INTERNATIONAL STANDARD

ISO 15548-1

Second edition
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Non-destructive testing — Equipment for eddy current examination —

Part 1: Instrument characteristics and verification

Essais non destructifs — Appareillage pour examen par courants de Foucault —

Partie 1: Caractéristiques de l'appareil et vérifications

Reference number
ISO 15548-1:2013(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

The committee responsible for this document is ISO/TC 135, *Non-destructive Testing*, Subcommittee SC 4, *Eddy current methods*.

This second edition cancels and replaces the first edition (ISO 15548-1:2008), of which it constitutes a minor revision. It also incorporates the Correction ISO 15548-1:2008/Cor 1:2010.

ISO 15548 consists of the following parts, under the general title *Non-destructive testing — Equipment for eddy current examination*:

— *Part 1: Instrument characteristics and verification*

— *Part 2: Probe characteristics and verification*

— *Part 3: System characteristics and verification*

Non-destructive testing — Equipment for eddy current examination —

Part 1: Instrument characteristics and verification

1 Scope

This part of ISO 15548 identifies the functional characteristics of a general-purpose eddy current instrument and provides methods for their measurement and verification.

The evaluation of these characteristics permits a well-defined description and comparability of eddy current equipment.

By careful choice of the characteristics, a consistent and effective eddy current examination system can be designed for a specific application.

Where accessories are used, these are characterised using the principles of this part of ISO 15548.

This part of ISO 15548 gives neither the extent of verification nor acceptance criteria for the characteristics. They are given in the application documents.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12718, *Non-destructive testing — Eddy current testing — Vocabulary*

ISO 15549, *Non-destructive testing — Eddy current testing — General principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12718 apply.

4 Eddy current instrument characteristics

4.1 General characteristics

4.1.1 Type of instrument

a) An instrument has a general-purpose application when the relationship between the measured quantity and the display or output is established by the user. A range of probes can be connected to the instrument. The instrument manufacturer shall provide details of the internal electrical characteristics, in order that the user can design the examination system. The examination system shall be in accordance with ISO 15549. The user shall be able to vary the value of frequency, gain, balance (unless an automatic balance is used), phase, filters and gain and zero of the display.

b) An instrument is of specific application when the relationship between the measured quantity and the display or output is explicitly defined in the range of application. The probe is specific to the instrument. For this type of instrument, this part of ISO 15548 may be partially applied.

4.1.2 Power supply

The instrument can be powered by batteries or by the local AC power supply. The nominal values of voltage, frequency and power consumption shall be stated, together with the tolerance for correct operation.

4.1.3 Safety

The instrument and its accessories shall meet the applicable safety regulations, for example, electrical hazard, surface temperature, explosion, etc.

4.1.4 Technology

The instrument can be wholly analogue or partly analogue and partly digital.

The excitation can be single frequency, multifrequency, swept frequency or pulsed.

The instrument can be single or multichannel.

The instrument settings can be manual, remote controlled, stored or preset.

The instrument shall have component outputs and can be with or without a self-contained display.

4.1.5 Physical presentation

The instrument can be portable, cased or rack mounted, with the component parts integrated or modular.

The weight and size shall be specified for the instrument and its accessories.

The plugs and sockets shall be specified regarding type and pin interconnections.

The instrument model number and the serial number shall be clearly readable and located in a readily accessible place.

4.1.6 Environmental effects

The warm-up time necessary for the instrument to reach stable operating conditions within specified limits shall be stated.

The temperature, humidity and vibration ranges for normal use, storage and transport shall be specified for the instrument and its accessories.

The instrument shall conform to relevant electromagnetic compatibility (EMC) regulations.

4.2 Electrical characteristics

4.2.1 General

The electrical characteristics of an instrument shall be evaluated after the warm-up time has elapsed.

The electrical characteristics are only valid for the stated operating conditions.

When relevant, the stability of the specified values with time, for specified environmental conditions, shall be stated.

The electrical characteristics apply to various items of the functional block diagram of the instrument. Where applicable, they are provided by the manufacturer. Some of these characteristics can be verified according to the methodology described in Clause 6.

4.2.2 Functional block diagram

The functional block diagram of a typical general-purpose eddy current instrument is shown in Figure 1.

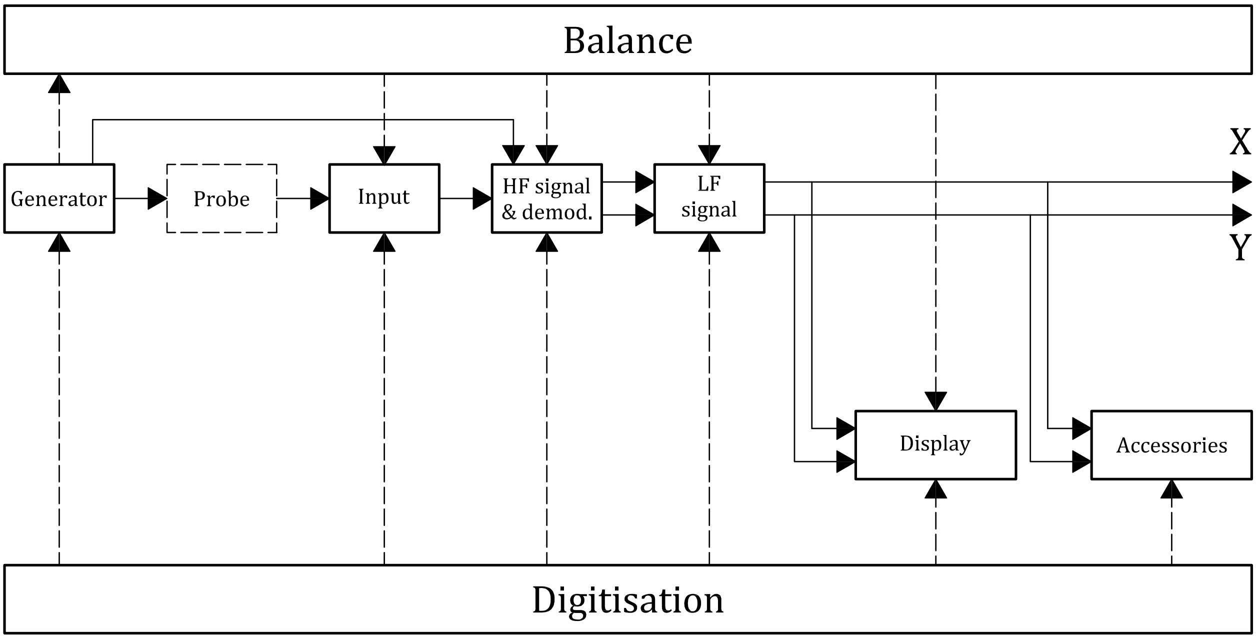


Figure 1 — Functional block diagram of eddy current instrument

4.2.3 Generator unit

The source of excitation is the generator unit.

In the case of alternating excitation (sinusoidal, triangular, rectangular, etc.), the characteristics to be defined are as follows:

— type of generator: current or voltage;

— type of excitation: single or multifrequency;

— frequency setting: range, step size, deviation from nominal value;

— harmonic distortion;

— amplitude setting: range, step size, deviation from nominal value, maximum output voltage or current;

— source impedance with frequency dependence.

In the case of multifrequency excitation, it shall be stated whether frequencies are injected simultaneously or multiplexed, independent or related, and the multiplexing sequence shall be specified, when relevant.

4.2.4 Input stage characteristics

The input stage interfaces the probe to the instrument. It provides impedance matching and amplification, as required.

The characteristics to be defined are as follows:

— input impedance with frequency dependence;

— gain setting range, step size, deviation from nominal value;

— maximum input voltage;

— common-mode operating parameters, when relevant.

4.2.5 Balance

Balance is the compensation of the signal to achieve a predetermined operating point, e.g. zero. The compensation may be performed manually or automatically, at the input stage, or during HF signal processing, or during demodulated signal processing, or on the display.

The characteristics to be defined are as follows:

— maximum input range, which can be compensated;

— residual value at balance (expressed as a percentage of a specified range, e.g. full-scale output).

4.2.6 High-frequency signal processing

4.2.6.1 HF filtering

Filters reduce the signal frequency content which can have an undesirable effect on the test result.

The filters used before demodulation are referred to as carrier frequency filters (HF filters). These are usually band-pass filters which suppress any signal frequencies which do not correspond to the excitation frequency.

The characteristics to be defined are as follows:

— gain;

— bandwidth at 3 dB attenuation;

— rate of attenuation;

— transient response.

4.2.6.2 HF amplification

The characteristics to be defined are as follows:

— gain setting range, step size, deviation from nominal value;

— input signal range;

— bandwidth;

— output saturation level.

4.2.6.3 Demodulation

Synchronous demodulation extracts the vector components from the HF signal.

For positive polarity of demodulation, a delay in the signal will cause the signal vector to rotate clockwise. The polarity of demodulation shall be positive and shall be confirmed.

The characteristics to be defined are as follows:

— wave shape of the reference signal, e.g. sine, square, pulse;

— bandwidth for each wave shape of the reference signal;

— phase-dependent amplitude deviations;

— phase-dependent phase deviations.

Amplitude demodulation extracts the low-frequency amplitude variations from the HF signal.

4.2.7 Demodulated signal processing

4.2.7.1 Vector amplification

Vector amplification generally consists of two transmission channels of identical design. These channels amplify the vector components produced by synchronous demodulation. In some instruments, these components can be amplified with different gains.

The characteristics to be defined are as follows:

— gain setting range, step size, deviation from nominal value;

— input signal ranges;

— bandwidth;

— output saturation level.

4.2.7.2 LF filtering

The filters used after demodulation are referred to as low-frequency filters (LF filters). The bandwidth of the filter is chosen to suit the application, e.g. wobble, surface speed, etc.

The characteristics to be defined are as follows:

— gain;

— bandwidth at 3 dB attenuation;

— rate of attenuation;

— transient response.

4.2.7.3 Phase setting

Phase setting permits rotation of the demodulated signal vector on the complex plane display.

The characteristics to be defined are as follows:

— range;

— step size;

— amplitude variation of the signal vector with phase setting;

— deviation of indicated phase rotation from actual phase rotation.

4.2.8 Output and signal display

The type of display can be an indicator display, or a hard-copy display, or a screen display.

The type of presentation can be, for example, complex plane, ellipse, time-synchronous, frequency spectrum, imaging.

The related characteristics to be defined include:

- size;
- graticule divisions, major and minor;
- full-scale-display voltage range or time range;
- transfer factor e.g. volts/division;
- linearity;
- bandwidth.

The output can be analogue, digitised or logical.

The characteristics of analogue outputs to be defined are as follows:

- voltage or current range;
- output impedance;
- linearity;
- bandwidth.

The characteristics of digitised outputs to be defined are as follows:

- data protocol;
- serial or parallel;
- voltage and current levels;
- speed and format;
- sampling rate;
- analogue/digital A/D resolution, range and linearity.

The characteristics of logical outputs to be defined are as follows:

- voltage and current levels;
- settling delay;
- hysteresis;
- actively high or low.

4.2.9 Digitisation

4.2.9.1 General

Whenever digitisation is performed, the following characteristics shall be defined:

- stage of digitisation in the signal processing;
- digitisation technique;
- A/D resolution;

— sampling rate.

The information supplied by the manufacturer shall therefore include data on the parameters in 4.2.9.2 to 4.2.9.5.

4.2.9.2 Stage of digitisation

Digitisation may be performed either before or after signal demodulation.

4.2.9.3 Digitisation technique

Digitisation can be performed using an internal clock or an external encoder.

4.2.9.4 A/D resolution

Resolution is the nominal value of the converter input voltage corresponding to one digitisation bit.

The number of digitisation bits is equally useful information, even though it can be directly accessed through the maximum input voltage and the resolution.

4.2.9.5 Sampling rate

The sampling rate is the frequency, in hertz, at which the A/D conversion is made.

5 Verification

5.1 General

For a consistent and effective eddy current examination, it is necessary to verify that the performance of the component parts of the eddy current test system is maintained within acceptable limits.

The physical condition of the reference blocks shall be verified to be within acceptable limits before being used to verify the system or probes.

The measuring equipment used for verification shall be in a known state of calibration.

For a better understanding, the verification procedure is described identically in all three parts of ISO 15548.

5.2 Levels of verification

There are three levels of verification. Each level defines the time intervals between verification and the complexity of the verification.

It is understood that initial type testing has already been carried out by the manufacturer or under his control.

a) **Level 1: Global functional check**

A verification is performed at regular intervals of time on the eddy current test system, using reference blocks to verify that the performance is within specified limits.

The verification is usually performed at the examination location.

The time interval and the reference pieces are defined in the verification procedure.

b) **Level 2: Detailed functional check and calibration**

A verification on an extended time scale is performed to ensure the stability of selected characteristics of the eddy current instrument, probe, accessories and reference blocks.

c) **Level 3: Characterisation**

A verification is performed on the eddy current instrument, probe accessories and reference blocks to ensure conformity with the characteristics supplied by the manufacturer.

The organization requiring the verification shall specify the characteristics to be verified.

The main features of verification are shown in Table 1.

Table 1 — Verification levels

Level	Object	Typical time period	Instruments	Responsible entity
1 Global functional check	Stability of system performance	Frequently, e.g. hourly, daily	Reference blocks	User
2 Detailed functional check and calibration	Stability of selected characteristics of the instrument, probes and accessories	Less frequently but at least annually and after repair	Calibrated measuring instruments, reference blocks	User
3 Characterisation	All characteristics of the instrument, probes and accessories	Once (on release) and when required	Calibrated laboratory measuring instruments and reference blocks	Manufacturer, user

5.3 Verification procedure

The characteristics to be verified are dependant on the application. The essential characteristics and the level of verification shall be specified in a verification procedure.

The examination procedure for the application shall refer to the verification procedure. This can restrict the number of characteristics to be verified for a defined application.

Sufficient data on the characteristics featured in an instrument, probe and reference piece shall be provided, in order that verification can be performed within the scope of this part of ISO 15548.

5.4 Corrective actions

Level 1: When the performance is not within the specified limits, a decision shall be made concerning the product examined since the previous successful verification. Corrective actions shall be made to bring the performance within the acceptable limits.

Level 2: When the deviation of the characteristic is greater than the acceptable limits specified by the manufacturer or in the application document, a decision shall be made concerning the instrument, the probe or the accessory being verified.

Level 3: When the characteristic is out of the acceptable range specified by the manufacturer or by the application document, a decision shall be made concerning the instrument, the probe or the accessory being verified.

6 Measurement of electrical characteristics of instrument

6.1 Measuring requirements

All measurements described in the following subclauses are made at the inputs and outputs of the instrument. These measurements do not require opening the instrument (black-box concept).

Keeping the black-box concept, any alternative method, the equivalence of which shall be demonstrated, may be used.

Shielded, non-inductive resistors shall be used as loads. The resistors shall have a value of 50 Ω. Additional measurements may be made with other values of the resistor. However, it needs to be stressed that the characteristics of an instrument can be significantly altered if a different load is necessary for the instrument or the application. In such a case, the load used shall be noted in the test report.

The measurements described hereafter shall be made at three values in each decade of the frequency range, for example, using multiplication factors 1, 2 and 5. For example, in the decade between 10 and 100 kHz use 10, 20 and 50 kHz.

It should be noted that the filter settings used for a specific application will modify the characteristics, for example, bandwidth, gain setting accuracy and phase-setting accuracy. In this case, the measurement conditions for verification shall be specified in the application document.

6.2 Generator unit

6.2.1 Excitation frequency

6.2.1.1 Definition and measurement conditions

The frequency shall be measured at the generator output of the instrument loaded in accordance with 6.1.

The percentage deviation from the displayed value is:

$$\frac{V_\mathrm{d} - V_\mathrm{m}}{V_\mathrm{d}} \times 100 \qquad (1)$$

where

V_d is the displayed value;

V_m is the measured value.

The maximum modulus of deviation in the total range of frequencies measured shall be reported.

6.2.1.2 Measurement method

The frequency may be measured using the beat frequency method, a frequency meter or a spectrum analyser.

In the case of multifrequency, multiplexed instruments then appropriate instrumentation shall be used, e.g. spectrum analyser.

6.2.2 Harmonic distortion

6.2.2.1 Definition and measurement conditions

For a generator producing a sinusoidal waveform, the harmonic content is used as a measure of the deviation from a pure sinusoid.

The harmonic distortion is described by the distortion factor, k.

k is the ratio of the RMS value of harmonics and the RMS value of alternating quantity:

$$k = \sqrt{\sum U_n^2} / U \quad (2)$$

An approximate value is given by:

$$k = \frac{\sqrt{U^2 - U_1^2}}{U} \quad (3)$$

where

U is the RMS value of the alternating quantity;

U_1 is the RMS value of the first harmonic (fundamental);

U_n is the RMS value of the nth harmonic.

The distortion factor shall be measured at the generator output of the instrument loaded in accordance with 6.1.

In the case of multifrequency instruments, sufficient instrumentation shall be used, e.g. spectrum analyser.

The value to be stated is the maximum distortion factor for each frequency.

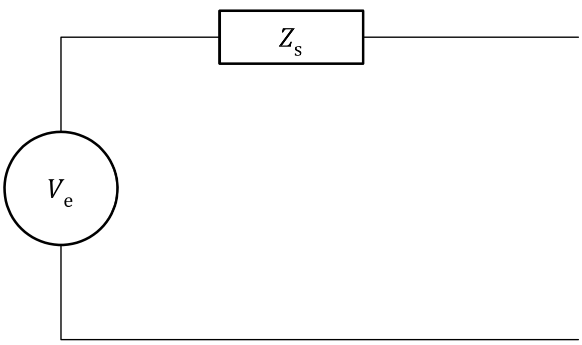
6.2.2.2 Measurement method

The distortion factor may be measured using a distortion-factor bridge, a spectrum analyser or a high-pass filter.

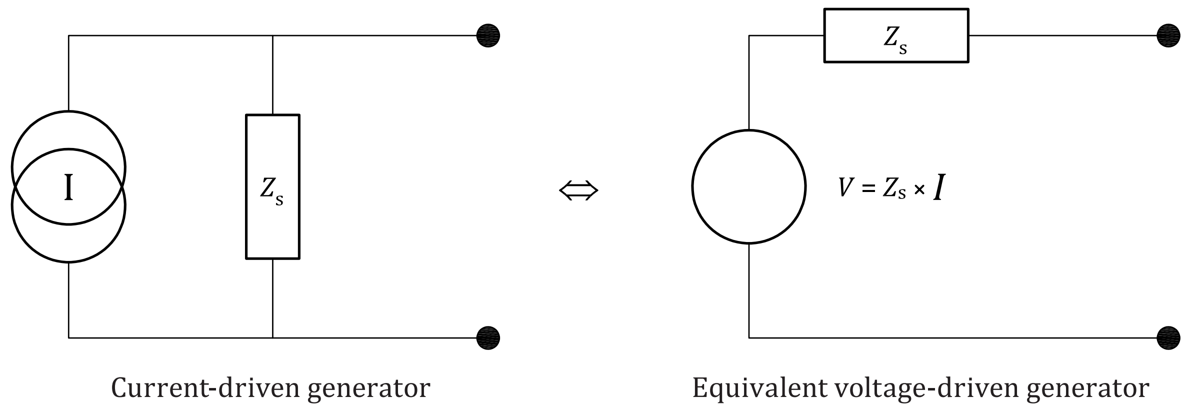
6.2.3 Source impedance

6.2.3.1 Definition and measurement conditions

The source impedance, Z_S, is the internal impedance of the generator unit (see Figure 2), measured at each independent output.



a) Voltage-driven generator



b) Current-driven generator

Key

I source impedance Z_s

Figure 2 — Internal impedance of generator unit

6.2.3.2 Measurement method

The method proposed is based on the assumption that the complex source impedance Z_s can be considered as resistive.

The generator output is loaded with a resistor R_1 (normally 50 Ω). The voltage V_1 is measured with an appropriate voltmeter. It is important to verify that the measured value is less than the maximum output voltage.

Repeat the measurement with a resistor R_2 (normally $R_2 = 0{,}5\ R_1$) and measure V_2.

Z_s, expressed in ohms, is:

$$Z_s = \frac{V_1 - V_2}{(V_2/R_2) - (V_1/R_1)} \quad (4)$$

NOTE 1 Verify that the values of V_1 and V_2 and the intensities V_1/R_1 and V_2/R_2 are less than the maximum output voltage and current.

NOTE 2 The choice of R_1 and R_2 determines the precision of the measured value of Z_s.

6.2.4 Maximum output voltage, V_{0max}

6.2.4.1 Definition and measurement conditions

The maximum output voltage is the peak-to-peak voltage at the generator terminals with no load applied and the generator set to give its maximum output.

6.2.4.2 Measurement method

The maximum output voltage is measured using an oscilloscope or an adequate voltmeter. The measuring instrument shall have a high input impedance (>1 MΩ) and a bandwidth compatible with the frequency range of the eddy current instrument. Typically, the maximum usable frequency of the measuring instrument shall be at least twice the maximum frequency of the eddy current instrument.

The measured values can be presented in graphical format.

6.2.5 Maximum output current, I_{0max}

6.2.5.1 Definition and measurement conditions

The maximum output current is the peak value of the current measured at the generator terminals when terminated with the lowest permissible resistive load, as defined by the manufacturer. The generator is set to give its maximum output.

6.2.5.2 Measurement method

The maximum output current is measured with a current probe connected to an oscilloscope or with an ammeter. The measuring instrument shall have a low impedance (typically less than 10 % of the smallest resistive load), and a bandwidth compatible with the frequency range of the eddy current instrument.

The measured values can be presented in graphical format.

6.3 Input stage characteristics

6.3.1 Maximum allowable input voltage

6.3.1.1 Definition and measurement conditions

The maximum allowable input voltage is related to safety, saturation and nonlinearity.

It is respectively the peak input voltage at minimum gain, corresponding to the following:

a) the maximum value given by the manufacturer; this is the safe input voltage such that the instrument is not damaged; it includes common-mode operating limits when relevant;

b) 90 % of the output at saturation;

c) the nonlinearity exceeding a given value. The maximum allowable deviation from linearity shall be defined in the application document.

In all cases, the input voltage applied shall not exceed that given in a).

6.3.1.2 Measurement method

6.3.1.2.1 Related to saturation

The frequency beat method is used (see principle in Annex A). The input voltage is to be provided by a sine-wave generator. The difference between the frequency of the signal generator and the selected frequency of the instrument shall not be greater than 10 % of the stated bandwidth of the instrument.

The gain of the instrument is set to minimum and the filters are set to have a minimum effect. The input and each output is loaded with a pure resistor.

Ensure that the instrument is balanced. The input signal is measured using a high-impedance voltmeter.

The output signal is displayed on an oscilloscope and its X and Y components are measured using a peak voltmeter.

The input voltage is increased from zero to the safe input voltage given by the manufacturer, and the positive and negative peak values of each component of the output voltage are plotted (V_{x+}, V_{x-}, V_{y+}, V_{y-}). The first value of the four variables (i.e. that corresponding to the smallest value of the input), which ceases to increase when reaching a steady value V_S, provides the saturation output level V_S. The input value V_{iS} thus obtained is then decreased until the component being monitored reaches an output value of 90 % V_S.

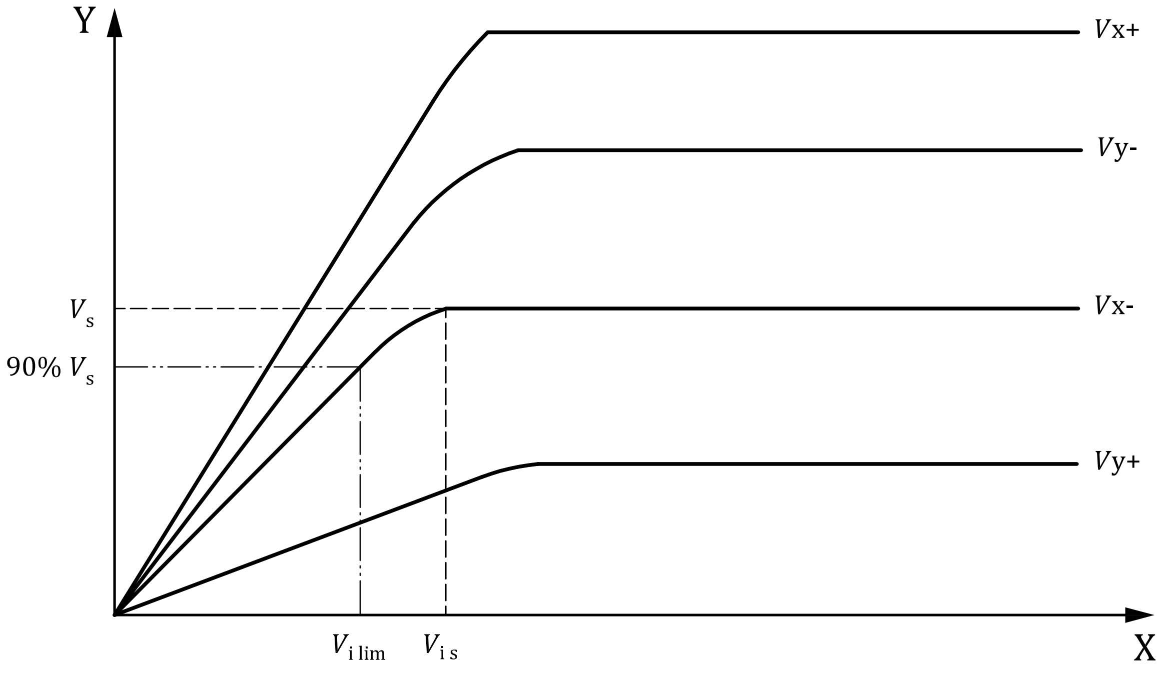
The input voltage obtained corresponds to the maximum allowable input voltage, related to saturation, defined as V_{ilim} in Figure 3.

6.3.1.2.2 Related to nonlinearity

Using the measurement method of 6.3.1.2.1, and the method for determining linearity given in Annex B, determine the maximum input voltage such that the nonlinearity is less than that given in the relevant application document.

For this specific case, substitute in Annex B the following:

I	= input voltage	O	= output voltage
I_{min}	= zero	I_{max}	= input voltage related to saturation (see 6.3.1.2.1)



Key

X input voltage (V_S saturation output level)

Y output voltage

NOTE The relative amplitudes of each output are for example only.

Figure 3 — Measurement of maximum allowable input voltage related to saturation

6.3.2 Input impedance

6.3.2.1 Definition and measurement conditions

The input impedance is the apparent impedance of the input stage. The equivalent circuit is the parallel combination of a resistor and a capacitor.

6.3.2.2 Measurement method

A network analyser or an impedance meter can be used.

The alternative method described in Annex C can be used. The use of any other alternative method shall be reported.

No voltage greater than the maximum input voltage shall be applied.

6.4 Signal processing

6.4.1 General

The signal processing stage comprises high-frequency and low-frequency signal processing, as specified on the block diagram in Figure 1.

6.4.2 Measurement conditions

These measurement conditions apply for 6.4.3 to 6.4.13, unless indicated otherwise.

The resistor terminating the input (see 6.1) shall be shielded. The gain of the instrument shall be set to its minimum value. The instrument shall be balanced with zero input voltage. All filters shall be set to have a minimum effect.

It should be noted that the filter settings used for a specific application will modify characteristics, for example, bandwidth, gain setting accuracy and phase-setting accuracy. In this case, the measurement conditions for verification shall be specified in the application document.

Since the measured value is the output value, no distinction can be made between the filtering effect of the HF filter and the demodulator. If the HF filter is adjustable, it should be set to the value recommended by the manufacturer for the selected test frequency.

Using the frequency beat method (see Annex A), adjust the output voltage of an external signal generator, connected to the input, to half of the maximum allowable input voltage of the instrument related to linearity.

The difference f_d between the frequency of the signal generator and the selected frequency of the instrument shall not be greater than 10 % of the bandwidth of the instrument, as specified by the manufacturer.

6.4.3 Balance

6.4.3.1 Residual output value at balance

6.4.3.1.1 Measured quantity and measurement conditions

The value of the output modulus that is obtained following the balancing operation. The value shall be described as a percentage of a specified range, e.g. full-scale output.

6.4.3.1.2 Measurement method

Following the balancing operation, measure the output value of each component.

The maximum value of several balancing operations (a minimum of five) shall be taken.

6.4.3.2 Maximum compensatable input voltage

6.4.3.2.1 Measured quantity and measurement conditions

The maximum value of the input voltage that may be nulled electrically.

6.4.3.2.2 Measurement method

A voltage derived from the instrument generator is applied to the input.

It is progressively increased and nulled until the residual value obtained equals twice the residual value at the balance, as obtained in 6.4.3.2.1.

The value of the input signal is measured with a high-impedance voltmeter with an adequate bandwidth.

The measured value shall be stated as a percentage of the maximum input voltage related to nonlinearity.

6.4.4 Harmonic attenuation

6.4.4.1 Measured quantity and measurement conditions

The voltage ratio of the nth harmonic response V_{fn} to the fundamental response V_{f1} is:

$$\text{Attenuation (in dB)} = 20\log\frac{V_{fn}}{V_{f1}} \quad (5)$$

6.4.4.2 Measurement method

Using the beat frequency method, adjust the frequency of an external signal generator to the fundamental frequency f_1, noting the difference frequency f_d. Measure the value V_{f1} at one of the component outputs.

Reset the signal generator frequency to the frequency $2f_1 + f_d$, that is the same difference in frequency used with the fundamental. Measure the value V_{f2}.

Repeat for each harmonic up to the fifth, and then, if necessary, until attenuation exceeds 60 dB.

6.4.5 Frequency response of the signal processing stage

6.4.5.1 Measured quantity and measurement conditions

The frequency range in which the demodulated signal is obtained with an amplification smaller than m dB and with an attenuation less than n dB.

The values of m and n shall be specified in the application document. Since the frequency response is generally stated at ± 3 dB, these values are used in this part of ISO 15548.

6.4.5.2 Measurement method

The difference f_d between the signal generator frequency and that of the instrument takes 10 values equally spaced on a logarithmic scale. The lowest value depends on the operating frequency of the instrument, and the highest value is twice the upper limit of the output bandwidth of the instrument specified by the manufacturer.

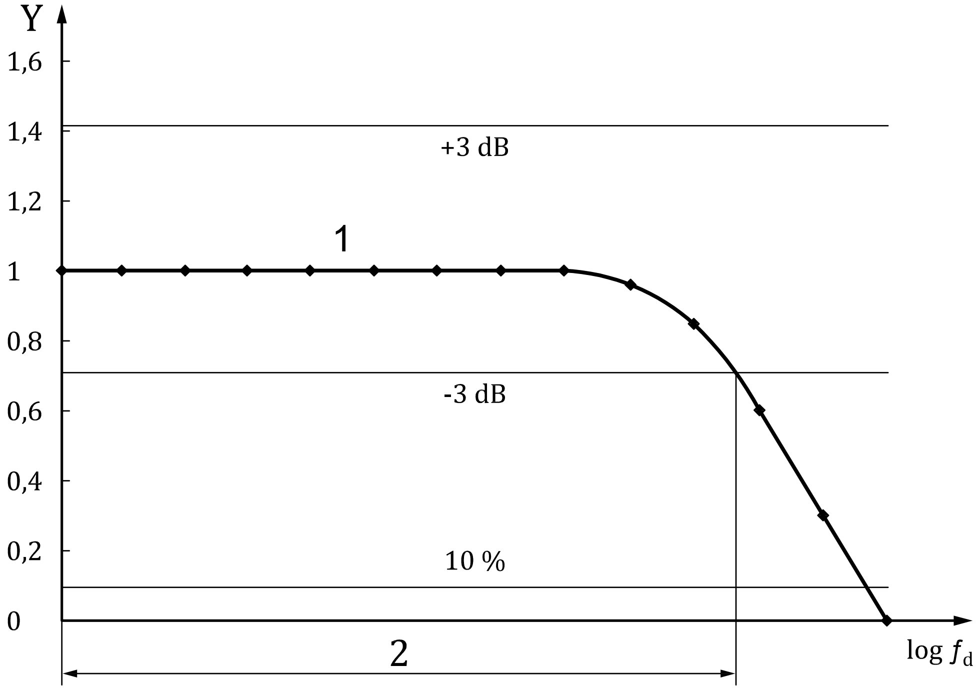
It is important to ensure that f_d remains constant during the measurement of each value.

The peak-to-peak amplitude of the component outputs and the frequency f_d are measured with a very-low-frequency voltmeter and a frequency meter. Results may be stated in the form of a table of frequency and amplitude for each component of the output signal.

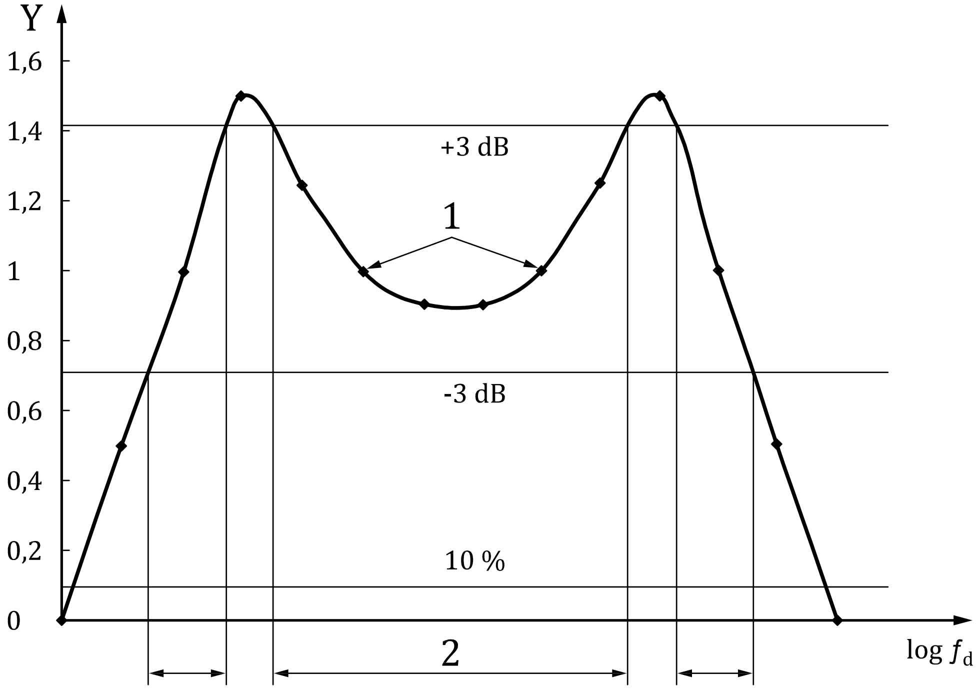
The voltage reference value for each component is obtained in the following way. Starting from the maximum amplitude, the median value is calculated from the measured values which fall in the range between 10 % of the maximum and the maximum.

The points, the amplitude of which are ± 3 dB of the median value, are the extremes of the frequency response.

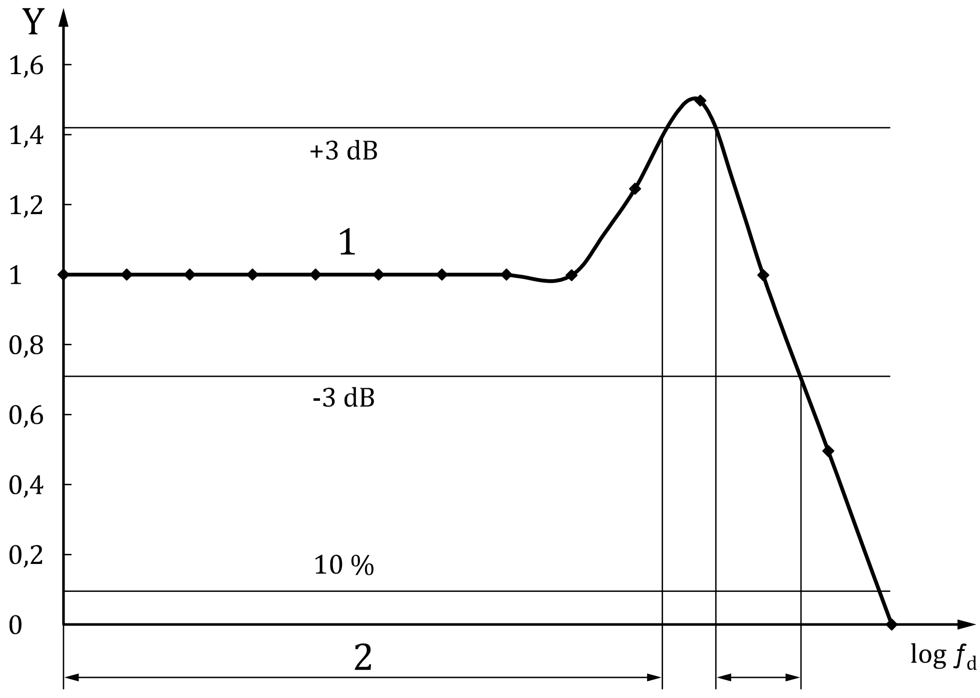
Figure 4 shows three different examples of frequency response. It can be seen that, in some cases, the frequency range can include several sections.



Example 1



Example 2



Example 3

Key

Y output (arbitrary unit)

1 median value

2 ±3 dB level response

Figure 4 — Examples of frequency response

6.4.6 Bandwidth

6.4.6.1 Measured quantity and measurement conditions

Bandwidth is obtained by taking the values from 6.4.5.2 and applying only the attenuation of n dB. Generally n will be equal to 3.

6.4.6.2 Measurement method

Use the method described in 6.4.5.2.

6.4.7 Phase linearity

6.4.7.1 Measured quantity and measurement conditions

Phase linearity of the instrument is the constancy of the difference between the phase angle of the output components and the phase angle of the input signal.

It is characterised by the maximum deviation from linearity obtained on the output, over 0° to 360° change in the value of the input phase angle.

6.4.7.2 Measurement method

The frequency beat method requires a dynamic measurement described as an example hereafter.

The two components of the output are synchronously acquired with a data acquisition system having a sampling frequency f_e greater than $36f_d$ (i.e. a maximum of 10° per sample).

For one period of the output signal, the set of data are stated in Table 2:

Table 2 — Example of table for statement of data set

i	1	2	...										*n*
X													
Y													

A table of recentred values is obtained by subtraction of the continuous component from the X and Y components. The continuous component is X_{av} or Y_{av}, the average of all the samples, and where $X_{irec} = X_1 - X_{av}$ and $Y_{irec} = Y_1 - Y_{av}$.

The phase angle of the ith sample is:

$$\Phi_{mi} = \arctan\left(Y_{irec} / X_{irec}\right) \text{ if } X_{irec} \geq 0 \tag{6}$$

$$\Phi_{mi} = \arctan\left(Y_{irec} / X_{irec}\right) + 180° \text{ if } X_{irec} < 0 \tag{7}$$

This value is to be compared to the theoretical value for the ith sample: $\Phi_{thi} = i(f_d/f_e) \times 360 + \Phi_{mo}$. See Table 3.

Table 3 — Example for comparison table of phase angle value with theoretical value

i	1	2	...										*n*
X_{rec}													
Y_{rec}													
Φ_m													
Φ_{th}													

The maximum deviation from linearity in degrees is given by $\Delta\Phi_{m\,max} = \max(\Phi_{mi} - \Phi_{thi})$

6.4.8 Orthogonality of components

6.4.8.1 Definition and measurement conditions

Orthogonality of components is the capability of the instrument to output quadrature-demodulated components.

It is characterised by the deviation from orthogonality, or the deviation between 90° and the actual phase shift between channel X and channel Y.

6.4.8.2 Measurement method

The phase angle between the X and Y outputs is measured with a phase meter or lock-in amplifier.

Alternatively, it may be taken from the data collected in 6.4.6, but with the sampling frequency f_e greater than 360 f_d (i.e. a resolution of at least 1°).

6.4.9 Gain-setting accuracy

6.4.9.1 Definition and measurement conditions

Gain-setting accuracy is the capability of the instrument to amplify a signal in a linear way. It is characterised by the maximum deviation from linearity in decibels (dB) between a set value and the measured value. It shall be measured for each component.

6.4.9.2 Measurement method

If the signal generator does not include an attenuator then a calibrated attenuator shall be fitted between the signal generator and the instrument.

With the initial condition of minimum gain, the output values of each component are measured and taken as the references, X_{ref} and Y_{ref}.

The gain range of the instrument shall be divided into at least five equispaced intervals, e.g. 6 dB or 10 dB.

The gain of the instrument is increased by this interval and the output of the generator reduced by the same interval. The two components of the output are measured for each interval.

The deviation in gain at each interval value, in decibels, is given by:

$$E_x = 20\log\left(V_x / V_{x\,ref}\right) \quad (8)$$

$$E_y = 20\log\left(V_y / V_{y\,ref}\right) \quad (9)$$

The maximum deviation is the largest value of the deviation in gain.

6.4.10 Phase-setting accuracy

6.4.10.1 Definition and measuring conditions

Phase-setting accuracy is the difference between the expected and the actual change in the value of the phase of the output vector when a phase shift is made using the phase control. The amplitude deviation due to the phase setting shall be reported.

6.4.10.2 Measurement method

The instrument generator output is connected through an attenuator to the input.

With no input voltage, balance the instrument and measure each component of the output, X_{ref} and Y_{ref}.

Adjust the input voltage to half the maximum input voltage related to nonlinearity.

With the phase control set to 0°(Φ_0), measure the output of each component, X_0, X_0 and Y_0. Calculate the amplitude and the phase angle of the output vector.

$$V_0 = \sqrt{\left(X_0 - X_{ref}\right)^2 + \left(Y_0 - Y_{ref}\right)^2} \quad (10)$$

$$\Phi_0 = \arctan\frac{\left(Y_0 - Y_{ref}\right)}{\left(X_0 - X_{ref}\right)} \qquad \text{if } X_0 - X_{ref} \geq 0 \quad (11)$$

$$\Phi_0 = \arctan\frac{(Y_0 - Y_{ref})}{(X_0 - X_{ref})} + 180° \qquad \text{if } X_0 - X_{ref} < 0 \tag{12}$$

Change the phase control in i steps not exceeding 10° ($i\Phi_e$) and repeat the measurement and calculation, for a total of 360°.

The phase deviation, in degrees, is:

$$\Phi_d = \Phi_i - (i\Phi_e) \tag{13}$$

The amplitude deviation, in percentage, is:

$$V_d = \left[(V_i - V_0)/V_0 \right] \times 100 \tag{14}$$

The maximum values of Φ_d and V_d shall be reported.

6.4.11 Cross-talk

6.4.11.1 Definition and measuring conditions

Cross-talk characterises the mutual interference between channels of a multichannel instrument or between absolute and differential channels.

6.4.11.2 Measurement method

6.4.11.2.1 Multichannel instrument

All channels are set to the same frequency.

The input of each channel in turn is connected to an external signal generator. The generator output shall be the maximum input voltage related to linearity.

With the gain of the other channels set to maximum, the value of the component outputs of each of the other channels is measured.

For n channels where j = 1, n, the output of the jth channel is:

$$\left| V_{Sj} \right| = \sqrt{V^2{}_{Xj} + V^2{}_{Yj}} \tag{15}$$

When feeding the ith channel, the cross-talk factor, t_i, for the channel is:

$$t_i = 20 \log \left[\max_{j \neq i} \frac{\left| V_{Sj} \right|}{\left| V_{Si} \right|} \right] \tag{16}$$

The cross-talk factor for the instrument is defined as $t = \max(t_i)$

6.4.11.2.2 Absolute and differential channels

6.4.11.2.2.1 Cross-talk between absolute output and differential output

This measurement is a particular case of the measurement in 6.4.11.2.1 with only two channels. The absolute channel (replace index 1 by index A) and the differential channel (replace index 2 by index D).

In the measurement described in 6.4.11.2.1, i and j take the values of A and D.

6.4.11.2.2.2 Cross-talk between absolute and differential inputs

Replace the probe by two matched resistors (see Figure 5). Using the frequency beat method, an external sine-wave generator is connected to the input.

The signal of the absolute output is displayed on an oscilloscope and its X and Y components are measured using a peak voltmeter (V_{XA} and V_{YA}).

Apply the maximum input voltage related to linearity and place the switch in position 1.

V_{XA} and V_{YA} become V_{XA1} and V_{YA1}.

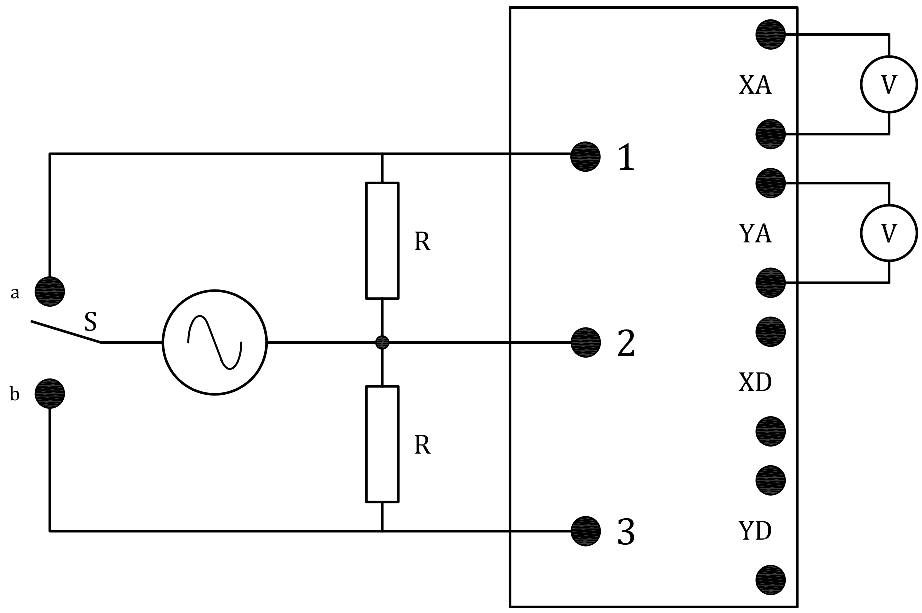
The switch is then placed on position 2.

V_{XA} and V_{YA} become V_{XA2} and V_{YA2}.

$$\left|V_{SAi}\right| = \sqrt{V_{XAi}^2 + V_{YAi}^2} \qquad i = 1 \text{ or } 2 \tag{17}$$

The cross-talk factor t, expressed in decibels, is:

$$t_i = 20\log\frac{\left|V_{SA2}\right|}{\left|V_{SA1}\right|} \tag{18}$$



Key

1 input 1
2 common
3 input 2
a Switch position 1.
b Switch position 2.

Figure 5 — Arrangement for measurement of cross-talk between absolute and differential inputs

6.4.12 Common-mode rejection

6.4.12.1 Definition and measuring conditions

This measurement characterises the ability of the instrument to suppress the common-mode signal. This verification procedure only applies to instruments used for differential measurement.

6.4.12.2 Measurement method

Replace the probe by two matched resistors (see Figure 6). Using the frequency beat method, an external sine-wave generator is connected to the input.

Apply the maximum input voltage related to linearity and place the switch in position 1.

V_X and V_Y become V_{X1} and V_{Y1}.

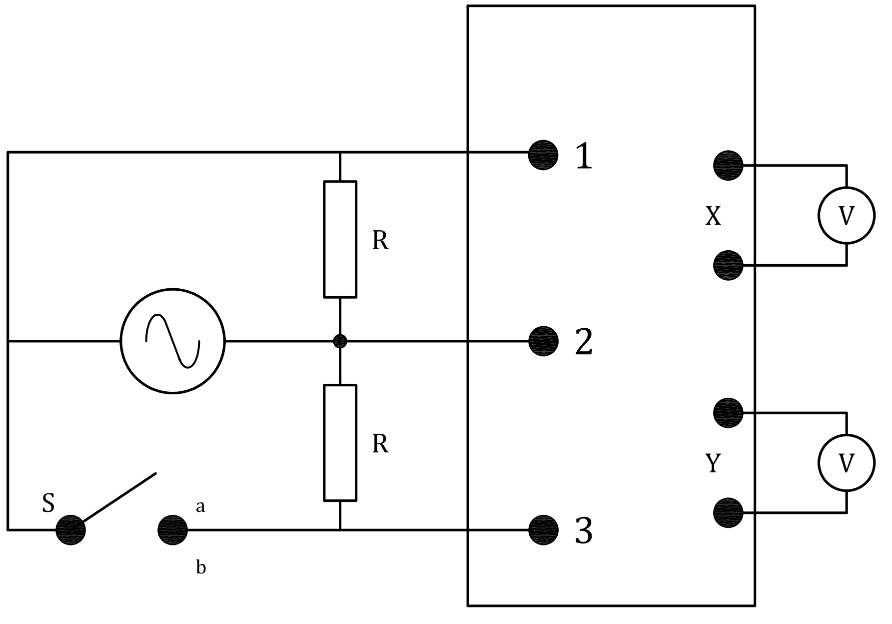
The switch is then placed on position 2 and the input voltage is divided by 2.

V_X and V_Y become V_{X2} and V_{Y2}.

$$\left|V_{Si}\right| = \sqrt{V_{Xi}^2 + V_{Yi}^2} \qquad i = 1 \text{ or } 2 \tag{19}$$

The rejection quality factor q_r is:

$$q_r = V_{S1}/V_{S2} \tag{20}$$



Key

1 input 1

2 common

3 input 2

a Switch position 1.

b Switch position 2.

Figure 6 — Arrangement for measurement of common-mode rejection

6.4.13 Maximum instrument noise

6.4.13.1 Definition and measuring conditions

The maximum instrument noise corresponds to the input voltage equivalent to the maximum residual output signal when no input signal is applied with the instrument set at maximum bandwidth.

The instrument noise may be measured under other operating conditions specified in the application document.

In all cases, the bandwidth shall be reported.

6.4.13.2 Measurement method

Apply to the input the maximum allowed voltage $V_{\text{max in}}$ (gain = G_{min}).

Measure the resulting output $V_{\text{max out}}$.

Increase the gain (if possible to maximum gain) G_{max}.

With zero input, measure the output due to instrument noise $V_{\text{noise out}}$, using a true RMS voltmeter with a bandwidth greater than or equal to the bandwidth of the instrument.

Calculate the equivalent noise at the input.

$$V_{\text{eq}} = V_{\text{noise out}} \frac{V_{\text{max in}}}{V_{\text{max out}}} \times \frac{G_{\text{min}}}{G_{\text{max}}} \quad (21)$$

6.5 Output

Full-scale output is the output value corresponding to the maximum allowable input voltage related to saturation or to linearity, as measured in 6.3.1.

6.6 Digitisation

With the instrument being considered as a black box, there is no general method allowing the parameters characterising digitisation, defined in 4.2.9, to be measured.

Annex A
(informative)

Principle of frequency beat method

The principle is described using, as an example, an eddy current instrument with multiplier and associated filter demodulation.

The method consists in applying at the input of the instrument a sinusoidal voltage, the frequency of which slightly differs from that of the frequency on the instrument: $f_s = f_1 + f_d$. At the level of the internal demodulation circuit (see Figure A.1), a beat is thus produced with the frequency f_1 of the generator.

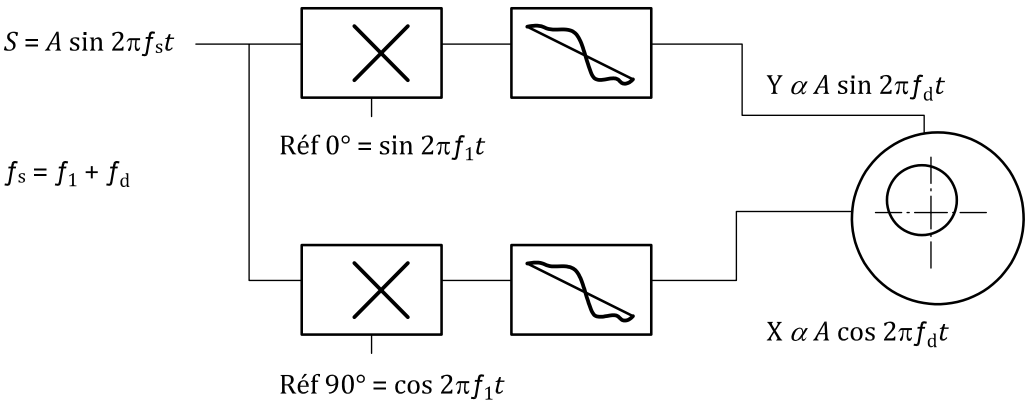


Figure A.1 — Demodulation circuit

In this example, demodulation consists in determining the real and imaginary components of the signal.

$$S_x(t) = A\sin[2\pi(f_1 + f_d)t]\ \sin 2\pi f_1 \cdot t$$

Rewritten as

$$S_x(t) = A/2[\cos 2\pi f_d \cdot t - \cos 2\pi(2f_1 + f_d)\cdot t] \quad \text{(A.1)}$$

$$S_y(t) = A\sin[2\pi(f_1 + f_d)\ t]\ \cos 2\pi f_1 \cdot t$$

Rewritten as

$$S_y(t) = A/2[\sin 2\pi f_d \cdot t + \sin 2\pi(2f_1 + f_d)\cdot t] \quad \text{(A.2)}$$

The low-pass filters included in the circuit suppress the second terms in Formulae (A.1) and (A.2) which contain the frequency $(2f_1 + f_d)$.

At the outputs of the instrument, two signals X and Y, the amplitude of which is proportional to A, modulated respectively by a cosine and a sine at the frequency f_d, are available.

In the case of an ideal instrument, these two voltages, applied to an oscilloscope, display on the screen a circle, the radius of which is proportional to *A*, the spot rotating at f_d.

Generally, the difference f_d between the frequency of the signal generator and the selected frequency of the instrument shall not be greater then 10 % of the bandwidth of the instrument, as specified by the manufacturer.

To measure the frequency of the instrument generator, the frequency of the input signal f_s is adjusted, in order that the spot stops rotating on the screen.

In this case, $f_1 = f_s$.

Annex B
(informative)

Method of measurement of linearity range between output and input

The extreme values of the parameter input, I, are I_{min} and I_{max}.

The parameter I varies in constant steps between I_{min} and I_{max}. For each value of I, the corresponding value of the parameter ouput, O, is measured.

A linear regression is performed between these values of I and O. A relationship $O\text{lin}(I)$ is thus obtained.

The deviation, $\Delta(I)$, in percentage, is defined as follows:

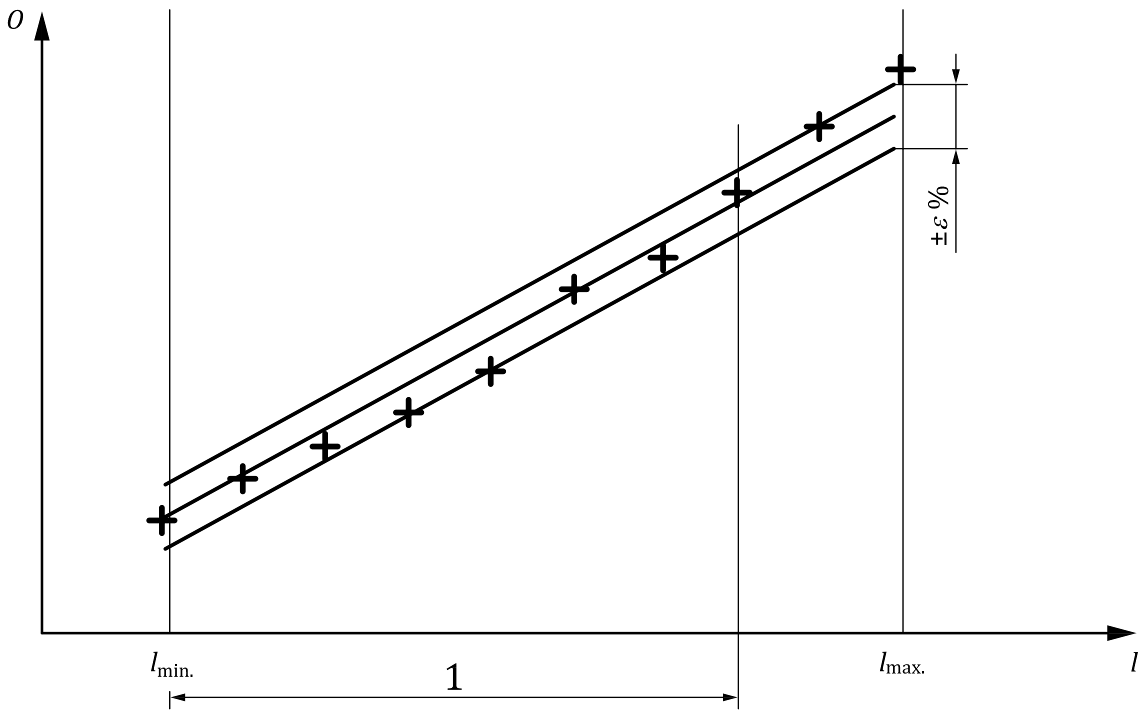
$$\Delta(I)=\left[\left|O(I)-O\text{lin}(I)\right|\right]/\left[\left|O\text{lin}(I_{max})-O\text{lin}(I_{min})\right|\right]\times 100$$

The ε % linearity range is the set of values of I such that:

$$\Delta\ \% \leq \varepsilon\ \%$$

where ε is the maximum allowable deviation of linearity, in percentage.

Figure B.1 shows the determination of the linearity range, using the above procedure.



Key

1 linearity range

NOTE Such a measurement applies to amplitude linearity. For phase linearity, deviations are measured in degrees (0 to 360° scale instead of 0 to 100 %).

Figure B.1 — Determination of linearity range

Annex C
(normative)

Alternative measurement of the input impedance

A sine-wave generator feeds the input of the eddy current instrument through a series resistor R_v (see Figure C.1 in which the input impedance of the instrument is represented by a resistor R_e in parallel with a capacitor C_e).

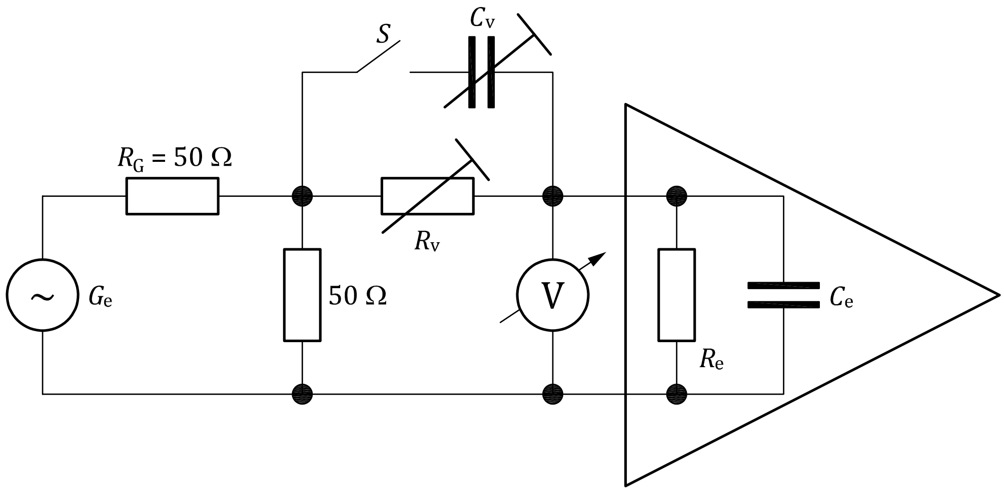


Figure C.1 — Arrangement for measurement of input impedance

The source impedance R_G of the generator (G_e) shall be smaller than the input resistance R_e of the eddy current instrument. In general, this condition is fulfilled if the 50 Ω rule is applied.

At first, determine R_e for a low generator frequency f_{G1} (preferably 1 kHz) and open the switch S. For this purpose, measure the input voltage V_e across R_e. The resistance R_v is increased until the input voltage obtained reaches half the value obtained in the case R_v = 0.

$$V_{e1} = 0{,}5V_e \qquad (R_v = 0)$$

The values of R_v and R_e are now identical:

$$R_v = R_e$$

For the determination of C_e, the setting of R_v remains unchanged and the generator frequency is increased to a value f_{G2} for which the input voltage is reduced to half the value of V_{e1}:

$$V_{e2} = 0{,}5V_{e1} \qquad (R_v = R_e)$$

At this stage, S is closed and C_v is changed until the original voltage V_{e1} ($R_v = R_e$) is reached again. When the frequency is varied between f_{G1} and f_{G2}, the input voltages V_{e1} and V_{e2} shall not show any variation. In these conditions:

$$C_v = C_e$$

R_v and C_v may be measured by means of a universal bridge.

The measuring set-up chosen for the determination of the shunt capacitance C_e should be of an extreme low-capacitance design. It shall be particularly kept in mind that the input capacitance of the voltmeter is added to C_e.

When determining C_e, the value of the stray capacitances of the measuring set-up have to be subtracted from the determined C_v value.

R_e and C_e shall be determined for all possible input circuitry options.

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