bullet N_S = I_P \bullet N_P$

As the I_μ magnetising current is absorbed by the filter, the current resulting in T2 is the secondary current I_S, without superimposed ripple. The output current at point C is then:

$I_S = I_P \bullet N_P/N_S$

which is converted into an output voltage V_M by the I/U current/voltage converter ④.

The electronic circuit is designed so as to automatically compensate the amplifier offsets and voltage drops within a wide temperature range, thus eliminating the need for adjustments.

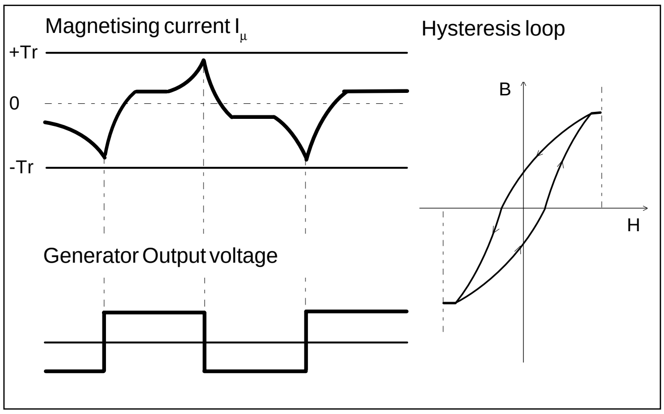

Fig. 13 Hysteresis loop and waveform signals

4.2 Characteristics and features

The CT series transducers measure currents up to 150 A maximum. They have a typical 0.1 % accuracy and a bandwidth from 0 to 500 kHz.

The CD series transducers measure differential currents. They are capable of measuring the difference between two primary currents flowing in opposite directions in the main conductors. The value of the differential current to be measured can be about 1000 times smaller than the value of the main current flowing in each primary conductor. For example 0.1 A differential for a main current of 100 A, or 1 A differential for a current of 1000 A. The measurement accuracy is of about 5 to 10 % within the specified operating temperature range.

The CV series transducers measure voltages up to 7000 V. They have a typical accuracy of 0.2 % and a bandwidth of 0 to 700 kHz.

The series C transducers provide an output voltage which can take a value up to 10 V.

4.2.1 CT current transducers

Main advantages

- Excellent accuracy throughout the whole operating temperature range.
- Wide bandwidth.
- Very good immunity to surrounding magnetic fields.
- Extremely short response time.

- They withstand high current overload (a CT 1-S transducer of nominal 1 A current will, for instance, withstand an overload of 150 kA during 150 ms).
- The output is protected against short circuits.
- Thanks to the intrinsic product design, it is possible to obtain very high isolation levels and an excellent performance against partial discharges (the CT 5-T/SP3, for instance, has a 50 kV rms isolation and a partial discharges extinction level of <10 pC at 14 kV).

Limitations

- The transducers inject into the primary circuit under measurement a rectangular voltage ripple which depends on the turns ratio. This voltage induces a current in the primary circuit the amplitude of which depends on its impedance. This will be more significant the primary impedance is lower (see calculation examples at § 4.4.1b).

4.2.2 CD differential current transducers

Main advantages

- Very good differential resolution: ability to measure low differential currents with respect to the high main currents.
- Possibility to have an external adjustment of the level of the differential current to be measured (a special design provides external terminals in the housing, where the adjustment resistors will be connected by the user).
- Special design allow the user to adjust the time constant of the differential current measured. This is practical when using the output signal of the transducers as a trigger in safety systems.
- Possibility of defining several levels of differential currents to be measured (the transducer is then designed with a separate individual output for each level).
- The devices are protected against primary current overloads.

Limitations

- In this design the frequency bandwidth is reduced.
- Because of the structure of each transducer (size of the magnetic circuit, the shieldings and the defined dimensions), the main current must be limited to a maximum value so as to avoid local magnetic saturations which can influence the measurement accuracy.

4.2.3 CV voltage transducers

Main advantages

- Excellent accuracy throughout the whole operating temperature range.
- Wide frequency bandwidth.
- Very good immunity against surrounding magnetic fields.
- Very good immunity against common mode voltage variations.
- Very short response time.
- Excellent following of voltage steps dv/dt.

Limitations

- The present housing achieves a dielectric voltage strength level of 6 kV rms with a partial discharges extinction level of <10 pC at 2 kV rms.

4.3 Typical applications

Thanks to their high measuring accuracy and their absolute stability against temperature, these transducers are mainly used in laboratories and for calibrations. These recently developed transducers are also used for industrial applications where the required accuracy is very high, as for instance in calibrators, diagnosis systems and test platforms.

4.3.1 CT current transducers

- Current measurement in transmitters
- Measurement of the magnetising current in power transformers or detection of a DC component in order to avoid saturation (industrial equipment and electric traction).
- Current measurement in induction heating systems.
- Measurement of charge and discharge currents for battery testers.
- Calibration benches for power converters and motors.
- Current measurement in the electric energy distribution simulators and sub-stations.
- Current measurement in the photovoltaic type plants (precise measurement of the maximum power point).
- Laboratory measurement instruments: Isolated measurement of currents (connectable to an oscilloscope or DMM); power measurement for inverters as an interface with a power analyser.
- Measurement of the heating current in the cathode of a KLYSTRON equipment (CERN).

4.3.2 CD differential current transducers

- Measurement and detection of earth leakage currents.
- Replacement of the classic differential relays with a better accuracy and detection of much smaller currents.
- Measurement of differential currents, as a safety function, in electric traction equipment.

4.3.3 CV voltage transducers

- Measurement of AC voltages in high power industrial inverters.
- Voltage measurement in electric traction converters (DC and AC).
- Voltage measurement between phases of power cyclo-converters.
- Calibration benches for power converters and motors.
- Voltage measurement in photovoltaic type plants (precise measurement of the maximum power point).
- Laboratory measurement instruments: Isolated measurement of voltages, power measurement for inverters power as an interface with a power analyser.

4.4 Calculation of the measurement accuracy

As already indicated in the previous chapters for other products, the aim is to calculate the maximum error.

4.4.1 CT current transducer

a) Accuracy obtained with the transducer CT 100-S

100 A direct current is measured with the current trans-ducer CT 100-S. According to the data sheet, the output voltage must be 5 V. The indicated accuracy is ±0,15 %.
Within the temperature range of -25 °C to +70 °C, the temperature drift of the offset voltage is ±0.6 mV maximum. The individual errors then show the following values:

Accuracy	±0.15 %
Offset voltage temperature drift ± 0.6 mV/5 V	±0.012 %
Maximum total error	**±0.162 %**

It represents the maximum error, expressed as a percentage of the nominal value.

b) Calculation of the ripple rejection in the primary circuit with the transducer CT 5-T

The internal square-wave generator (① Fig 12) provides a voltage of ±6.8 V.
Number of turns on the primary $N_P = 10$
Number of turns on the secondary $N_S = 1000$
I/V converter resistance (④ Fig 12) $R_C = 100\ \Omega$
Induced voltage in the primary: $V = 6.8\ V \cdot N_P/N_S$
$V = 6.8 \cdot 10/1000 = 68\ mV$

- If the primary circuit impedance $Z_P = 1\ \Omega$, the induced I_P will be: $I_{Pind} = 68\ mV/1\ \Omega = 68\ mA$ primary, namely an induced secondary voltage of:
  $V_{Sind} = I_{Pind} \cdot R_C \cdot N_P/N_S = 68\ mA \cdot 100 \cdot 10/1000 = 68\ mV$.

  Whence an error E on the output signal 5 V:
  $E = 68\ mV/5\ V = 1.36\ \%$.
- If the primary circuit impedance $Z_P = 100\ \Omega$, the error E will become 0.0136 %, in fact a negligible error.

4.4.2 CV voltage transducer

Accuracy calculation

	T_A +25 °C	$T_{A\,max}$ +70 °C
Typical accuracy of the primary resistances, nominal variation with temperature (typical coefficient 20 ppm/°C)	0.05 %	0.05 % 0.10 %
Typical resistance accuracy of the converter, nominal variation with temperature (typical coefficient 20 ppm/°C)	0.05 %	0.05 % 0.10 %
Secondary offset voltage Nominal: 5 mV Maximum with temperature: 10 mV	0.10 %	0.20 %
Maximum total error	**0.20 %**	**0.5 %**

5 Closed loop transducers, IT type

The IT series of closed loop transducers allows current measurements with very high accuracy, linearity and high stability.

5.1 Construction and principle of operation

The system consists of a current measuring head controlled by an electronic module. The centre hole in the transducer head accepts a conductor carrying the current (I_P) to be measured. Normally, 1 to 4 turns are used, depending on the application.

Using the zero flux principle, the primary ampere-turns are compensated by the secondary current "I_C" multiplied by the number of turns of the compensation winding. This current is selected to a value that can be measured using a small resistor. Typical values are 400 mA and 200 mA with an output voltage of 1 V.

Operating principle
Figure 14 shows the block diagram of the system.

When a primary current is flowing, the amplifier drives the compensation current so that the secondary ampere-turns cancel the primary ampere turns.

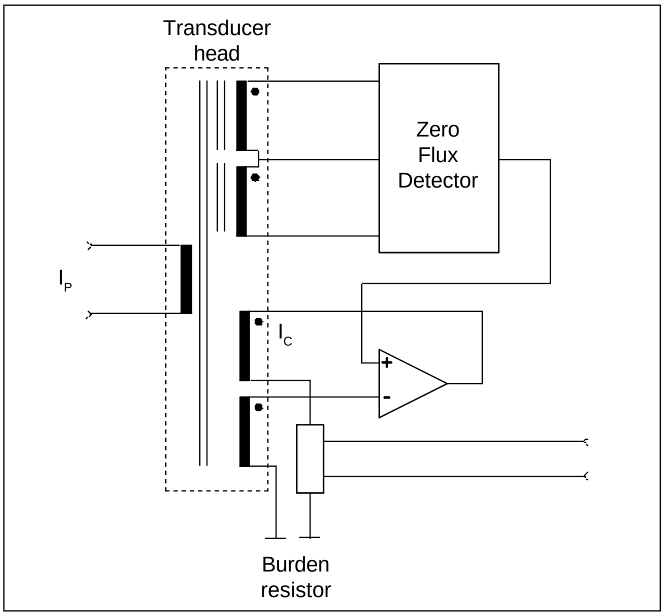

Figure 14 Total block diagram of closed loop IT transducers

For the low to high frequency range this is done by the amplifier forcing the induced signal on the feedback winding close to zero. For DC to low frequency the zero flux detector gives a correction signal to the amplifier.

The zero flux detector is a symmetry detector using two cores connected to a square-wave generator as shown in Figure 15.

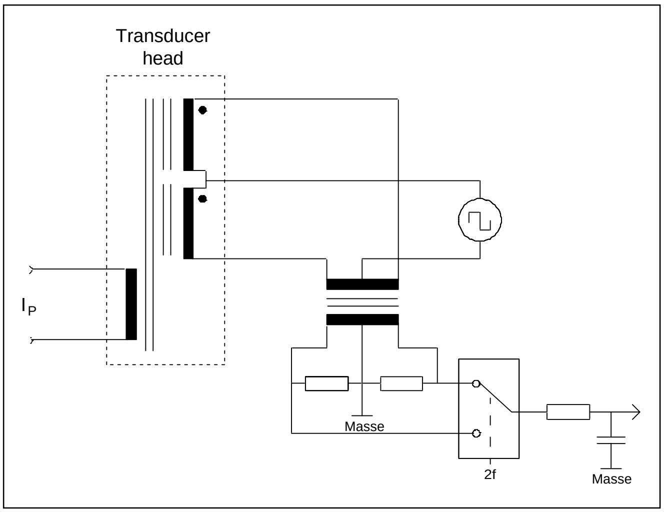

Figure 15 Block diagram of symmetrical zero flux detector

When the primary and the secondary ampere-turns cancel each other, there is no offset field in the cores. The square wave generator drives the two identical cores inside the main core to saturation resulting in two (almost) identical currents. In the centre-tapped transformer the two currents cancel each other resulting in zero output.

The two cores are installed in such a way that they give zero flux to the main core. This results in minimum noise feed-back to the primary circuit.

If the flux in the main core is not zero, the cores are no longer driven symmetrically into saturation. The two currents will be asymmetrical, which means that they will contain even harmonics.

Due to the connection, one core will be driven deeper into saturation and simultaneously the other core will be less saturated. The net result is that the signal on the centre-tapped transformer will be the added asymmetric signals from the two cores.

In the ideal case, the output signal from the transformer will only contain even harmonics of the driving signal.

An analogue switch driven with double frequency of the driver signal is used for synchronous double rectification. The output signal is filtered in a low-pass filter before connection to the compensation amplifier.

Advantages and limitations for IT series

Main advantages

- Very high accuracy and stabiliy.
- Large bandwidth from 0 to 100 kHz.
- Very low cross-over distortion for accurate measurement of AC currents.
- Excellent linearity <1 ppm
- Very good stability with temperature (< 0.3 ppm/°C)
- Very low noise on the output signal
- Very low inital offset and drift with temperature

Limitations

- Operating temperature presently limited to laboratory or clean environment usage (basically 10 °C to 50 °C).
- Consumption on the power supply.

5.2 Typical applications

- Feedback element in precision current regulated power supplies
- Precision current control in gradient amplifiers for medical imaging
- Isolated interface for power analyser
- Current calibration for test benches
- Battery charging equipment requiring high resolution measurement
- Laboratory/metrology requiring high accuracy measurement

5.3 Calculation of the measurement accuracy

Example with the IT 600-S transducer

The data sheet indicates:

Normal operating measuring range	0 to 600 A
Overload capacity	
- permanent 110 %	660 A
- overcurrent max. 0.1 s, 500 %	3000 A

In the following example, the user needs to know the measurement accuracy at DC currents of 60 A and 600 A, ambient temperature being +50 °C.

To be able to measure 600 A full scale, the output voltage shall be fixed at max. 1 V (see derating curve in the data sheet). The turns ratio being 1:1500, the secondary current will be 400 mA. Therefore the load resistance shall be 2.5 Ω.

a) Accuracy at 60 A

At T_A = 25 °C				**10^{-3} % of reading**
DC offset current at I_P = 0:	<	4	µA	10
Non-linearity: <1 ppm of full scale	<	0.4	µA	1
Measuring ratio stability: <2 ppm of reading	<	0.08	µA	0.2
Total error at +25 °C	**<**	**4.48**	**µA**	**11.2**
Drift with temperature (from 25 °C to 50 °C):				
DC offset drift: 0.1 µA/K		2.5	µA	6.25
Measuring ratio stability 0.3 ppm of reading/K		0.3	µA	0.75
Maximum global error at 50 °C	**<**	**7.28**	**µA**	**< 18.2**

b) Accuracy at 600 A

At T_A = 25 °C				**10^{-3} % of reading**
DC offset current at I_P = 0	<	4	µA	1
Non-linearity: <1 ppm of full scale	<	0.4	µA	0.1
Measuring ratio stability: <2 ppm of reading	<	0.8	µA	0.2
Total error at 25°C	**<**	**5.2**	**µA**	**1.3**
Drift with temperature (from 25 °C to 50 °C):				
DC offset drift: 0.1 µA/K		2.5	µA	0.625
Measuring ratio stability 0.3 ppm of reading/K		3	µA	0.75
Maximum global error at 50°C:	**<**	**10.7**	**µA**	**< 2.7**

6 Advice for protection against disturbances

External disturbances can impair the functioning of the transducers. Hereafter a few examples:

6.1 Power supply polarity inversion

When connecting the transducer and in order to avoid any damage due to polarity inversion of the power supply voltage, LEM advises to insert a diode into each power supply line, both positive and negative. These diodes are already incorporated as a standard design in a number of transducers. Please consult us for further informations.

6.2 Capacitive dv/dt noise

Nowadays power converters frequently use fast switches such as IGBTs (Insulated Gate Bipolar Transistors). During commutation sudden voltage variations with high dv/dt may occur. These produce a capacitive current between the primary winding and the secondary circuit of the current transducer. A parasitic voltage ensues which can reach very high levels, depending on the amplitude of the applied voltage and its dv/dt. It is possible to attenuate these disturbances with a capacitive filter. This solution can, however, attenuate the transducer’s bandwidth.

When long cables are used for the secondary connection of the transducer, it is advisable to take shielded cables and to connect the shielding at both ends to the earth, such as prescribed by the rules of EMC.

6.3 Magnetic disturbances

When measuring currents on the output phases of converters for instance, the conductors are often near to one another. The magnetic disturbances created by these conductors in the nearby transducers are stronger still when the current transducers are confined near the conductors and when the intensity of the nearby current is high. In this case it is the position of the nearby conductor relative to the Hall element of the transducer which is the determining factor.

A remedy is found by increasing the distance of the transducer to the conductor by modifying the layout of the conductors, by twinning the supply and return conductors and by locating them far from the disturbances. It is also possible to divide the conductors adjoining the transducer into equal parts and place them symmetrically on each side of the transducer in order to cancel out the magnetic influence. As the case may be, shielding may also prove necessary.

Measurements of sensitivity to external magnetic fields have been carried out for certain types of transducers. The results are available upon request.

Most of our transducers undergo a very complete series of tests in the field of disturbances. A characterisation file is available for the more recent products, and we would advise you to consult us if you have a specific problem to solve.

7 LEM-flex - the flexible AC current transducers

LEM-flex series transducers have been designed to conveniently measure single and three-phase AC as well as pulsed DC currents. These transducers offer three key advantages:

- flexibility
- high frequency bandwidth
- light weight

Two basic construction configurations are available: The first is for the measurement of single phase currents while the second is for the measurement of three-phase currents. Standard ranges include 30/300 A, 300/3000 A, 600/6000 A and 60 kA rms, but scaling can easily be designed for other currents.

Due to the flexibility of the measuring heads it is possible to position them around one or more irregularly shaped or difficult to access conductors or bus bars. The LEM~flex measuring heads have standard circumferences of 61 cm, 91 cm or 122 cm. Custom sizes can also be designed.

Theoretically, there is no limit to the size of the measuring head or measurement range. Installation and measurement is performed without mechanical or electrical interruption of the conductor carrying the current, whilst ensuring galvanic isolation.

7.1 Construction and principle of operation

The main part of the LEM-flex is the measuring head which is fundamentally a coil uniformly wound around a flexible cylinder of insulating material. At one end, the winding is connected to a conductor located in the centre of the cylinder of insulated material. At the other end, the winding and centre conductor provide the basic signal output. This construction makes both electrical connections available at a single point.
To make measurements, the flexible measuring head is wrapped around the conductor carrying the current to be measured and the two ends are brought together and mechanically connected by a coupling latch. The voltage induced in the measuring head is proportional to the current variation di/dt and is calculated as follows:

$$E_{out} = 4\,\pi\,10^{-7} \bullet N \bullet A \bullet di/dt = H \bullet di/dt$$

where N = Number of turns per metre (turns around the flexible centre insulating cylinder)
A = Section of the winding in m^2 (cross-section of the flexible centre insulating cylinder)
i = Current to be measured in A
H = Sensitivity of the winding in Vs/A

The specific winding in the LEM~flex head has a sensitivity of $3.078 \bullet 10^{-7}$ Vs/A. Thus, for an AC sinusoidal current and incorporating the physical dimensions of the measuring head, the induced effective voltage has the following value:

$$E\,(V_{rms}) = 1.934\,\mu V \bullet I\,(A_{rms}) \bullet f\,(Hz)$$

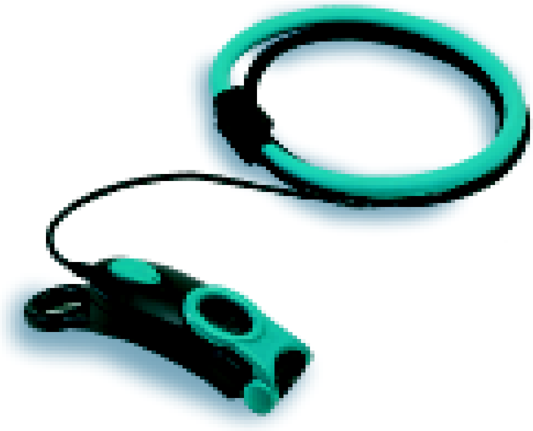

Fig. 16 The air-core coil of the LEM-flex is wound around a flexible plastic cylinder, having an internal coaxial conductor.

In order to reproduce the true waveform of the measured current, it is necessary to integrate the voltage induced in the measuring head. This task is carried out by an electronic integrating circuit located in a small plastic housing which is supplied with the device (Fig. 16).

Taking into account the T_i integration duration, the integrated output voltage is:

$$V_A = 1/T_I \int E \bullet dt = R_H \bullet i$$

The measurement unit of the transducer sensitivity defined by $R_H = H/T_i$ is: Ω = V/A.

7.2 Characteristics and features

As the LEM~flex measuring head is fundamentally an air-core coil, there is no magnetic hysteresis, no saturation phenomena nor non-linearities, as is present with magnetic material cores. The air-core coil supplies a voltage which is proportional only to the di/dt variation. Consequently, a constant DC current will not produce any voltage and cannot therefore be measured.
The standard LEM~flex current transducer integrator provides a sensitivity up to 100 mV/A. Its analogue output

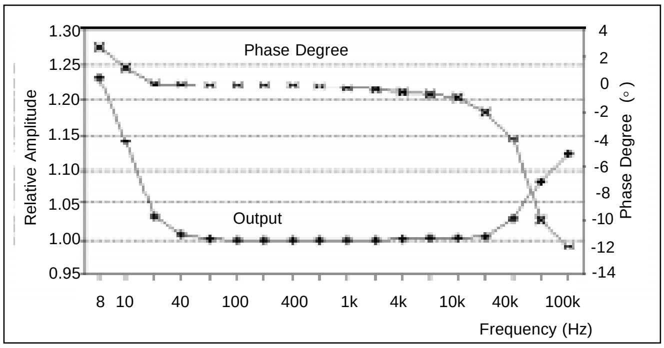

Fig. 17. Integrator circuit with logarithmic presentation of the frequency response.

voltage, physically isolated from the measured current, is 0 to 3 V rms namely 4.2 V peak. The output signal gives a true image of the waveform of the current to be measured (fig. 16). With supplied cabling and adapters, it is possible to directly connect an oscilloscope, digital multimeter or any test and measurements instrument with voltage inputs.

The operating status is shown by a flashing LED on the housing of the electronics. A socket on the integrator housing is provided for connecting an external power supply which functions as a battery eliminator.

Due to the tolerances of the wound coil, the position of the current conductor inside the LEM-flex measuring head has a slight influence typically below 1 % (2 % max.). Currents higher than the measured current flowing through conductors immediately near by, but not through the LEM-flex, can impact the measurement accuracy by typically less than 1 %. Phase angle error and relative amplitude within the frequency range is given in fig. 17.

Frequency limits
The performance of the LEM-flex transducer is similar in concept to a band-pass type circuit exhibiting both high and low cut-off frequencies. As the integrator gain can be very high, very low frequencies must be neutralised by shielding and appropriate circuits in the integrator. As for high frequency performance, the upper cut-off frequency is determined by the inductance and the winding capacity. It should also be noted that the integrator also includes compensation circuits which limit the thermal drift.

7.3 Typical applications

Among the main advantages of LEM-flex transducers are easy positioning around one or several conductors regardless of size and shape. The transducer can be quickly and easily installed as well as removed. The LEM-flex can be used almost anywhere thanks to its battery power supply. Measurements can therefore be conveniently made without requiring mains power. These advantages combined with the LEM-flex's theoretically unlimited size and current range make them ideal for measuring most of all the pulsed and AC single or three-phase currents. The analogue voltage output permits connection to most measuring instruments including multimeters, oscilloscopes, recording devices, dataloggers, etc.

One example application is measuring currents in bus-bar sets, in particular in induction heating equipment, frequency converters, variable speed drives and generators. LEM~flex can also be used for the control of power semiconductors, analysis of the current distribution in mains networks, the analysis of harmonics, power measurements, measurement of the peak load in the mains, and in UPS's. Applications are also found in switched mode power supplies, low or medium voltage distribution installations and power electronics installations (Fig. 18). They are also used as input devices for wattmeters and network analysers installed by electric power distribution companies. General applications

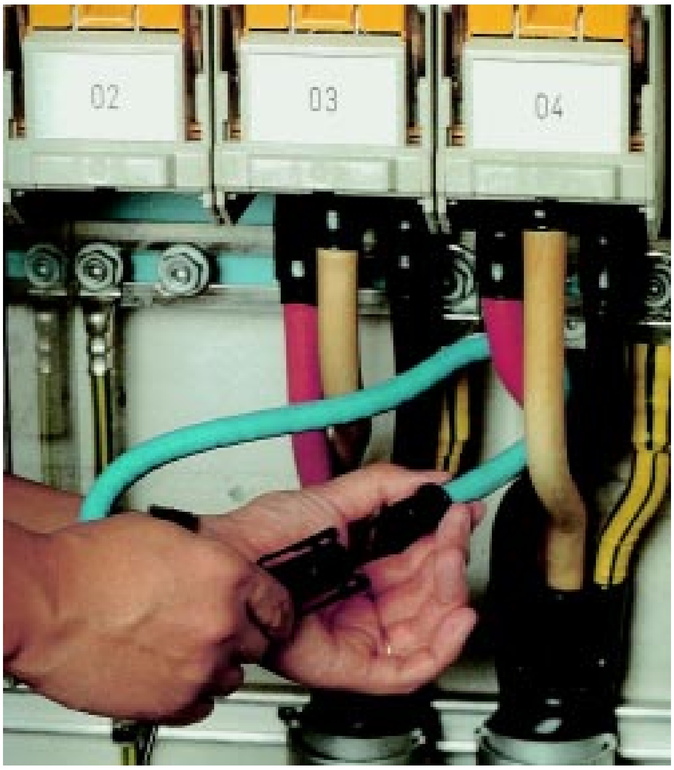

Fig. 18 The flexible current probe LEM-flex can measure AC currents and be wrapped around one or several conductors.

include electrical maintenance, repair and machine installation and start-up applications.

7.4 Calculation of the measurement accuracy

Example: LEM-flex RR 3000-SD/24
It is able to measure 300 A rms and 3000 A rms full scale (a range selector switch is integrated in the device). The out-put signal is 3 V rms. Measurement of an AC current of 300 A rms at an ambient temperature of +50 °C is required.

According to the data sheet, the value of the individual errors is:

Accuracy at 25 °C relative to the full scale value	±1 %
Temperature drift	
- Gain drift: ±0.08 %/K viz. ±0.08 %/°C (50-25) °C =	±2 %
- Offset drift: ±0.006 mV/K viz. ±0.15 mV/3 V =	±0.005 %
- Maximum error due to the position of the primary conductor (relative deviation to the loop center)	±1 %
Total maximum error:	**±4.005 %**

The example shows that the offset temperature drift is negligible in relation to the other individual errors. The maximum total error, in relation to the full-scale value (here 300 A) can thus be rounded out to ±4 %.

8 Current probes

The comprehensive range of LEM clamp-on current probes allows current measurements from 5 mA to 2000 A. As with the other transducers, it is based on modern Hall effect technology (see chapter 3) and a special configuration of the magnetic circuit.

8.1 Construction and principle of operation

A highly linear Hall effect sensor integrated in the clamp-on current probe provides quick and accurate current measurements in numerous applications with isolated and bare conductors. The magnetic circuit around the current-carrying conductor has been designed such that the position of the conductor in the tongs has minimal effect on the result of the measurement (Fig. 19).

Figure 19 The clamp-on current probes provide quick and accurate current measurements without interrupting the current circuit. They are offered with different interior diameters.

The clamp-on current probes generate an output voltage which is a true image of the current, no matter if it's a DC, an AC or a mixed current or a current with a complex waveform. This kind of measuring device offers the users of multimeters and oscilloscopes high performance, cost-effective and quick solutions for contactless current measurements.

8.2 Characteristics and features

Since the Hall effect current probes provide a non-delayed output voltage proportional to the current measured, real rms, average and peak values can be measured simply by connecting an appropriate multimeter, oscilloscope or recorder. The probe has an output cable with two usual banana plugs (∅ 4 mm) or a BNC connector for connection to any off-the-shelf test and measuring instrument. This concept enlarges the current measurement capabilities of standard multimeters to such an extent, that they can now be used for precise, contactless measurements from 5 mA to 2000 A. A great advantage when using Hall effect current probes, compared to usual current transducers based on the transformer principle, is their ability to measure DC and AC currents as well as currents of complex waveforms in a dynamic range of a few milliamperes up to 2000 A and with frequencies ranging from 0 to 100 kHz. For further technical details, see table 2. Due to the compact size of the tongs, the user has also an easy access to tight places. The different interior diameters (∅ 19 mm, ∅ 31 mm and ∅ 50 mm) allow to accept all kinds of conductors such as single cables or bus bars. Current probes complying with the safety standard IEC 1010 give the user added confidence when making measurements in hazardous voltage areas. The safety measures include a tactile barrier, which indicates to the operator a safe working distance for his hand to be from the live conductors, and a reinforced or double-isolated output cable with safety connectors. Special care was taken to ensure safe and electrically isolated current measurements with bare conductors.

Table 2: Specifications of some standard and customer-tailored clamp-on current probes

Typ	PR 20	PR 30	PR 200		PR 1001		PR 2000	PR 50/SP2	PR 100/SP1	PR 1000/SP7
Version	Standard							Customized		
Current ranges	20 A~ 30 A -	20 A~ 30 A -	20 A~ 30 A -	200 A~ 300 A -	200 A~ 300 A -	1000 A~ peak 1000 A -	2000 A~ peak 2000 A -	50 A unipolar	100 A~ 150 A -	1000 A~ peak 1000 A -
Resolution	±1 mA	±1 mA	±10 mA	±100 mA	±100 mA	±100 mA	±100 mA	±1 mA	±1 mA	±200 mA
Output voltage	100 mV/A	100 mV/A	10 mV/A	1 mV/A	1 mV/A	1 mV/A	1 mV/A	10 mV/A diff.	20 mV/A diff.	10 mV/A
Accuracy of reading	±1 % ±2 mA	±1 % ±2 mA	±1 % ±0.03 A	±1 % ±0.3 A	±1 % ±0.5 A	±1 % ±0.5 A	±1 % ±0.5 A	±1 % ±2 mA	±1 % ±2 mA	±1 % ±1 A
Frequency range	DC up to 20 kHz	DC up to 100 kHz	DC up to 10 kHz		DC up to 10 kHz		DC up to 10 kHz	DC up to 10 kHz	DC up to 100 kHz	DC up to 1 kHz
Probes jaw ∅	19 mm	19 mm	19 mm		31 mm		50 mm	19 mm	19 mm	31 mm
Power supply	9 V battery	9 V battery	9 V battery		9 V battery		9 V battery	ext. +5 V unipolar	ext. ±7.5 V	ext. ±12 V

8.3 Typical applications

Thanks to their high performance, the clamp-on current probes open many new application possibilities in maintenance, repair-shops, and for the installation and commissioning of industrial machines and equipment. Automobile diagnostics in the factory and in garages, electroplating plants, telecommunication and computer equipment, drives controlled by frequency inverters, industrial controllers and electrical vehicles are important application areas, too.

Earth-leakage measurements in single or three-phase AC networks are possible by inserting two or three conductors in one single probe. The connection to an oscilloscope allows a precise analysis of the current shape with a content of harmonics up to 100 kHz. In HiFi amplifiers, the different loudspeaker currents can be easily measured. For measuring the 4 to 20 mA current loops, the current probes are also frequently used in process control. The battery can be changed easily and offers a service life of about 50 hours.

8.4 Calculation of the measurement accuracy

The output voltage of the clamp-on current probes may vary due to changing environmental conditions or stray fields. Therefore, we advise to check the zero voltage before starting the measurement and, if necessary, to adjust the output voltage to „0.000 V“, using the zero potentiometer (ZERO ADJ for standard models) while keeping the thumbwheel pressed and the primary conductor free of current or outside the jaw. With customer-tailored models, the zero adjustment is performed externally, in the connected evaluation system.

The clamp-on current probes exhibit an error of up to ±1 % of the measured value (±2 mA), when the current-carrying conductor is placed in the centre of the jaws. When measuring alternating currents, the corresponding diagrams for gain and phase shift shown in the instruction sheet must be taken into account.

9 Glossary A-Z

Ampere-turns
Magnetic quantity inside a coil, corresponding to the product of current and number of turns.

Closed loop current transducers
Current transducers in which the primary ampere-turns are compensated by an opposed secondary ampere-turns. The turns ratio determines the value of the secondary current in relation with the primary current.

Closed loop transducers
For these transducers, the magnetic field created by the primary current to be measured, is compensated by a magnetic field of apposed direction, created by the secondary current. The secondary current is a true image of the primary current in proportion of the turns ratio.

C type closed loop transducers
LEM patented, highly accurate transducers operating on the principle of compensating the ampere-turns. A sophisticated electronic circuitry ensures that the first core is maintained within the limits of non-saturation by the compensation current supplied by generator. Temperature effects are eliminated.

Current transformers
As soon as frequency increases, closed loop transducers behave more like current transformers.

Delay time
Delay taken at 10 % of the total variation.

Differential current transducers
The CD differential current transducers can measure differential or leakage currents from several tens of milliamperes up to several amperes.

Eddy currents
Eddy currents in magnetic circuits are generated by magnetic flux changes and increase as the amplitude and frequency of the current grow. They produce heat (Joule effect) which can lead to a temperature increase and may affect the performances and damage the components used.

Frequency range, frequency bandwidth
Current transducers have an upper frequency limit above which the sensitivity decreases by more than 3 dB (1 dB). The AC current transducer LEM-flex shows also a low-end frequency limit of a few Hertz. The frequency range is between the low-end frequency (mostly 0 Hz) and the upper frequency limit.

Frequency response
Dependence of the sensitivity on the frequency of the measuring current.

Hall constant
The Hall constant K depends on the material of the thin sheet used in the Hall effect generator.

Hall effect
This effect was discovered in 1879 by the American physicist Edwin Herbert Hall, at the John Hopkins University in Baltimore. It is caused by the Lorentz force, which acts on the mobile electrical charge carriers in the conductor, when they are exposed to a magnetic field that is perpendicular to the current direction. At the edges of the conductor (thin sheet), a Hall voltage V_H is proportional to the magnetic flux generated.

Hall generator
A thin sheet of semiconductor traversed by a constant current, generating a Hall voltage V_H proportional to the perpendicular magnetic flux B.

Hall sensitivity
It expresses the Hall voltage/magnetic flux ratio and is determined by the Hall constant K of the material, the control current Ic and the reciprocal value of the sheet thickness d: $S_H = K \bullet I_C/d$

Hall voltage
The Hall voltage V_H generated at both edges of the current-carrying thin sheet is proportional to the perpendicular magnetic flux B.

Hysteresis cycle
The hysteresis cycle comprises a complete magnetisation in the positive direction followed by a magnetisation in the reverse direction, starting and ending at $I_P = 0$.

Joule effect
Changes of the magnetic flux generate eddy currents in the conductors, which depend on the amplitude and frequency of I_P and cause a heat effect.

Linearity error
The linearity error is a value that indicates the difference between the actually measured value and the desired value on an ideal straight line. This straight line is generally situated between the null offset and the final value, but it can also be the best fit straight line situated such that the measuring points with positive and negative differences are equally balanced.

Load resistor
Load resistor is connected to the transducer output to convert output current into voltage.

Load voltage
Voltage across the load resistor connected to the transducer output.

Lorentz force
The Hall effect is related to the Lorentz force that acts upon the mobile electrical charge carriers in the conductor, when they are exposed to a magnetic field that is perpendicular to the current direction. This generates a Hall voltage V_H.

Magnetic hysteresis
The magnetic hysteresis is conditioned by the material characteristics of the magnetic circuit and corresponds to the percentage value of the output signal change, with regard to the output signal at nominal current.

Magnetic induction
The magnetic induction or flux B is mostly indicated in millitesla (mT) and can be calculated from the magnetic field strength H, the permeability of vacuum μ_o and the relative permeability μ_r as follows: $B = \mu_o \bullet \mu_r \bullet H$

Magnetic offset
The magnetic offset is due to the residual magnetism and characterises the remaining magnetic flux (null offset), after the return to $I_P = 0$, which can be positive or negative, depending on the direction of the pravious current.

Magnetisation curve
The magnetisation curve illustrates the relation between the primary current I_P (magnetic field strength) and the magnetic flux B.

Maximum error
The maximum error equals the sum of the maximum individual errors of linearity, offset and drift. The real total error is usually smaller.

Multirange closed loop transducers
These universal current transducers have several primary windings which can be connected in series and/or in parallel, thus obtaining different numbers of turns and current ranges. This allows the same current transducer to cover several ranges.

Nominal current
Maximum permantent thermal current that the transducer can carry. Maximum rms current which may flow through the transducer, under specific conditions, so that the temperature during continous operation does not exceed the specified value.

Offset drift
Temperature-conditioned the null offset drift of the output signal. It is specified in mV/K.

Offset error
Difference of the output signal for $I_P = 0$ with reference to zero. In most cases, it is due to electrical criteria, but there can be additional magnetic influences.

Offset voltage
Output voltage differing from zero at $I_P = 0$.

Open loop current transducers
With open loop current transducers, the output signal is a true image of the measuring current. In the gap of the magnetic circuit, the measuring current generates a magnetic field, which is converted into a Hall voltage by the Hall generator and then amplified.

Primary winding
Winding traversed by the primary current to be measured.

Probable error
The probable error is given by the square root of the sum of the squares of the typical individual errors of linearity, offset and drift.

Reaction time
As a response to a sudden current or voltage rise, the delay time is defined as the time interval in which the output signal rises from 0 to 10 % of its final change.

Response time t_r
Response to a sudden rise of the measuring current from zero to the nominal current. The response time is defined as the rise time of the output signal from 10 % to 90 % of the final value.

RMS value
The root mean square value refers to pulse currents, sinusoidal AC currents or any other waveform and is equivalent to a DC current, that would cause the same heat dissipation in an ohmic resistance. For sinusoidal AC currents the rms value is 70.7 % of the amplitude.

Secondary winding
In closed loop current transducers, the secondary winding is used to balance the magnetic flux created by the primary current, so that $N_P \bullet I_P = N_S \bullet I_S$

Sensitivity drift
The sensitivity drift or gain drift only concerns open loop current transducers. It occurs during temperature changes and is specified in %/K.

Temperature drift
Null offset and sensitivity drift caused by temperature changes.

Turns ratio
With closed loop current transducers, the turns ratio represents the ratio of the number of primary turns to the number of secondary turns. For a typical value of 1:1000, a primary current of 1 A results in a secondary current of 1 mA.

Note

Design Specification	LEM Subsidiary ____________ Date : ______	LEM
Type ____________	Contact person ____________	

Customer

Company ____________ City ____________ Country ____________

Contact person ____________

Dept ____________ Phone ____________ Fax ____________

Activity ____________ Project name ____________

Application ☐ industrial ☐ traction ☐ other ____________

Utilisation ☐ voltage ☐ current ☐ other ____________

Function ☐ control ☐ display ☐ ground fault detection
☐ detection ☐ differential meas. ☐ other (provide a separate description)

Electrical characteristics

Transducer reference (if relevant) :

Type of signal ☐ AC sinewave ☐ DC ☐ square ☐ pulse ☐ other
☐ bidirectional ☐ unidirectional

Nominal value: _____ rms, ________ Peak (please provide a graph of the waveform)

Overload value to be measured: ______ rms, ____________ Peak duration: ______ s

Non measured overload: ______ rms, ____________ Peak duration: ______ s

di/dt to be followed: ________ A/µs

Operating frequency: ______ Hz to ______ Hz; Ripple: _____ Peak-Peak Frequency: ______ Hz

Isolation: ____________ kVrms/50Hz/1min. Operating voltage: ____________

Power supply ☐ 12 V ☐ 15 V ☐ 24 V ☐ other ____________
☐ bipolar ☐ unipolar Tolerance: ± _____ %

Preferred Output: ________ mA/A or mV/A ; ________ mA/V or mV/V

Environmental requirements

Temperature range Operating: ______ °C to ______ °C; Storage: ______ °C to ______ °C

Accuracy (in % of nominal value):
Global at 25 °C: ________ %
Allowable offset at 25 °C: ________ %
Overall accuracy over operating temp. range: ________ %

dv/dt applied on primary circuit: ________ kV/µs Bus bar config. (500 A up): provide a lay-out

Mechanical requirements

Maximum dimensions required: L _____ mm x W _____ mm x H _____ mm

Mounting on ☐ PCB ☐ Panel

Output terminals ☐ PCB ☐ Faston ☐ Threaded studs ☐ Molex ☐ Cable
☐ Other

Primary connection ☐ Needed aperture ________ mm x ________ mm or Ø ________ mm
☐ Threaded studs Ø: ________ mm ☐ busbar
☐ Other:

Applicable standards: industrial ☐ EN 50178; traction ☐ EN 50155

If not relevant, please specify: ____________

Total quantity for the project: ____________ Target price: ____________

Delivery schedule: prototype: ____________
(preproduction): ____________
production: ____________

Attached documents: ____________

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