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INTERNATIONAL STANDARD

colour inside

Measurement of quartz crystal unit parameters –
Part 6: Measurement of drive level dependence (DLD)

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MEASUREMENT OF QUARTZ CRYSTAL UNIT PARAMETERS –

Part 6: Measurement of drive level dependence (DLD)

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 60444-6:2013. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC 60444-6 has been prepared by IEC technical committee 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection. It is an International Standard.

This third edition cancels and replaces the second edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) some equations have been removed and corrected;
b) it has been specified in the note of the Scope that the measurement methods specified in this document are not only applicable to AT-cut but also to other crystal cuts and vibration modes.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
49/1374/FDIS	49/1377/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 60444 series, published under the general title *Measurement of quartz crystal unit parameters*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The drive level (expressed as power/voltage across or current through the crystal unit) forces the resonator to produce mechanical oscillations by way of piezoelectric effect. In this process, the acceleration work is converted to kinetic and elastic energy and the power loss to heat. The latter conversion is due to the inner and outer friction of the quartz resonator.

The frictional losses depend on the velocity of the vibrating masses and increase when the oscillation is no longer linear or when critical velocities, elongations or strains, excursions or accelerations are attained in the quartz resonator or at its surfaces and mounting points (see Annex A). This causes changes in resistance and frequency, as well as further changes due to the temperature dependence of these parameters.

At "high" drive levels (e.g. above 1 mW or 1 mA for AT-cut crystal units) changes are observed by all crystal units and these also can result in irreversible amplitude and frequency changes. Any further increase of the drive level may could destroy the resonator.

Apart from this effect, changes in frequency and resistance are observed at "low" drive levels in some crystal units (e.g. below 1 mW µW or 50 µA for AT-cut crystal units). In this case, if the loop gain is not sufficient, the start-up of the oscillation is difficult. In crystal filters, the transducer attenuation and ripple will change.

Furthermore, the coupling between a specified mode of vibration and other modes (e.g. of the resonator itself, the mounting and the back-fill gas) also depends on the level of drive.

Due to the differing temperature response of these modes, these couplings give rise to changes of frequency and resistance of the specified mode within narrow temperature ranges. These changes increase with increasing drive level. However, this effect will not be considered further in this part of IEC 60444.

~~The first edition of IEC 60444-6 was published in 1995. However, it has not been revised until today. In the meantime the demand for tighter specification and measurement of DLD has increased.~~

In this new edition, the concept of DLD in IEC 60444-6:~~1995~~2013 is maintained. However, the more suitable contents for the user's severe requirements have been introduced. ~~Also, the specifications based on the matters arranged in the Stanford meeting in June, 2011 are taken into consideration.~~

MEASUREMENT OF QUARTZ CRYSTAL UNIT PARAMETERS –

Part 6: Measurement of drive level dependence (DLD)

1 Scope

This part of IEC 60444 applies to the measurements of drive level dependence (DLD) of quartz crystal units. Two test methods (A and C) and one referential method (B) are described. "Method A", based on the π-network according to ~~IEC 60444-1~~ IEC 60444-5, can be used in the complete frequency range covered by this part of IEC 60444. "Reference Method B", based on the π-network or reflection method according to ~~IEC 60444-1,~~ IEC 60444-5 or IEC 60444-8 can be used in the complete frequency range covered by this part of IEC 60444. "Method C", an oscillator method, is suitable for measurements of fundamental mode crystal units in larger quantities with fixed conditions.

NOTE The measurement methods specified in this document are not only applicable to AT-cut, but also to other crystal cuts and vibration modes, such as doubly rotated cuts (IT,SC) and to tuning fork crystal units (by using a high impedance test fixture).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60444-1, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 1: Basic method for the measurement of resonance frequency and resonance resistance of quartz crystal units by zero phase technique in a π-network*~~

IEC 60444-5, *Measurement of quartz crystal unit parameters – Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error correction*

IEC 60444-8, *Measurement of quartz crystal unit parameters – Part 8: Test fixture for surface mounted quartz crystal units*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 DLD effects

4.1 Reversible changes in frequency and resistance

Reversible changes are changes in frequency and resistance occurring under the same drive levels after repeated measurements made alternatively at low and high levels, or after continuous or quasi-continuous measurements from the lowest to the highest level and back, if these changes remain within the limits of the measurement accuracy.

4.2 Irreversible changes in frequency and resistance

Irreversible changes are significant changes in frequency and/or resistance occurring at low level after an intermediate measurement at high level e.g. when a previously high resistance at low level has changed in the repeated measurement to a low resistance. Especially, when the crystal unit has not been operated for several days, its resistance may have changed back to a high value when operated again at a lower level. Greater attention should be paid to the irreversible effect since it can significantly impair the performance of devices, which are operated only sporadically.

4.3 Causes of DLD effects

Whereas the mostly reversible effects are due to excessive crystal drive level, the irreversible effects are due to production, especially to imperfect production techniques. Examples of causes are:

- particles on the resonator surface (partly bound by oils, cleaning agents, solvents or bound electro-statically);
- mechanical damage of the resonator (e.g. fissures due to excessively coarse lapping abrasive which may increase in size);
- gas and oil inclusions in the electrodes (e.g. due to a poor vacuum or an inadequate coating rate during evaporation);
- poor contacting of the electrodes at the mounting (e.g. the conductive adhesive has an inadequate metal component, was insufficiently baked out or was overheated; also excessive contact resistance between the conductive adhesive and the electrodes or mounting);
- mechanical stresses between mounting, electrodes and quartz element.

5 Drive levels for DLD measurement

For the DLD measurement, a low and a high level of drive (and possibly further levels) are applied. The high level is the nominal drive level, which should be equal to the level in the application at its steady state.

It should be noted that this level should be below the maximum applicable level that is derived in Annex A. If not specified, a standard value for the crystal current of 1 mA, corresponding to the velocity ~~v max = = 0,2 m/s~~ v_{max} = 0,2 m/s for AT-cut crystal units, shall be used. The drive level in watt is then calculated with the mean value of the specified maximum and minimum resistances.

The minimum drive level occurring at the start-up of an oscillator can be determined only in a few cases by active or passive measuring methods due to the noise limits of the measuring instruments for measurements according to ~~IEC 60444-1~~ IEC 60444-5, at approximately 1 nW or 10 μA (depending on the equipment, the lowest power value can be reduced to 0,1 nW or 1 μA).

A velocity ~~v max = 0,01 m/s~~ v_{max} = 0,01 m/s, corresponding to 50 μA for AT-cut crystals, has proved to be practical value for π-network measurements (see "Method A").

Two methods and one referential method of DLD measurement are described below.

"Method A" is based on the π-network method according to ~~IEC 60444-1~~ IEC 60444-5, which can be used in the complete frequency range covered by this document. It allows the fast selection of drive level sensitive quartz crystal units by a sequence of three measurements. The allowed variation of the series resonance resistances given in Figure 1 is based on long-term examinations of crystal units of different manufacturers and proved to be a reliable indicator for crystal units showing start-up problems. If necessary, this method should also be extended by measuring a large number of different drive levels. However, in practice, this is not necessary in most cases (see 6.1).

In the industrial area, there are some commercially available crystal test systems like Saunders 250B or Kolinker KH1820[1]. Their software offers several variants for measuring DLD.

"Method B" is used for devices where strict oscillation start-up requirements have to be fulfilled and for high reliability devices.

"Method C" as shown in Annex B is an oscillator method, which is especially suitable for measuring fundamental mode crystal units in larger quantities with fixed measurement conditions (maximum drive level, ~~R_r max~~ $R_{1,\max}$) in an economical way.

If the proposed measurement techniques are not sufficient in special cases, the user should have an original oscillator with slightly reduced feedback or an original filter.

"Method B" is stricter than "Method A".

"Method B" is based on the π-network method or reflection method according to ~~IEC 60444-1,~~ IEC 60444-5 or IEC 60444-8, which can be used in the complete frequency range covered by this document.

Recommendation: These methods can be used for all types of crystals, however:

– "Method A" is recommended for filter and oscillator crystals;
– "Method B" is recommended for applications with strict start-up conditions, for high reliability and for high stability applications. It is the reference method for failure analysis etc.;
– "Method C" in Annex B is a go/no-go measurement technique for oscillator crystals.

6 Test methods

6.1 Method A (fast standard measurement method)

6.1.1 Testing at two drive levels

Testing is performed at low and high drive levels as described in Clause ~~3~~ 5 with measurements of series resonance frequency and resistance according to ~~IEC 60444-1~~ IEC 60444-5. The tolerances are ± 10 % for the levels of current and ± 20 % for those of power.

a) Storage for at least one day at 105 °C and after that at least 2 hours at room temperature or, storage for one week at room temperature.
b) The temperature should be kept constant during the measurement (in accordance with ~~IEC 60444-1 and~~ IEC 60444-5).
c) Measurement at low drive level (10 µA): ~~$f_r = f_{r1}$, $R_r = R_{11}$~~ $f_s = f_{s1}$, $R_1 = R_{11}$.
d) Measurement at high drive level (1 mA): ~~$f_r = f_{r2}$, $R_r = R_{12}$~~ $f_s = f_{s2}$, $R_1 = R_{12}$.
e) Measurement at low drive level (10 µA): ~~$f_r = f_{r3}$, $R_r = R_{13}$~~ $f_s = f_{s3}$, $R_1 = R_{13}$.

[1] Saunders 250B and Kolinker KH1820 are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

e) Calculation of $\gamma_{12} = R_{11}/R_{12}$. The value of γ_{12} shall be smaller than the maximum value of γ given by the line drawn in Figure 1 (abscissa = R_{12}).

g) The tolerable frequency change ~~$|f_{r2} - f_{r1}|$~~ $|f_{s2} - f_{s1}|$ shall be 5 × 10^{-6} × ~~f_{r1}~~ f_{s1} unless otherwise specified in the detail specification.

g) Calculation of $\gamma_{13} = R_{11}/R_{13}$. The value of γ_{13} shall be smaller than $(\gamma+1)/2$, where the value of γ is taken from Figure 1 (abscissa = R_{13}).

i) The tolerable frequency change ~~$|f_{r3} - f_{r1}|$~~ $|f_{s3} - f_{s1}|$ shall be 2,5 × 10^{-6} × ~~f_{r1}~~ f_{s1}, unless otherwise specified in the detail specification.

j) The resistance value shall not exceed the maximum value given by the detail specification at any drive levels.

6.1.2 Testing according to specification

Testing is performed at low to high drive levels and back again to low level as described in 6.1.1. These and, if necessary, further levels with their tolerances, the permissible deviations of the frequency and resistance as well as storage conditions shall be specified in the detail specification.

NOTE The given γ-curve was verified by results obtained over many years of experience with crystal units for many oscillator types. In most cases, there will be no trouble in start-up, but in critical oscillator configurations, problems ~~may~~ could occur. As it is not possible to manufacture crystal units, which have a constant resistance at any drive level, the proposed γ-curve gives tolerable relations.

Definition of drive level values can be agreed between manufacturer and customer.

Use the nominal drive level of the detail specification as value for the high drive level. For measurement at very high drive levels, an additional amplifier may be required.

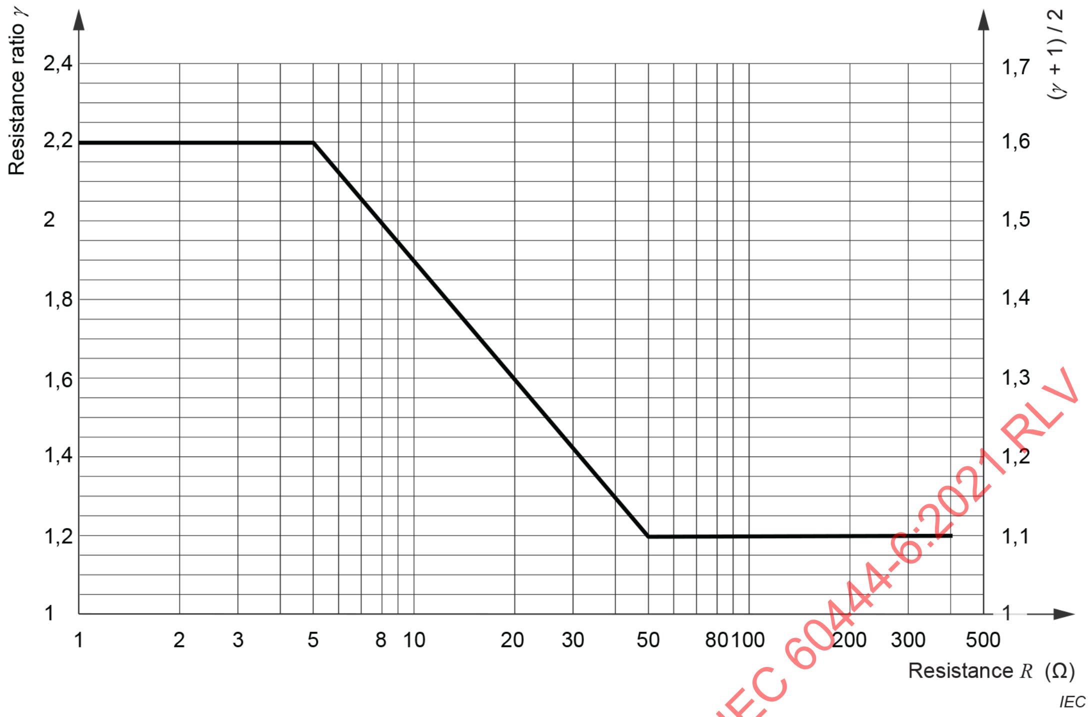

Figure 1 – Maximum tolerable resistance ratio γ for the drive level dependence as a function of the resistances ~~R_{r2} or R_{r3}~~ R_{12} or R_{13}

~~NOTE 2 The equation for the recommended drive level (if not otherwise specified in the data sheet) is as follows. Details can be found in Annex A of IEC 60122-2-1:1991, Amendment 1:1993.~~

The maximum drive level recommended to be selected so that with a further increase of the drive level by 50 %, the resistance does not increase reversibly by more than 10 % or the frequency changes by more than 0,5 × 10^{-6}.

$$I_q = K \cdot \frac{nA}{\sqrt{f}}$$

where

I_q is the recommended current for oscillating state;

n is the overtone order~~, fundamental vibration mode, n = 1~~;

A is the electrode size in mm^2;

f is the frequency in MHz;

K is 0,35 mA · mm^{-2} · s$^{-1/2}$.

6.2 Method B (Multi-level reference measurement method)

Testing is performed at low and high drive levels as described in Clause ~~3~~ 5 with measurements of resonance frequency and resistance according to IEC 60444-5. The tolerances are ±10 % for the levels of current and ±20 % for those of power.

a) Storage for at least one day at 105 °C and after that at least 2 hours at room temperature or storage for one week at room temperature.

NOTE If considered as necessary, the customer and the maker agree on a higher temperature and a longer duration for the storage before DLD measurement.

b) The temperature should be kept constant during the measurement IAW (in accordance with IEC 60444-5).

c) The drive level is applied by two types of measurement units. It should also be applied sequentially starting from the lowest to the highest value and then back to the lowest value. A definition for the unit of drive levels shall be specified between the crystal manufacturer and the user.

   1) When the unit of a drive level is mA;

      Measurement drives level: from 2 μA to nominal drive level in at least 7 levels which are logarithmically scaled. (Refer to the equation given under item f)).

   2) When the unit of a drive level is μW;

      Measurement drives level: From 2 nW to nominal drive level in at least 7 levels which are logarithmically scaled. (Refer to the equation given under item f)).

d) The maximum frequency excursion over all drive levels shall be less than the following specifications.

   1) $$\frac{f_s(i)_{,\max} - f_s(i)_{,\min}}{f_{\text{NOM}}} < 5 \times 10^{-6}$$

   or,

   2) $$\frac{f_s(i)_{,\max} - f_s(i)_{,\min}}{f_{\text{NOM}}} < 0.5 \times f_{\text{ADJ}}$$

   where

   $f_s(i)_{,\max}$ is the maximum value for frequency measurement values with i = 1 to 2·N-1 drive levels;

   $f_s(i)_{,\min}$ is the minimum value for frequency measurement values with i = 1 to 2·N-1 drive levels;

   f_{NOM} is the nominal frequency;

   f_{ADJ} is the practical specification for frequency adjustment tolerance.

e) The maximum ratio of resistance change and the maximum resistance over drive levels shall be as the following specifications:

   1) $$\frac{R_1(i)_{,\max}}{R_1(i)_{,\min}} < \gamma$$

   and

   2) $$\frac{R_1(1)}{R_1(2 \cdot N - 1)} < \frac{(\gamma + 1)}{2}$$

   and

   3) $$R_1(i)_{,\max} < R_{1,\max}$$

   where,

   $R_1(i)_{,\max}$ is the maximum value for resistance measurement values with i = 1 to 2·N-1 drive levels;

   $R_1(i)_{,\min}$ is the minimum value for resistance measurement values with i = 1 to 2·N-1 drive levels;

   $R_{1,\max}$ is the maximum resistance, specified by the detail specification;

   γ is the resistance ratio.

f) The N drive levels should be logarithmically scaled, i.e. $DL_{N+1} = DL_N \times K$. The equation for the recommended drive level (if not otherwise specified in the data sheet) is as follows:

$$K = \left(\frac{DL_{max}}{DL_{min}} \right)^{\frac{1}{N-1}}$$

g) A larger number of drive levels may be necessary in special applications, e.g. those caused by mechanical coupling with nonlinear spurious resonances (dips) and for failure analysis.

Annex A
(normative)

Relationship between electrical drive level and mechanical displacement of quartz crystal units

The power loss of a crystal unit in watt is given by:

$$P_c = I^2 \cdot R_1$$

where

I is the current through the crystal unit in amperes;

R_1 is the motional resistance in ohms.

The reactive power is given by:

$$P_B = \frac{I^2}{2\pi f \cdot C_1} = P_c \cdot Q$$

where

f is the resonance frequency in hertz;

C_1 is the motional capacitance in farads;

Q is the quality factor.

The electric energy in watt seconds is given by:

$$A_{EL} = \frac{P_B}{f} = \frac{I^2}{2\pi f^2 \cdot C_1}$$

The mechanical energy of a crystal unit can be represented by the following terms:

$$A_{mech} = A_{kin} + A_{elast} + A_{pot} + A_B$$

$A_{kin} = \frac{1}{2} \cdot \rho \cdot V \cdot v^2$ (kinetic energy)

$A_{elast} = \frac{1}{2} \cdot c \cdot V \cdot x^2$ (elastic energy)

$A_{pot} = \frac{1}{2} \cdot \rho \cdot V \cdot s^2 \cdot (2\pi f)^2$ (potential energy)

$A_B = \frac{1}{2} \cdot \frac{\rho \cdot V \cdot b^2}{(2\pi f)^2}$ (acceleration work)

ρ = 2 650 kg/m^3 (density)

where

V is the volume of the oscillating area in cubic meters (m^3);

v = ds/dt is the velocity in meters per seconds (m/s);

c is the modulus of elasticity of the mode of vibration (for AT-cut crystal units, $c = c'_{66} = 2{,}93 \times 10^{10}$ N/m^2)

$x = \Delta l/l$ is the elongation;

s is the excursion from rest position in metres;

b = d^2s/dt^2 is the acceleration in meters per square seconds (m/s^2);

n is the overtone order.

The volume V can be approximately calculated from the electrode area F_{EL} and the electrode spacing d.

From the static capacitance:

$$C_e = \varepsilon_r \cdot \varepsilon_0 \cdot \frac{F_{EL}}{d} = C_0$$

where

ε_r is the relative dielectric constant of AT-cut quartz material and is equal to 4,54;

ε_0 is the electric field constant and is equal to $8{,}86 \times 10^{-12}$ F/m;

N is the frequency constant equal to $f \cdot (d/n)$. N = 1 665 Hz·m for AT-cut crystal units;

n is the overtone order.

The following is obtained:

$$V \approx \frac{C_0}{\varepsilon_r \cdot \varepsilon_0} \cdot \frac{n^2 \cdot N^2}{f^2}$$

and the maximum current from the maximum velocities, elongations, excursions or accelerations of the mechanical vibrations:

$$I_{max} = K_1 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot v_{max} \quad \text{where} \quad K_1 = \sqrt{\frac{\pi \cdot \rho \cdot N^2}{\varepsilon_r \cdot \varepsilon_0}}$$

$$I_{max} = K_2 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot x_{max} \quad \text{where} \quad K_2 = \sqrt{\frac{\pi \cdot c \cdot N^2}{\varepsilon_r \cdot \varepsilon_0}}$$

$$I_{max} = K_3 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot s_{max} \quad \text{where} \quad K_3 = \sqrt{\frac{4 \cdot \pi^3 \cdot \rho \cdot N^2}{\varepsilon_r \cdot \varepsilon_0}}$$

$$I_{max} = K_4 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot \frac{b_{max}}{f} \quad \text{where} \quad K_4 = \sqrt{\frac{\rho \cdot N^2}{4 \cdot \pi \cdot \varepsilon_r \cdot \varepsilon_0}}$$

$$I = K_1 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot v \qquad \text{where} \quad K_1 = \sqrt{\frac{\pi \cdot \rho \cdot N^2}{\varepsilon_r \cdot \varepsilon_0}}$$

$$I = K_2 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot x \qquad \text{where } K_2 = \sqrt{\frac{\pi \cdot c \cdot N^2}{\varepsilon_r \cdot \varepsilon_0}}$$

$$I = K_3 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot s \cdot f \qquad \text{where } K_3 = \sqrt{\frac{4 \cdot \pi^3 \cdot \rho \cdot N^2}{\varepsilon_r \cdot \varepsilon_0}}$$

$$I = K_4 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot \frac{b}{f} \qquad \text{where } K_4 = \sqrt{\frac{\rho \cdot N^2}{4 \cdot \pi \cdot \varepsilon_r \cdot \varepsilon_0}}$$

For non-convex AT-cut crystal units, the following also applies:

$$C_0 / C_1 = \gamma = 200 \cdot n^2$$

$$\frac{C_0}{C_1} = \gamma \approx 250 \cdot n^2$$

where

n is the overtone order.

The constant "250" fits well with the measurement value when it is used in the case of miniaturized crystal units such as surface mounted crystals. On the other hand, in the case of conventional crystal units, such as HU-6/U, HC-43/U, it is recommended to use "200" as the constant.

The following is obtained with C_0 = 5 pF for the currents:

$I_{max,1}$ = 50 mA µA $I_{max,2}$ = 1 mA

v_1 = 0,01 m/s v_2 = 0,2 m/s

$x_1 = 1{,}8 \times 10^{-6}$ $x_2 = 3{,}6 \times 10^{-5}$

at f = 10 MHz:

$s_1 = 6{,}7 \times 10^{-11}$ m $s_2 = 1{,}3 \times 10^{-9}$ m

$b_1 = 2{,}6 \times 10^5$ m/s² $b_1 = 5{,}3 \times 10^6$ m/s²

at f = 100 MHz:

$s_1 = 6{,}7 \times 10^{-12}$ m $s_2 = 1{,}3 \times 10^{-10}$ m

$b_1 = 2{,}6 \times 10^6$ m/s² $b_2 = 5{,}3 \times 10^7$ m/s²

Depending on the frequency, quality factor and mode of vibration of the crystal unit and the volume of the vibrating zone, maximum currents or levels result from limit considerations for every type of a crystal unit. These shall not be exceeded when using these devices in oscillators and filters.

~~The maximum drive level shall be selected so that with a further increase of the drive level by 50 %, the resistance does not increase reversibly by more than 10 % or the frequency changes by more than $0,5 \times 10^{-6}$.~~

Annex B
(normative)

Method C: DLD measurement with oscillation circuit

To detect the DLD effect over the whole drive level range, the method described in 6.1 is very costly and is not applicable as a 100 % go/no-go test. The method proposed below tests the crystal units on its maximum R_r during start-up in an economical manner. This method can be applied as a 100 % final inspection as well as in a 100 % incoming inspection. It can also be used as an instrument to judge whether the crystal unit meets the requirements on ~~R_{rmax}~~ R_{max} given in the detail specification.

The crystal unit in the oscillator can be represented as indicated in Figure B.1.

There will be no oscillation when the magnitude of the $-R_{osc}$ of the circuit is lower than R_r of the crystal unit.

During start-up, the R_r of the crystal unit may behave as shown in Figure B.2.

When measuring the crystal unit several times, the characteristic can shift slightly to the right or to the left or it can flatten.

The ratio $\gamma = R_{r2}/R_{r1}$ may also differ from measurement to measurement. This ratio does not necessarily mean that the oscillator may stop working if a certain value of γ is reached. The most important aspect is the safety margin between the maximum occurring R_r of the crystal unit and the value of R_{osc} of the oscillator circuit.

It is recommended that the circuit should have a $|-R_{osc}|$ of $\geq 3|R_{r\ max}|$ because in the temperature range, the $R_{r\ max}$ as well as $-R_{osc}$ can shift.

During the start-up, the drive level will move from the low values (left side of the graphics in Figure B.3) to the nominal drive level.

The principle of measurement is presented in Figure B.4.

The test set-up consists of a carefully designed crystal oscillator which can be considered as a true negative resistance over a wide frequency range, a feedback network which limits the power dissipation in the crystal unit to 1 mW and a detector circuit with an LED for visual indication.

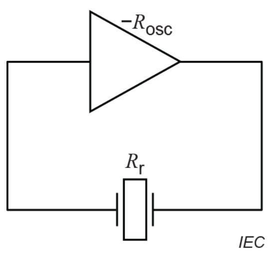

Figure B.1 – Insertion of a quartz crystal unit in an oscillator

Oscillation conditions:

- loop gain > 1, which means $|-R_{osc}| > R_r$
- feedback signal at oscillator input shall have correct phase.

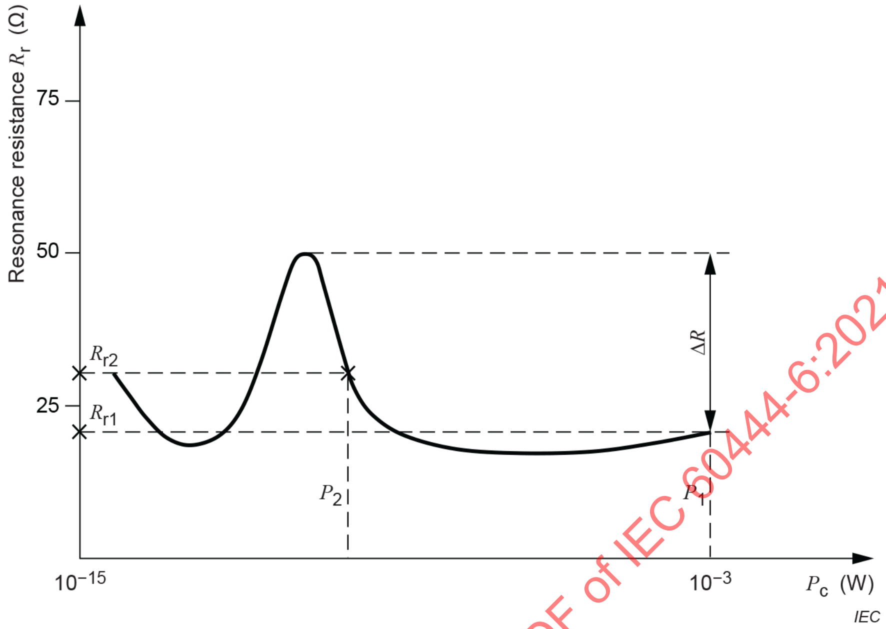

Figure B.2 – Crystal unit loss resistance as a function of dissipated power

NOTE The ratio R_{r2}/R_{r1} is not a reproducible value since the crystal unit curve slightly shifts at different measurement cycles.

The negative resistance (and with it the DLD reject level) of the oscillator can be changed by connecting a positive resistor in series with the oscillator. In this manner, each value between 0 Ω and 200 Ω may be selected. Connecting a quartz crystal unit with a sufficiently low R_r value between the test clamps, the oscillation will build up starting from the initial noise level (approximately 10^{-16} W to 10^{-15} W) to its limiting point for 1 mW as shown in Figure B.5.

During the start-up, the R_{rmax} of the crystal unit is continuously compared with a Calibrated-R_{osc} and the result is detected and transferred into a go/no-go decision.

If the crystal unit under test shows a certain degree of DLD, it is possible that the oscillation amplitude will not reach the 1 mW limiting point (point B in Figure B.6). In the example given in Figure B.6, the build-up of the oscillation is terminated at a much lower level of drive (point A). Normally in such cases, no oscillation is observed and only with very sensitive equipment can some oscillation be detected.

If a crystal unit reaches the 1 mW level (point B), the LED indicator will light up. This means that the quartz crystal unit's resonance resistance did not exceed the DLD reject level during the start-up.

The advantages of this measurement method are that it is fast, easy to calibrate, inexpensive and it has a simple set-up. A detailed electrical diagram is shown in Figure B.7. The equipment is commercially available.

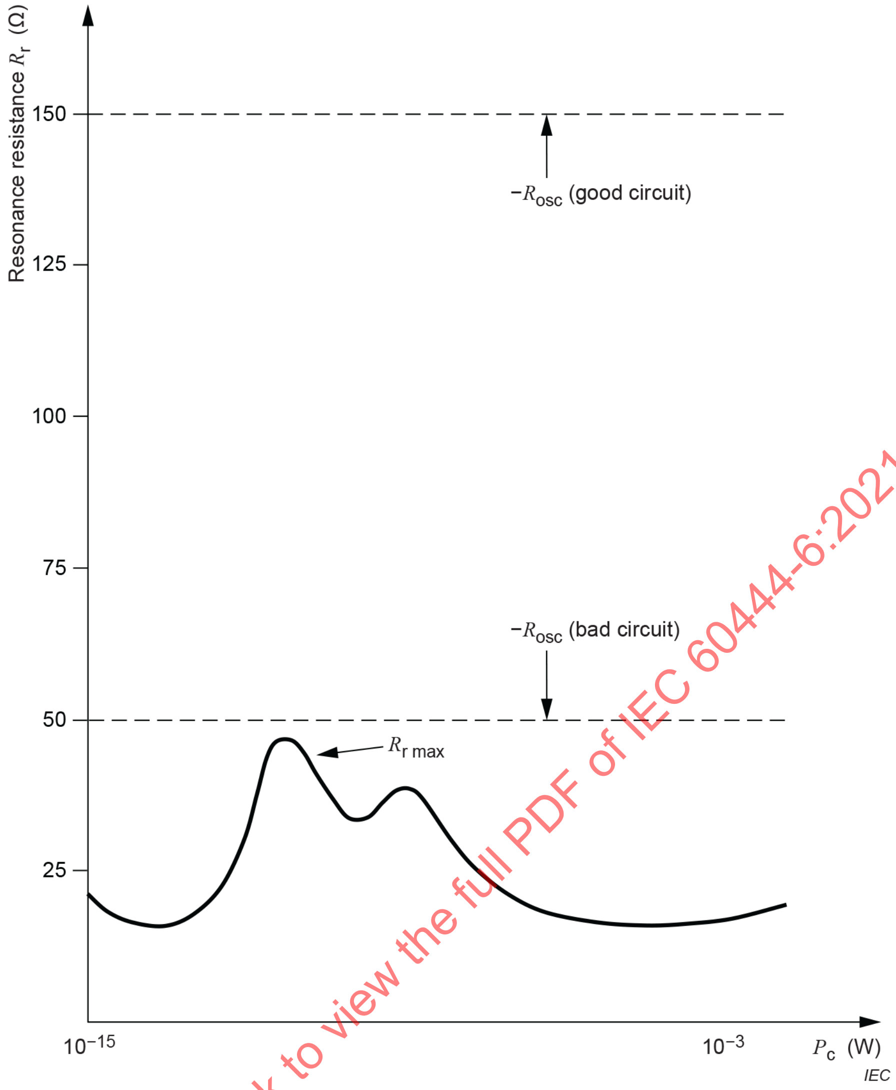

Figure B.3 – Behaviour of the R_r of a quartz crystal unit

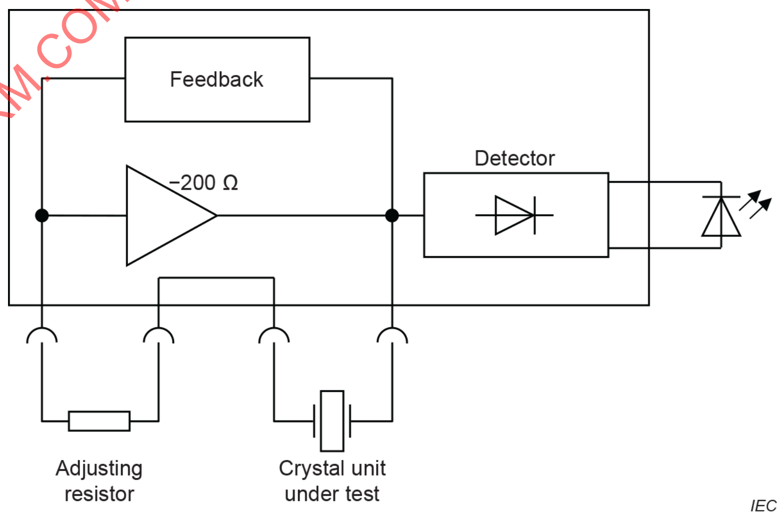

Figure B.4 – Block diagram of circuit system

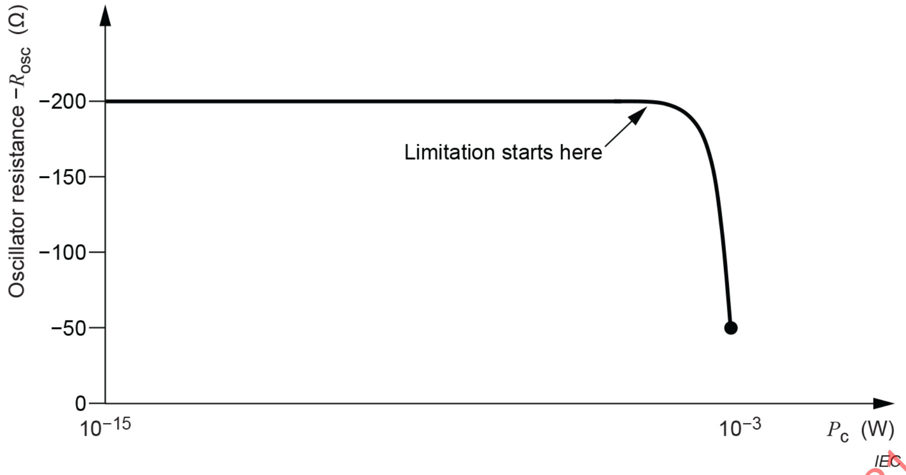

Figure B.5 – Installed $-R_{osc}$ in scanned drive level range

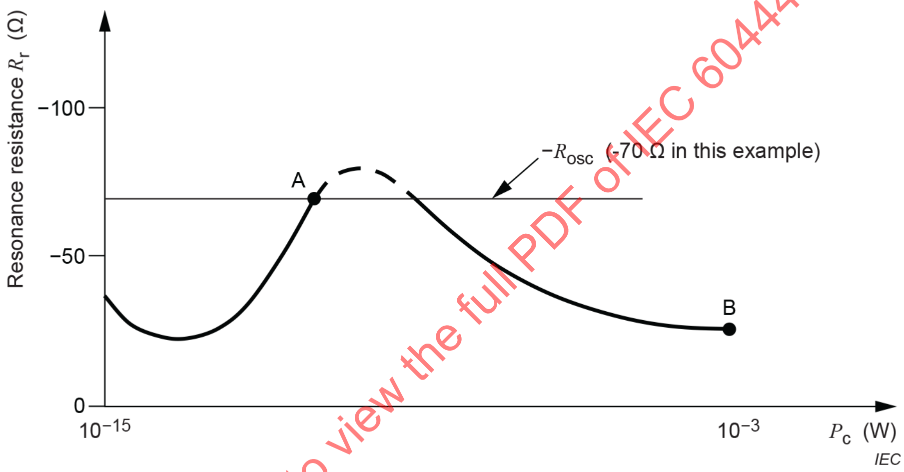

Figure B.6 – Drive level behaviour of a quartz crystal unit if $-R_{osc}$ = 70 Ω is used as test limit in the Annex B test

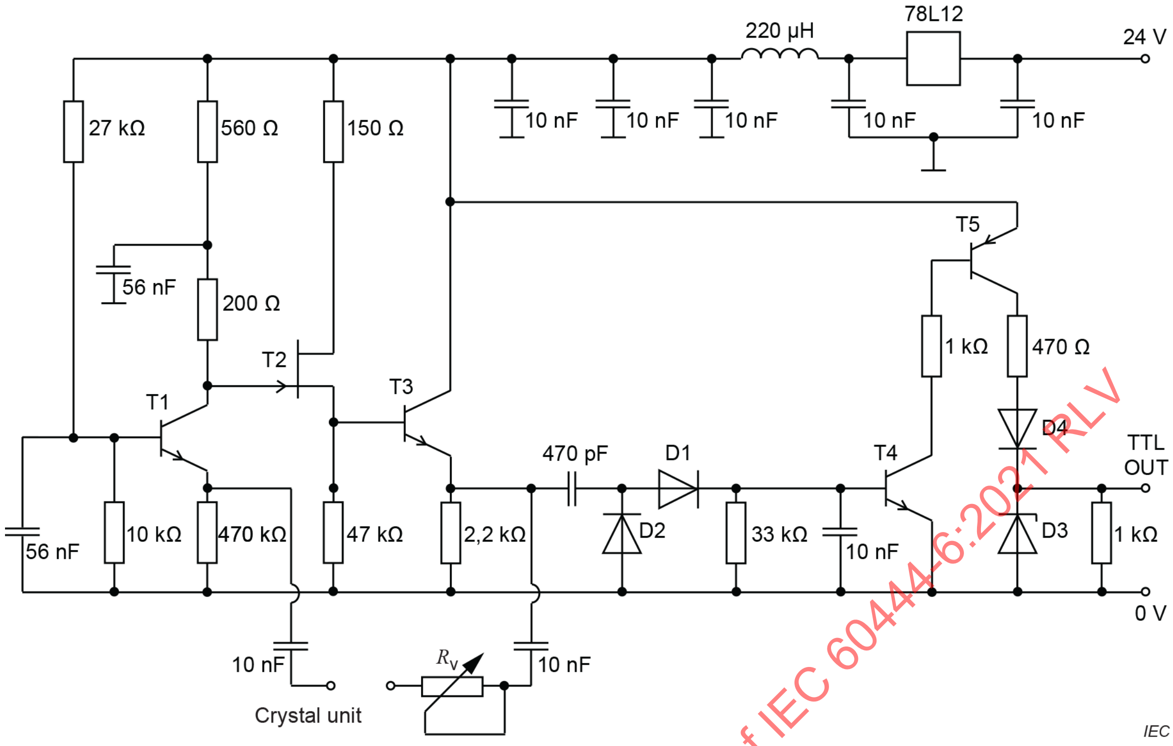

Figure B.7 – Principal schematic diagram of the go/no-go test circuit

Bibliography

IEC 60122-2-1:1991, *Quartz crystal units for frequency control and selection – Part 2: Guide to the use of quartz crystal units for frequency control and selection – Section one: Quartz crystal units for microprocessor clock supply*
Amendment 1:1993

IEC 60444-1, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 1: Basic method for the measurement of resonance frequency and resonance resistance of quartz crystal units by zero phase technique in a π-network*

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IEC 60444-6

Edition 3.0 2021-09

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Measurement of quartz crystal unit parameters –
Part 6: Measurement of drive level dependence (DLD)

Mesure des paramètres des résonateurs à quartz –
Partie 6: Mesure de la dépendance du niveau d'excitation (DNE)

IEC 60444-6:2021-09(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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MEASUREMENT OF QUARTZ CRYSTAL UNIT PARAMETERS –

Part 6: Measurement of drive level dependence (DLD)

FOREWORD

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IEC 60444-6 has been prepared by IEC technical committee 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection. It is an International Standard.

This third edition cancels and replaces the second edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) some equations have been removed and corrected;
b) it has been specified in the note of the Scope that the measurement methods specified in this document are not only applicable to AT-cut but also to other crystal cuts and vibration modes.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
49/1374/FDIS	49/1377/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 60444 series, published under the general title *Measurement of quartz crystal unit parameters*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

The drive level (expressed as power/voltage across or current through the crystal unit) forces the resonator to produce mechanical oscillations by way of piezoelectric effect. In this process, the acceleration work is converted to kinetic and elastic energy and the power loss to heat. The latter conversion is due to the inner and outer friction of the quartz resonator.

The frictional losses depend on the velocity of the vibrating masses and increase when the oscillation is no longer linear or when critical velocities, elongations or strains, excursions or accelerations are attained in the quartz resonator or at its surfaces and mounting points (see Annex A). This causes changes in resistance and frequency, as well as further changes due to the temperature dependence of these parameters.

At “high” drive levels (e.g. above 1 mW or 1 mA for AT-cut crystal units) changes are observed by all crystal units and these also can result in irreversible amplitude and frequency changes. Any further increase of the drive level may could destroy the resonator.

Apart from this effect, changes in frequency and resistance are observed at “low” drive levels in some crystal units (e.g. below 1 μW or 50 μA for AT-cut crystal units). In this case, if the loop gain is not sufficient, the start-up of the oscillation is difficult. In crystal filters, the transducer attenuation and ripple will change.

Furthermore, the coupling between a specified mode of vibration and other modes (e.g. of the resonator itself, the mounting and the back-fill gas) also depends on the level of drive.

Due to the differing temperature response of these modes, these couplings give rise to changes of frequency and resistance of the specified mode within narrow temperature ranges. These changes increase with increasing drive level. However, this effect will not be considered further in this part of IEC 60444.

In this new edition, the concept of DLD in IEC 60444-6:2013 is maintained. However, the more suitable contents for the user’s severe requirements have been introduced.

MEASUREMENT OF QUARTZ CRYSTAL UNIT PARAMETERS –

Part 6: Measurement of drive level dependence (DLD)

1 Scope

This part of IEC 60444 applies to the measurements of drive level dependence (DLD) of quartz crystal units. Two test methods (A and C) and one referential method (B) are described. “Method A”, based on the π-network according to IEC 60444-5, can be used in the complete frequency range covered by this part of IEC 60444. “Reference Method B”, based on the π-network or reflection method according to IEC 60444-5 or IEC 60444-8 can be used in the complete frequency range covered by this part of IEC 60444. “Method C”, an oscillator method, is suitable for measurements of fundamental mode crystal units in larger quantities with fixed conditions.

NOTE The measurement methods specified in this document are not only applicable to AT-cut, but also to other crystal cuts and vibration modes, such as doubly rotated cuts (IT,SC) and to tuning fork crystal units (by using a high impedance test fixture).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60444-5, *Measurement of quartz crystal unit parameters – Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error correction*

IEC 60444-8, *Measurement of quartz crystal unit parameters – Part 8: Test fixture for surface mounted quartz crystal units*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 DLD effects

4.1 Reversible changes in frequency and resistance

Reversible changes are changes in frequency and resistance occurring under the same drive levels after repeated measurements made alternatively at low and high levels, or after continuous or quasi-continuous measurements from the lowest to the highest level and back, if these changes remain within the limits of the measurement accuracy.

4.2 Irreversible changes in frequency and resistance

Irreversible changes are significant changes in frequency and/or resistance occurring at low level after an intermediate measurement at high level e.g. when a previously high resistance at low level has changed in the repeated measurement to a low resistance. Especially, when the crystal unit has not been operated for several days, its resistance may have changed back to a high value when operated again at a lower level. Greater attention should be paid to the irreversible effect since it can significantly impair the performance of devices, which are operated only sporadically.

4.3 Causes of DLD effects

Whereas the mostly reversible effects are due to excessive crystal drive level, the irreversible effects are due to production, especially to imperfect production techniques. Examples of causes are:

– particles on the resonator surface (partly bound by oils, cleaning agents, solvents or bound electro-statically);
– mechanical damage of the resonator (e.g. fissures due to excessively coarse lapping abrasive which may increase in size);
– gas and oil inclusions in the electrodes (e.g. due to a poor vacuum or an inadequate coating rate during evaporation);
– poor contacting of the electrodes at the mounting (e.g. the conductive adhesive has an inadequate metal component, was insufficiently baked out or was overheated; also excessive contact resistance between the conductive adhesive and the electrodes or mounting);
– mechanical stresses between mounting, electrodes and quartz element.

5 Drive levels for DLD measurement

For the DLD measurement, a low and a high level of drive (and possibly further levels) are applied. The high level is the nominal drive level, which should be equal to the level in the application at its steady state.

It should be noted that this level should be below the maximum applicable level that is derived in Annex A. If not specified, a standard value for the crystal current of 1 mA, corresponding to the velocity v_{max} = 0,2 m/s for AT-cut crystal units, shall be used. The drive level in watt is then calculated with the mean value of the specified maximum and minimum resistances.

The minimum drive level occurring at the start-up of an oscillator can be determined only in a few cases by active or passive measuring methods due to the noise limits of the measuring instruments for measurements according to IEC 60444-5, at approximately 1 nW or 10 µA (depending on the equipment, the lowest power value can be reduced to 0,1 nW or 1 µA).

A velocity v_{max} = 0,01 m/s, corresponding to 50 µA for AT-cut crystals, has proved to be practical value for π-network measurements (see "Method A").

Two methods and one referential method of DLD measurement are described below.

"Method A" is based on the π-network method according to IEC 60444-5, which can be used in the complete frequency range covered by this document. It allows the fast selection of drive level sensitive quartz crystal units by a sequence of three measurements. The allowed variation of the series resonance resistances given in Figure 1 is based on long-term examinations of crystal units of different manufacturers and proved to be a reliable indicator for crystal units showing start-up problems. If necessary, this method should also be extended by measuring a large number of different drive levels. However, in practice, this is not necessary in most cases (see 6.1).

In the industrial area, there are some commercially available crystal test systems like Saunders 250B or Kolinker KH1820[1]. Their software offers several variants for measuring DLD.

"Method B" is used for devices where strict oscillation start-up requirements have to be fulfilled and for high reliability devices.

"Method C" as shown in Annex B is an oscillator method, which is especially suitable for measuring fundamental mode crystal units in larger quantities with fixed measurement conditions (maximum drive level, $R_{1,\max}$) in an economical way.

If the proposed measurement techniques are not sufficient in special cases, the user should have an original oscillator with slightly reduced feedback or an original filter.

"Method B" is stricter than "Method A".

"Method B" is based on the π-network method or reflection method according to IEC 60444-5 or IEC 60444-8, which can be used in the complete frequency range covered by this document.

Recommendation: These methods can be used for all types of crystals, however:

– "Method A" is recommended for filter and oscillator crystals;
– "Method B" is recommended for applications with strict start-up conditions, for high reliability and for high stability applications. It is the reference method for failure analysis etc.;
– "Method C" in Annex B is a go/no-go measurement technique for oscillator crystals.

6 Test methods

6.1 Method A (fast standard measurement method)

6.1.1 Testing at two drive levels

Testing is performed at low and high drive levels as described in Clause 5 with measurements of series resonance frequency and resistance according to IEC 60444-5. The tolerances are ± 10 % for the levels of current and ± 20 % for those of power.

a) Storage for at least one day at 105 °C and after that at least 2 hours at room temperature or, storage for one week at room temperature.
b) The temperature should be kept constant during the measurement (in accordance with IEC 60444-5).
c) Measurement at low drive level (10 µA): $f_s = f_{s1}$, $R_1 = R_{11}$.
d) Measurement at high drive level (1 mA): $f_s = f_{s2}$, $R_1 = R_{12}$.
e) Measurement at low drive level (10 µA): $f_s = f_{s3}$, $R_1 = R_{13}$.
f) Calculation of $\gamma_{12} = R_{11}/R_{12}$. The value of γ_{12} shall be smaller than the maximum value of γ given by the line drawn in Figure 1 (abscissa = R_{12}).
g) The tolerable frequency change $|f_{s2} - f_{s1}|$ shall be 5 × 10^{-6} × f_{s1} unless otherwise specified in the detail specification.
h) Calculation of $\gamma_{13} = R_{11}/R_{13}$. The value of γ_{13} shall be smaller than $(\gamma+1)/2$, where the value of γ is taken from Figure 1 (abscissa = R_{13}).

[1] Saunders 250B and Kolinker KH1820 are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

i) The tolerable frequency change $|f_{s3} - f_{s1}|$ shall be 2,5 × 10^{-6} × f_{s1}, unless otherwise specified in the detail specification.

j) The resistance value shall not exceed the maximum value given by the detail specification at any drive levels.

6.1.2 Testing according to specification

Testing is performed at low to high drive levels and back again to low level as described in 6.1.1. These and, if necessary, further levels with their tolerances, the permissible deviations of the frequency and resistance as well as storage conditions shall be specified in the detail specification.

NOTE The given γ-curve was verified by results obtained over many years of experience with crystal units for many oscillator types. In most cases, there will be no trouble in start-up, but in critical oscillator configurations, problems could occur. As it is not possible to manufacture crystal units, which have a constant resistance at any drive level, the proposed γ-curve gives tolerable relations.

Definition of drive level values can be agreed between manufacturer and customer.

Use the nominal drive level of the detail specification as value for the high drive level. For measurement at very high drive levels, an additional amplifier may be required.

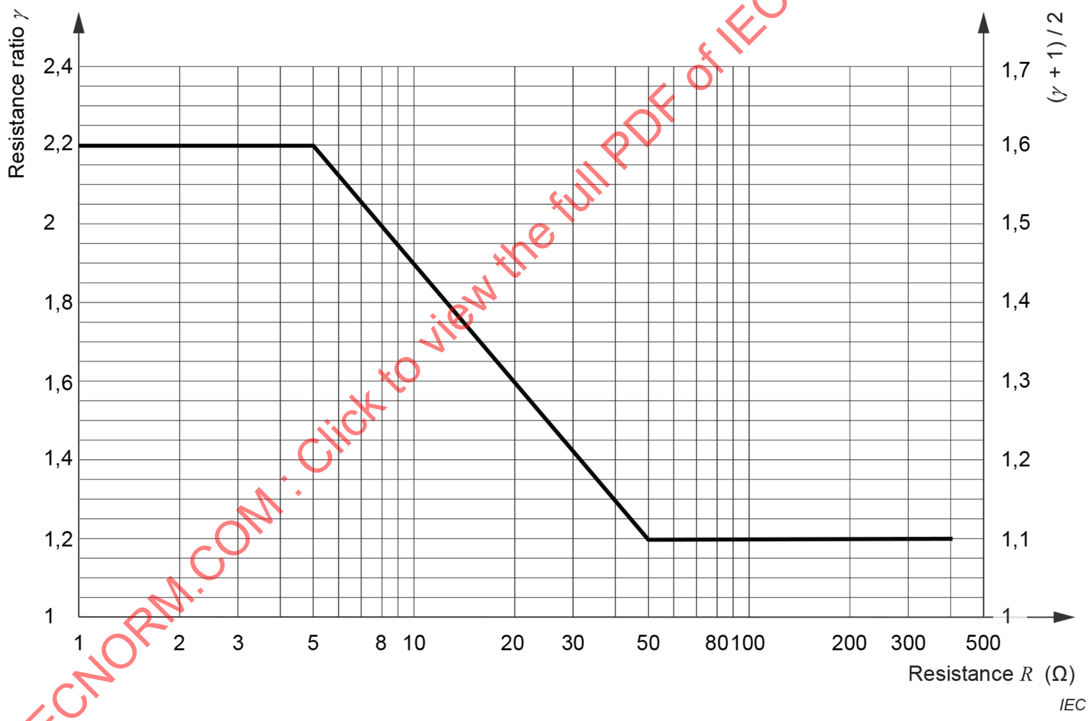

Figure 1 – Maximum tolerable resistance ratio γ for the drive level dependence as a function of the resistances R_{12} or R_{13}

The maximum drive level recommended to be selected so that with a further increase of the drive level by 50 %, the resistance does not increase reversibly by more than 10 % or the frequency changes by more than 0,5 × 10^{-6}.

$$I_q = K \cdot \frac{nA}{\sqrt{f}}$$

where

I_q is the recommended current for oscillating state;

n is the overtone order;

A is the electrode size in mm^2;

f is the frequency in MHz;

K is 0,35 mA · mm^{-2} · s$^{-1/2}$.

6.2 Method B (Multi-level reference measurement method)

Testing is performed at low and high drive levels as described in Clause 5 with measurements of resonance frequency and resistance according to IEC 60444-5. The tolerances are ±10 % for the levels of current and ±20 % for those of power.

a) Storage for at least one day at 105 °C and after that at least 2 hours at room temperature or storage for one week at room temperature.

NOTE If considered as necessary, the customer and the maker agree on a higher temperature and a longer duration for the storage before DLD measurement.

b) The temperature should be kept constant during the measurement IAW (in accordance with IEC 60444-5).

c) The drive level is applied by two types of measurement units. It should also be applied sequentially starting from the lowest to the highest value and then back to the lowest value. A definition for the unit of drive levels shall be specified between the crystal manufacturer and the user.

   1) When the unit of a drive level is mA;

      Measurement drives level: from 2 µA to nominal drive level in at least 7 levels which are logarithmically scaled. (Refer to the equation given under item f)).

   2) When the unit of a drive level is µW;

      Measurement drives level: From 2 nW to nominal drive level in at least 7 levels which are logarithmically scaled. (Refer to the equation given under item f)).

d) The maximum frequency excursion over all drive levels shall be less than the following specifications.

   1) $$\frac{f_s(i)_{,\max} - f_s(i)_{,\min}}{f_{\mathrm{NOM}}} < 5 \times 10^{-6}$$

   or,

   2) $$\frac{f_s(i)_{,\max} - f_s(i)_{,\min}}{f_{\mathrm{NOM}}} < 0.5 \times f_{\mathrm{ADJ}}$$

   where

   $f_s(i)_{,\max}$ is the maximum value for frequency measurement values with i = 1 to $2 \cdot N$-1 drive levels;

   $f_s(i)_{,\min}$ is the minimum value for frequency measurement values with i = 1 to $2 \cdot N$-1 drive levels;

   f_{NOM} is the nominal frequency;

   f_{ADJ} is the practical specification for frequency adjustment tolerance.

e) The maximum ratio of resistance change and the maximum resistance over drive levels shall be as the following specifications:

   1) $$\frac{R_1(i)_{,\max}}{R_1(i)_{,\min}} < \gamma$$

and

2) $\frac{R_1(1)}{R_1(2 \cdot N - 1)} < \frac{(\gamma + 1)}{2}$

and

3) $R_1(i)_{,\max} < R_{1,\max}$

where,

$R_1(i)_{,\max}$	is the maximum value for resistance measurement values with i = 1 to 2·N-1 drive levels;
$R_1(i)_{,\min}$	is the minimum value for resistance measurement values with i = 1 to 2·N-1 drive levels;
$R_{1,\max}$	is the maximum resistance, specified by the detail specification;
γ	is the resistance ratio.

f) The N drive levels should be logarithmically scaled, i.e. $DL_{N+1} = DL_N \times K$. The equation for the recommended drive level (if not otherwise specified in the data sheet) is as follows:

$$K = \left(\frac{DL_{\max}}{DL_{\min}} \right)^{\frac{1}{N-1}}$$

g) A larger number of drive levels may be necessary in special applications, e.g. those caused by mechanical coupling with nonlinear spurious resonances (dips) and for failure analysis.

Annex A
(normative)

Relationship between electrical drive level and mechanical displacement of quartz crystal units

The power loss of a crystal unit in watt is given by:

$$P_c = I^2 \cdot R_1$$

where

I is the current through the crystal unit in amperes;

R_1 is the motional resistance in ohms.

The reactive power is given by:

$$P_B = \frac{I^2}{2\pi f \cdot C_1} = P_c \cdot Q$$

where

f is the resonance frequency in hertz;

C_1 is the motional capacitance in farads;

Q is the quality factor.

The electric energy in watt seconds is given by:

$$A_{EL} = \frac{P_B}{f} = \frac{I^2}{2\pi f^2 \cdot C_1}$$

The mechanical energy of a crystal unit can be represented by the following terms:

$A_{kin} = \frac{1}{2} \cdot \rho \cdot V \cdot v^2$ (kinetic energy)

$A_{elast} = \frac{1}{2} \cdot c \cdot V \cdot x^2$ (elastic energy)

$A_{pot} = \frac{1}{2} \cdot \rho \cdot V \cdot s^2 \cdot (2\pi f)^2$ (potential energy)

$A_B = \frac{1}{2} \cdot \frac{\rho \cdot V \cdot b^2}{(2\pi f)^2}$ (acceleration work)

ρ = 2 650 kg/m^3 (density)

where

V is the volume of the oscillating area in cubic meters (m^3);

v = ds/dt is the velocity in meters per seconds (m/s);

c is the modulus of elasticity of the mode of vibration (for AT-cut crystal units, $c = c'_{66} = 2{,}93 \times 10^{10}$ N/m^2)

$x = \Delta l / l$ is the elongation;

s is the excursion from rest position in metres;

$b = \mathrm{d}^2 s/\mathrm{d}t^2$ is the acceleration in meters per square seconds (m/s^2);

n is the overtone order.

The volume V can be approximately calculated from the electrode area F_{EL} and the electrode spacing d.

From the static capacitance:

$$C_\mathrm{e} = \varepsilon_\mathrm{r} \cdot \varepsilon_0 \cdot \frac{F_{\mathrm{EL}}}{d} = C_0$$

where

ε_r is the relative dielectric constant of AT-cut quartz material and is equal to 4,54;

ε_0 is the electric field constant and is equal to $8{,}86 \times 10^{-12}$ F/m;

N is the frequency constant equal to $f \cdot (d/n)$. N = 1 665 Hz·m for AT-cut crystal units;

n is the overtone order.

The following is obtained:

$$V \approx \frac{C_0}{\varepsilon_\mathrm{r} \cdot \varepsilon_0} \cdot \frac{n^2 \cdot N^2}{f^2}$$

and the current from the velocities, elongations, excursions or accelerations of the mechanical vibrations:

$$I = K_1 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot v \quad \text{where } K_1 = \sqrt{\frac{\pi \cdot \rho \cdot N^2}{\varepsilon_\mathrm{r} \cdot \varepsilon_0}}$$

$$I = K_2 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot x \quad \text{where } K_2 = \sqrt{\frac{\pi \cdot c \cdot N^2}{\varepsilon_\mathrm{r} \cdot \varepsilon_0}}$$

$$I = K_3 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot s \cdot f \quad \text{where } K_3 = \sqrt{\frac{4 \cdot \pi^3 \cdot \rho \cdot N^2}{\varepsilon_\mathrm{r} \cdot \varepsilon_0}}$$

$$I = K_4 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot \frac{b}{f} \quad \text{where } K_4 = \sqrt{\frac{\rho \cdot N^2}{4 \cdot \pi \cdot \varepsilon_\mathrm{r} \cdot \varepsilon_0}}$$

For non-convex AT-cut crystal units, the following also applies:

$$\frac{C_0}{C_1} = \gamma \approx 250 \cdot n^2$$

where

n is the overtone order.

The constant "250" fits well with the measurement value when it is used in the case of miniaturized crystal units such as surface mounted crystals. On the other hand, in the case of conventional crystal units, such as HU-6/U, HC-43/U, it is recommended to use "200" as the constant.

The following is obtained with C_0 = 5 pF for the currents:

$I_{\text{max,1}}$ = 50 µA $I_{\text{max,2}}$ = 1 mA

v_1 = 0,01 m/s v_2 = 0,2 m/s

x_1 = 1,8 × 10^{-6} x_2 = 3,6 × 10^{-5}

at f = 10 MHz:

s_1 = 6,7 × 10^{-11} m s_2 = 1,3 × 10^{-9} m

b_1 = 2,6 × 10^5 m/s^2 b_1 = 5,3 × 10^6 m/s^2

at f = 100 MHz:

s_1 = 6,7 × 10^{-12} m s_2 = 1,3 × 10^{-10} m

b_1 = 2,6 × 10^6 m/s^2 b_2 = 5,3 × 10^7 m/s^2

Depending on the frequency, quality factor and mode of vibration of the crystal unit and the volume of the vibrating zone, maximum currents or levels result from limit considerations for every type of a crystal unit. These shall not be exceeded when using these devices in oscillators and filters.

Annex B
(normative)

Method C: DLD measurement with oscillation circuit

To detect the DLD effect over the whole drive level range, the method described in 6.1 is very costly and is not applicable as a 100 % go/no-go test. The method proposed below tests the crystal units on its maximum R_r during start-up in an economical manner. This method can be applied as a 100 % final inspection as well as in a 100 % incoming inspection. It can also be used as an instrument to judge whether the crystal unit meets the requirements on R_{max} given in the detail specification.

The crystal unit in the oscillator can be represented as indicated in Figure B.1.

There will be no oscillation when the magnitude of the $-R_{osc}$ of the circuit is lower than R_r of the crystal unit.

During start-up, the R_r of the crystal unit may behave as shown in Figure B.2.

When measuring the crystal unit several times, the characteristic can shift slightly to the right or to the left or it can flatten.

The ratio $\gamma = R_{r2}/R_{r1}$ may also differ from measurement to measurement. This ratio does not necessarily mean that the oscillator may stop working if a certain value of γ is reached. The most important aspect is the safety margin between the maximum occurring R_r of the crystal unit and the value of R_{osc} of the oscillator circuit.

It is recommended that the circuit should have a $|-R_{osc}|$ of $\geq 3|R_{r\ max}|$ because in the temperature range, the $R_{r\ max}$ as well as $-R_{osc}$ can shift.

During the start-up, the drive level will move from the low values (left side of the graphics in Figure B.3) to the nominal drive level.

The principle of measurement is presented in Figure B.4.

The test set-up consists of a carefully designed crystal oscillator which can be considered as a true negative resistance over a wide frequency range, a feedback network which limits the power dissipation in the crystal unit to 1 mW and a detector circuit with an LED for visual indication.

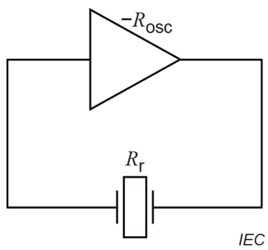

Figure B.1 – Insertion of a quartz crystal unit in an oscillator

Oscillation conditions:

- loop gain > 1, which means $|-R_{osc}| > R_r$
- feedback signal at oscillator input shall have correct phase.

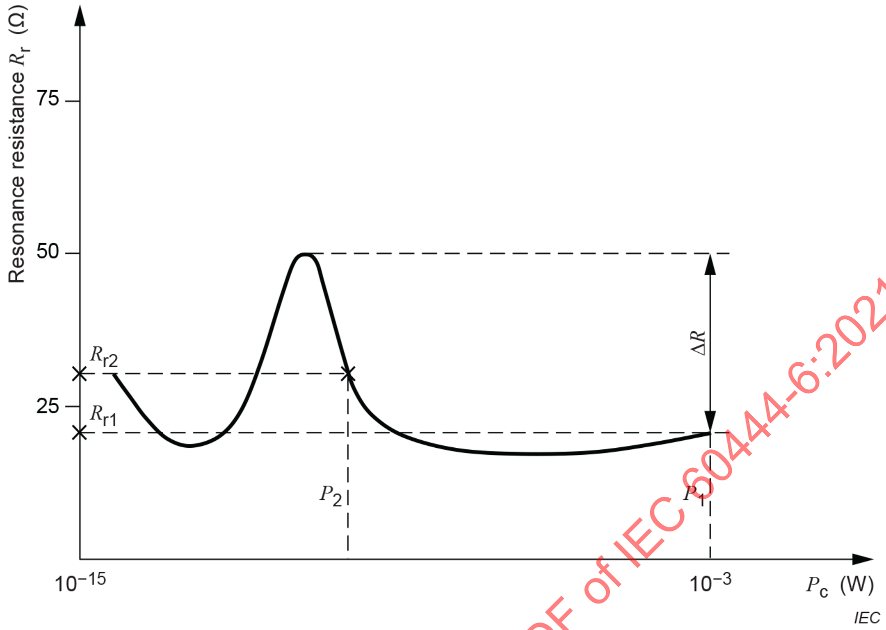

Figure B.2 – Crystal unit loss resistance as a function of dissipated power

NOTE The ratio R_{r2}/R_{r1} is not a reproducible value since the crystal unit curve slightly shifts at different measurement cycles.

The negative resistance (and with it the DLD reject level) of the oscillator can be changed by connecting a positive resistor in series with the oscillator. In this manner, each value between 0 Ω and 200 Ω may be selected. Connecting a quartz crystal unit with a sufficiently low R_r value between the test clamps, the oscillation will build up starting from the initial noise level (approximately 10^{-16} W to 10^{-15} W) to its limiting point for 1 mW as shown in Figure B.5.

During the start-up, the R_{rmax} of the crystal unit is continuously compared with a Calibrated-R_{osc} and the result is detected and transferred into a go/no-go decision.

If the crystal unit under test shows a certain degree of DLD, it is possible that the oscillation amplitude will not reach the 1 mW limiting point (point B in Figure B.6). In the example given in Figure B.6, the build-up of the oscillation is terminated at a much lower level of drive (point A). Normally in such cases, no oscillation is observed and only with very sensitive equipment can some oscillation be detected.

If a crystal unit reaches the 1 mW level (point B), the LED indicator will light up. This means that the quartz crystal unit's resonance resistance did not exceed the DLD reject level during the start-up.

The advantages of this measurement method are that it is fast, easy to calibrate, inexpensive and it has a simple set-up. A detailed electrical diagram is shown in Figure B.7. The equipment is commercially available.

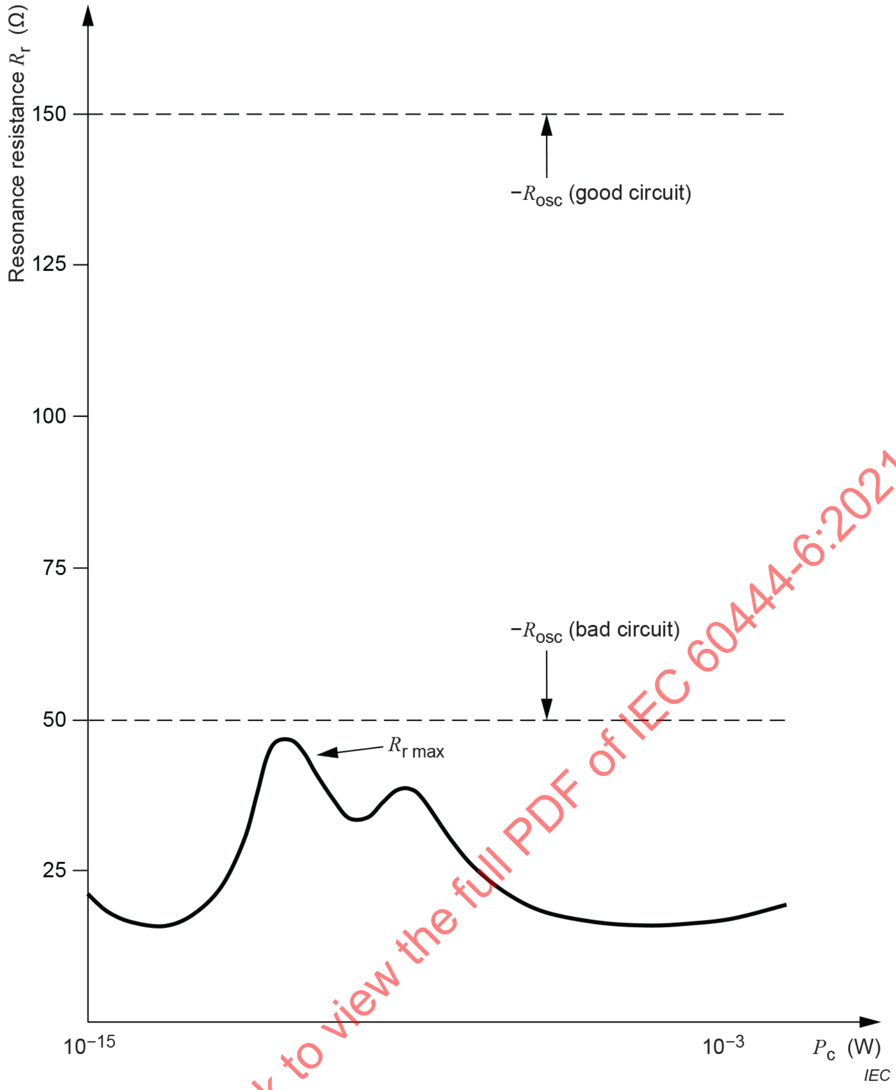

Figure B.3 – Behaviour of the R_r of a quartz crystal unit

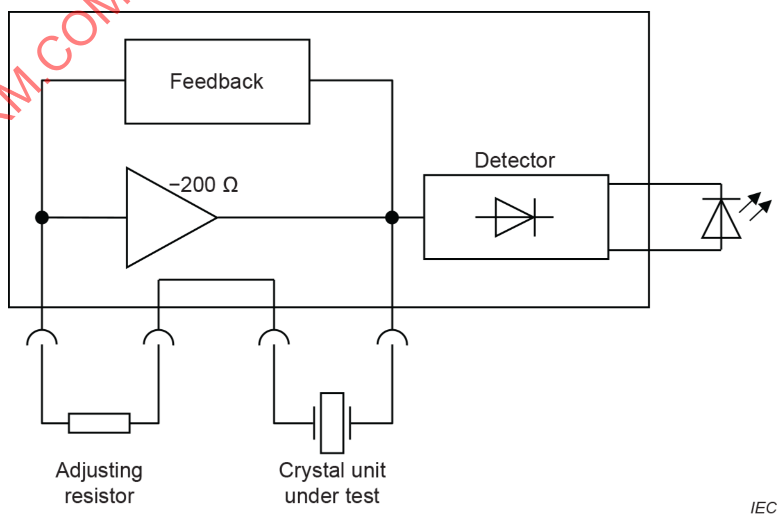

Figure B.4 – Block diagram of circuit system

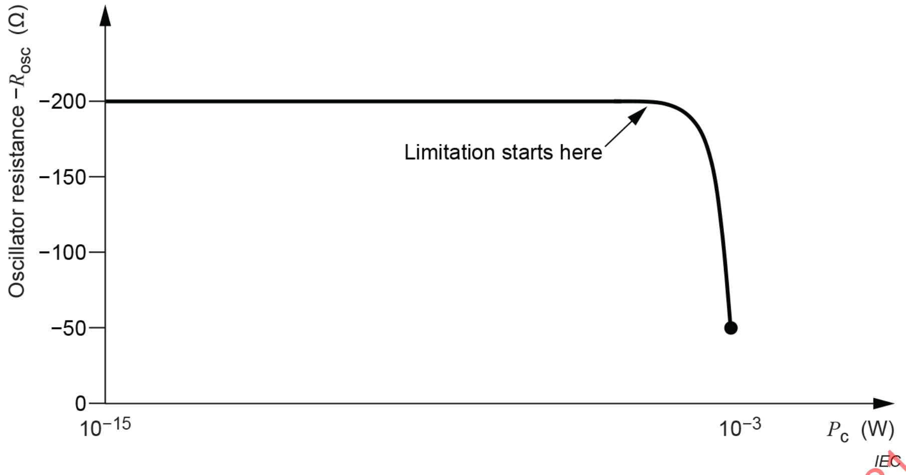

Figure B.5 – Installed $-R_{osc}$ in scanned drive level range

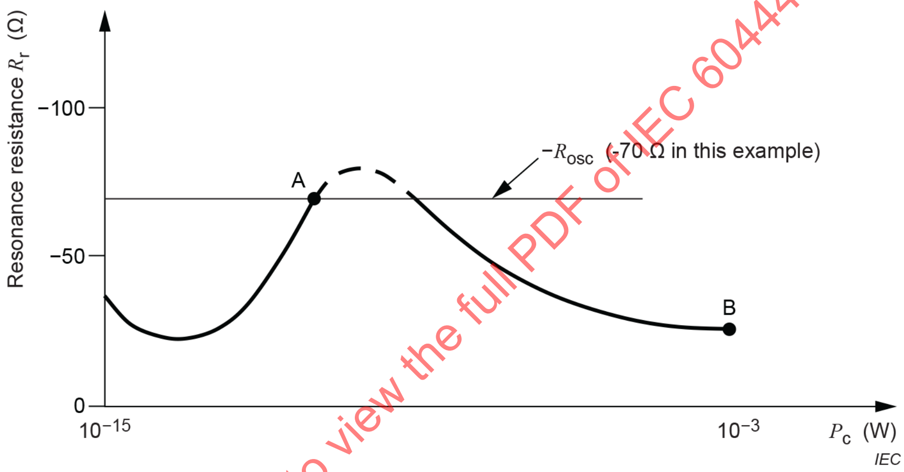

Figure B.6 – Drive level behaviour of a quartz crystal unit if $-R_{osc}$ = 70 Ω is used as test limit in the Annex B test

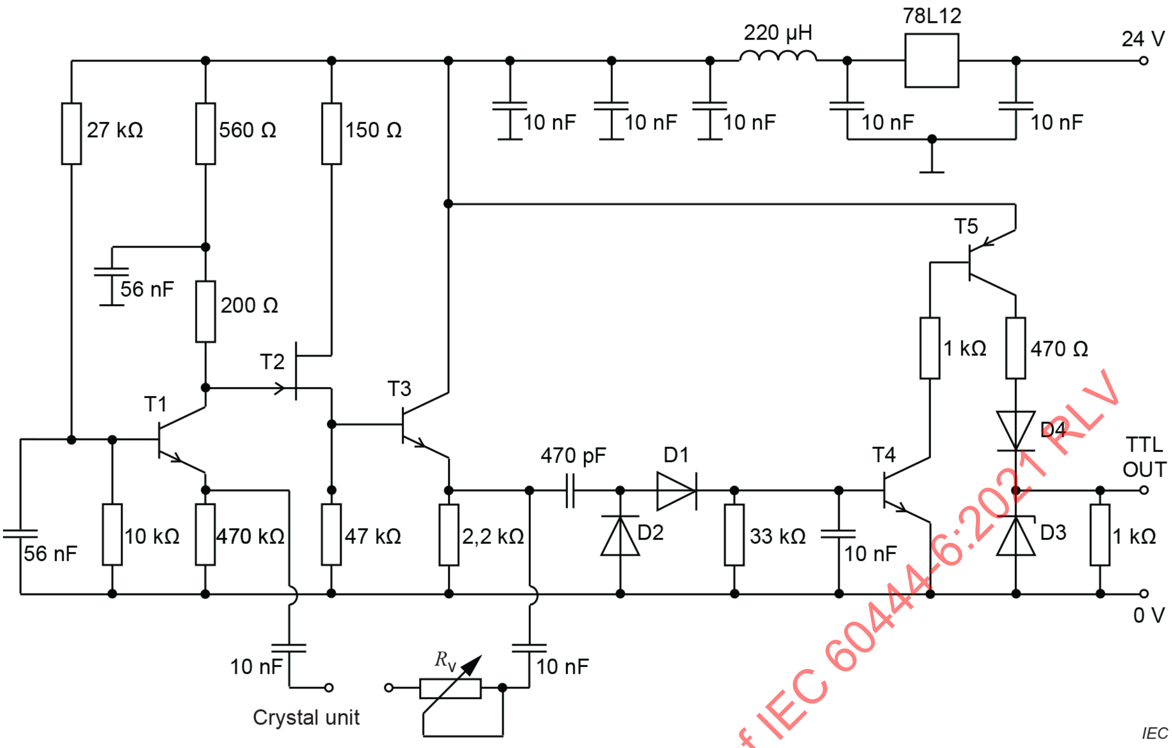

Figure B.7 – Principal schematic diagram of the go/no-go test circuit

Bibliography

IEC 60122-2-1:1991, *Quartz crystal units for frequency control and selection – Part 2: Guide to the use of quartz crystal units for frequency control and selection – Section one: Quartz crystal units for microprocessor clock supply*
Amendment 1:1993

IEC 60444-1, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 1: Basic method for the measurement of resonance frequency and resonance resistance of quartz crystal units by zero phase technique in a π-network*

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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MESURE DES PARAMÈTRES DES RÉSONATEURS À QUARTZ –

Partie 6: Mesure de la dépendance du niveau d'excitation (DNE)

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L'IEC 60444-6 a été établie par le comité d'études 49 de l'IEC: Dispositifs piézoélectriques, diélectriques et électrostatiques et matériaux associés pour la détection, le choix et la commande de la fréquence. Il s'agit d'une Norme internationale.

Cette troisième édition annule et remplace la deuxième édition parue en 2013. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) certaines équations ont été supprimées ou corrigées;
b) il est spécifié dans la note du Domaine d'application que les méthodes de mesure spécifiées dans le présent document ne s'appliquent pas uniquement à la coupe AT, mais aussi à d'autres coupes de cristaux et à d'autres modes de vibration.

Le texte de la présente Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
49/1374/FDIS	49/1377/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Le présent document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/standardsdev/publications.

Une liste de toutes les parties de la série IEC 60444, publiées sous le titre général *Mesure des paramètres des résonateurs à quartz*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

INTRODUCTION

Le niveau d'excitation (exprimé comme la puissance/la tension aux bornes du résonateur ou le courant qui traverse le résonateur) force le résonateur à produire des oscillations mécaniques par effet piézoélectrique. Dans ce processus, le travail d'accélération est converti en énergie cinétique et élastique et les pertes de puissance en chaleur. La dernière conversion est due au frottement interne et externe du résonateur à quartz.

Les pertes de frottement dépendent de la vitesse des masses vibrantes et elles augmentent lorsque l'oscillation n'est plus linéaire ou lorsque des vitesses critiques, des élongations ou des déformations, des excursions ou des accélérations sont atteintes dans le résonateur à quartz ou sur ses surfaces et points de montage (voir Annexe A). Cela provoque des changements de la résistance et de la fréquence, ainsi que des changements supplémentaires, du fait que ces paramètres dépendent de la température.

A des niveaux d'excitation "élevés" (par exemple supérieurs à 1 mW ou 1 mA pour des résonateurs de coupe AT), des changements sont observés sur tous les résonateurs, ceux-ci pouvant provoquer des changements irréversibles de l'amplitude et de la fréquence. Toute autre augmentation du niveau d'excitation pourrait détruire le résonateur.

A part cet effet, des changements de la fréquence et de la résistance sont observés dans certains résonateurs (par exemple inférieurs à 1 µW ou 50 µA pour les résonateurs de coupe AT) à des niveaux d'excitation "bas". Dans ce cas, lorsque le gain de boucle n'est pas suffisant, le démarrage des oscillations est difficile. Dans les filtres à cristaux, l'affaiblissement de transmission et l'ondulation changent.

De plus, le couplage entre un mode de vibration spécifié et d'autres modes (par exemple du résonateur à proprement parler, du montage et du gaz de remplissage) dépend aussi du niveau d'excitation.

En raison des caractéristiques de température différentes de ces modes, ces couplages contribueront à des changements de la fréquence et de la résistance du mode spécifié dans des gammes de températures étroites. Ces changements augmentent avec l'élévation du niveau d'excitation. Cependant, cet effet n'est pas pris en compte dans la présente partie de l'IEC 60444.

Dans cette nouvelle édition, le concept de la DNE de l'IEC 60444-6:2013 est maintenu. Toutefois, un contenu mieux adapté aux exigences strictes des utilisateurs a été introduit.

MESURE DES PARAMÈTRES DES RÉSONATEURS À QUARTZ –

Partie 6: Mesure de la dépendance du niveau d'excitation (DNE)

1 Domaine d'application

La présente partie de l'IEC 60444 s'applique aux mesures de la dépendance du niveau d'excitation (DNE) des résonateurs à quartz. Deux méthodes d'essai (A et C) et une méthode de référence (B) sont décrites. La méthode A, basée sur le réseau en π conformément à l'IEC 60444-5, peut être utilisée dans la plage de fréquences complète couverte par la présente partie de l'IEC 60444. La méthode de référence B, basée sur le réseau en π ou sur la méthode de réflexion conformément à l'IEC 60444-5 ou à l'IEC 60444-8, peut être utilisée dans la plage de fréquences complète couverte par la présente partie de l'IEC 60444. La méthode C, une méthode avec un oscillateur, est adaptée pour les mesures de résonateurs sur le mode fondamental en plus grandes quantités avec des conditions fixes.

NOTE Les méthodes de mesure spécifiées dans le présent document ne s'appliquent pas uniquement à la coupe AT, elles s'appliquent également à d'autres coupes de cristaux et d'autres modes de vibration, par exemple à des coupes à double rotation (IT, SC) et à des résonateurs à diapason (au moyen d'un dispositif d'essai à haute impédance).

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60444-5, *Mesure des paramètres des résonateurs à quartz – Partie 5: Méthodes pour la détermination des paramètres électriques équivalents utilisant des analyseurs automatiques de réseaux et correction des erreurs*

IEC 60444-8, *Mesure des paramètres des résonateurs à quartz – Partie 8: Dispositif d'essai pour les résonateurs à quartz montés en surface*

3 Termes et définitions

Aucun terme n'est défini dans le présent document.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia : disponible à l'adresst http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adress at http://www.iso.org/obp

4 Effets de la DNE

4.1 Changements réversibles de la fréquence et de la résistance

Les changements réversibles sont des changements de la fréquence et de la résistance qui ont lieu avec les mêmes niveaux d'excitation après des mesures répétées effectuées alternativement aux niveaux faible et élevé, ou après des mesures continues ou quasi continues du niveau le plus faible au niveau le plus élevé avant de revenir au niveau le plus faible, si ces changements restent dans les limites de la précision de mesure.

4.2 Changements irréversibles de la fréquence et de la résistance

Les changements irréversibles sont des changements significatifs de la fréquence et/ou de la résistance qui ont lieu au niveau bas après une mesure intermédiaire au niveau élevé, par exemple lorsqu'une résistance préalablement élevée, au niveau bas, est changée en résistance faible lorsque l'on refait la mesure. Spécialement lorsque le résonateur n'est pas utilisé pendant plusieurs jours, sa résistance peut revenir à une valeur élevée lorsqu'on l'utilise de nouveau à un niveau bas. Il convient de porter plus d'attention à l'effet irréversible, car il peut fortement compromettre la performance des dispositifs qui ne sont utilisés que de manière irrégulière.

4.3 Causes des effets de la DNE

Tandis que les effets réversibles sont, dans la plupart des cas, dus au niveau d'excitation excessif du cristal, les effets irréversibles quant à eux sont dus à la production, en particulier à des techniques de production imparfaites. Des exemples de causes sont:

– des particules sur la surface du résonateur (déposées par des huiles, des agents de nettoyage, des solvants ou par voie électrostatique);
– un endommagement mécanique du résonateur (par exemple des fissures dues à des abrasifs de polissage excessivement grossiers, dont les dimensions peuvent augmenter);
– des inclusions de gaz et d'huile dans les électrodes (par exemple en raison d'un vide de mauvaise qualité ou d'un taux de revêtement inapproprié pendant l'évaporation);
– un mauvais contact des électrodes au niveau du montage (par exemple la pâte conductrice a un composant métallique inadéquat, ou elle est insuffisamment cuite ou surchauffée; aussi une résistance de contact excessive entre la pâte conductrice et les électrodes ou le montage);
– des contraintes mécaniques entre le système de montage, les électrodes et le quartz.

5 Niveaux d'excitation pour la mesure de la DNE

Pour la mesure de la DNE, un niveau bas et un niveau élevé d'excitation (et éventuellement d'autres niveaux) sont appliqués. Le niveau élevé est le niveau d'excitation nominal. Il convient qu'il soit égal au niveau d'application en régime permanent.

Il convient de noter qu'il convient que ce niveau soit inférieur au niveau maximal applicable qui est donné dans l'Annexe A. Sauf spécification contraire, une valeur normalisée du courant de cristal doit être de 1 mA, ce qui correspond à une vitesse v_{max} = 0,2 m/s pour des résonateurs de coupe AT. Le niveau d'excitation en watt est alors calculé avec la valeur moyenne des résistances minimale et maximale spécifiées.

Le niveau d'excitation minimal qui a lieu pendant le démarrage d'un oscillateur peut être déterminé dans quelques cas seulement en utilisant les méthodes de mesure actives ou passives, en raison des limites de bruit des instruments de mesure pour des mesures conformes à l'IEC 60444-5 à environ 1 nW ou 10 µA (en fonction de l'équipement, la plus petite valeur de puissance peut être réduite à 0,1 nW ou 1 µA).

Une vitesse v_{max} = 0,01 m/s, correspondant à 50 µA pour des cristaux de coupe AT, est la valeur pratique reconnue pour des mesures dans le réseau en π (voir méthode A).

Deux méthodes et une méthode de référence de mesure de la DNE sont décrites ci-dessous.

La méthode A est basée sur la méthode du réseau en π conformément à l'IEC 60444-5, qui peut être utilisée dans la plage de fréquences complète couverte par le présent document. Elle permet de choisir rapidement des résonateurs à quartz sensibles au niveau d'excitation par une séquence de trois mesures. La variation admissible des résistances de résonance série données à la Figure 1 est basée sur des examens de longue durée des résonateurs de fabricants différents. Elle s'est révélée être une indication fiable pour les résonateurs ayant des problèmes de démarrage. Si nécessaire, il convient également d'étendre cette méthode en mesurant un grand nombre de niveaux d'excitation différents. Toutefois, dans la pratique, ce n'est pas nécessaire dans la plupart des cas (voir 6.1).

Pour le domaine industriel, il existe sur le marché des systèmes d'essai pour les cristaux, tels que le Saunders 250B ou le Kolinker KH1820[1]. Leurs logiciels présentent différentes variantes pour la mesure de la DNE.

La méthode B est utilisée pour des dispositifs dans lesquels des exigences strictes de démarrage des oscillations doivent être respectées et pour des dispositifs de fiabilité élevée.

La méthode C présentée à l'Annexe B est une méthode avec un oscillateur, qui est particulièrement adaptée pour la mesure de résonateurs sur le mode fondamental en plus grandes quantités, avec des conditions de mesure fixes (niveau d'excitation maximal, $R_{1,\max}$) de manière économique.

Si les techniques de mesure proposées ne sont pas suffisantes dans des cas spéciaux, il convient que l'utilisateur ait un oscillateur d'origine avec un filtre à rétroaction légèrement réduite ou un filtre d'origine.

La méthode B est plus stricte que la méthode A.

La méthode B est basée sur la méthode du réseau en π ou sur la méthode de réflexion conformément à l'IEC 60444-5 ou à l'IEC 60444-8, qui peut être utilisée dans la plage de fréquences complète couverte par le présent document.

Recommandation: Ces méthodes peuvent être utilisées pour tous les types de cristaux, toutefois:

– la méthode A est recommandée pour les cristaux pour filtres et pour oscillateurs;
– la méthode B est recommandée pour des applications avec des conditions de démarrage strictes, de fiabilité élevée et de stabilité élevée. C'est la méthode de référence pour les analyses de défaillance, etc.;
– la méthode C de l'Annexe B est une technique de mesure tout-ou-rien pour les cristaux pour oscillateurs.

[1] Le Saunders 250B et le Kolinker KH1820 sont des exemples de produits appropriés disponibles sur le marché. Cette information est donnée à l'intention des utilisateurs du présent document et ne signifie nullement que l'IEC approuve l'emploi des produits ainsi désignés.

6 Méthodes d'essai

6.1 Méthode A (méthode de mesure rapide normalisée)

6.1.1 Essai à deux niveaux d'excitation

L'essai est effectué au niveau d'excitation bas et au niveau d'excitation élevé, comme décrit à l'Article 5 avec des mesures de la fréquence de résonance et de la résistance en série conformément à l'IEC 60444-5. Les tolérances sont de ±10 % pour les niveaux de courant et de ± 20 % pour les niveaux de puissance.

a) Stockage pendant au moins un jour à 105 °C, puis pendant au moins 2 h à température ambiante ou stockage pendant une semaine à température ambiante.
b) Il convient de maintenir la température constante pendant la mesure (conformément à l'IEC 60444-5).
c) Mesure au niveau bas d'excitation (10 μA): $f_s = f_{s1}$, $R_1 = R_{11}$.
d) Mesure au niveau élevé d'excitation (1 mA): $f_s = f_{s2}$, $R_1 = R_{12}$.
e) Mesure au niveau bas d'excitation (10 μA): $f_s = f_{s3}$, $R_1 = R_{13}$.
f) Calcul de $\gamma_{12} = R_{11}/R_{12}$. La valeur de γ_{12} doit être inférieure à la valeur maximale de γ donnée par la ligne tracée sur la Figure 1 (abscisse = R_{12}).
g) La variation de fréquence tolérable $|f_{s2} - f_{s1}|$ doit être de 5 × 10^{-6} × f_{s1} sauf indication contraire dans la spécification particulière.
h) Calcul de $\gamma_{13} = R_{11}/R_{13}$. La valeur de γ_{13} doit être inférieure à $(\gamma+1)/2$, où la valeur de γ est tirée de la Figure 1 (abscisse = R_{13}).
i) La variation de fréquence tolérable $|f_{s3} - f_{s1}|$ doit être de 2,5 × 10^{-6} × f_{s1} sauf indication contraire dans la spécification particulière.
j) La valeur de la résistance ne doit pas dépasser la valeur maximale donnée dans la spécification particulière pour n'importe quel niveau d'excitation.

6.1.2 Essai conformément à la spécification

L'essai est effectué du niveau bas d'excitation au niveau élevé d'excitation avant de revenir au niveau bas comme décrit en 6.1.1. Ces niveaux et, si nécessaire, d'autres niveaux avec leurs tolérances, les écarts admissibles de la fréquence et de la résistance ainsi que les conditions de stockage doivent être spécifiés dans la spécification particulière.

NOTE La courbe γ donnée a été vérifiée en utilisant des résultats obtenus sur de nombreuses années d'expérience avec des résonateurs utilisés sur de nombreux types d'oscillateurs. Dans la plupart des cas, il n'y a pas de problème au démarrage, mais pour des configurations d'oscillateur critiques, des problèmes pourraient se produire. Puisqu'il n'est pas possible de fabriquer des résonateurs qui ont une résistance constante à n'importe quel niveau d'excitation, la courbe γ proposée donne des relations tolérables.

La définition des valeurs de niveaux d'excitation peut faire l'objet d'un accord entre le fabricant et le client.

Utiliser le niveau d'excitation nominal de la spécification particulière comme valeur du niveau élevé d'excitation. Pour les mesures à des niveaux d'excitation très élevés, un amplificateur additionnel peut être exigé.

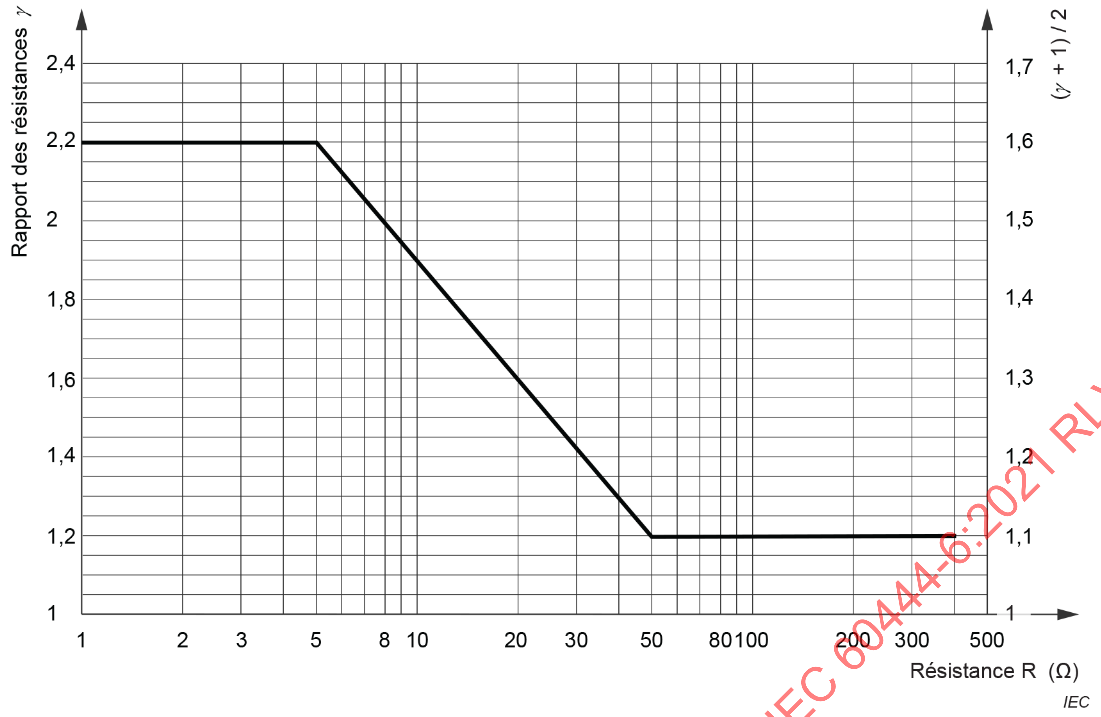

Figure 1 – Rapport des résistances maximales tolérables γ pour la dépendance du niveau d'excitation en fonction des résistances R_{12} ou R_{13}

Le niveau d'excitation maximal recommandé doit être choisi de façon qu'une augmentation supplémentaire du niveau d'excitation de 50 % n'augmente pas la résistance de manière réversible de plus de 10 % ni la variation de fréquence de plus de 0,5 × 10^{-6}.

$$I_q = K \cdot \frac{nA}{\sqrt{f}}$$

où

I_q est le courant recommandé pour l'état d'oscillation;

n est l'ordre d'un partiel;

A est la taille de l'électrode en mm^2;

f est la fréquence en MHz;

K est égal à 0,35 mA · mm^{-2} · $s^{-1/2}$.

6.2 Méthode B (méthode de mesure de référence à plusieurs niveaux)

L'essai est effectué au niveau d'excitation bas et au niveau d'excitation élevé, comme décrit à l'Article 5 avec des mesures de la fréquence de résonance et de la résistance conformément à l'IEC 60444-5. Les tolérances sont de ± 10 % pour les niveaux de courant et de ± 20 % pour les niveaux de puissance.

a) Stockage pendant au moins un jour à 105 °C, puis pendant au moins 2 h à température ambiante ou stockage pendant une semaine à température ambiante.

NOTE Si nécessaire, le client et le fabricant approuvent une température plus élevée et une durée plus longue de stockage avant une mesure de la DNE.

b) Il convient de maintenir la température constante pendant la mesure (conformément à l'IEC 60444-5).