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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)

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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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MEASUREMENT OF QUARTZ CRYSTAL UNIT PARAMETERS –

Part 6: Measurement of drive level dependence (DLD)

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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.

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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

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- replaced by a revised edition, or
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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 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.

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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/
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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.

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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).

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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.

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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.

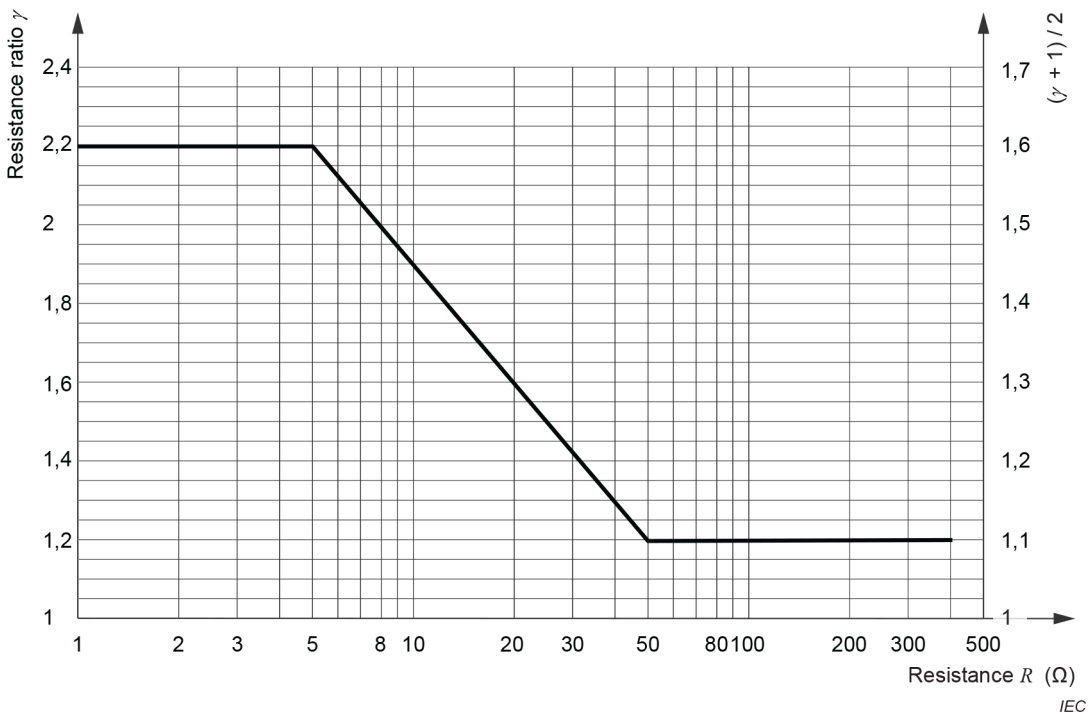

Figure 1 – Maximum tolerable resistance ratio γ for the drive level dependence as a function of the resistances R_{12} or R_{13}

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}.

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

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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) $$\frac{f_s(i),_{\max} - f_s(i),_{\min}}{f_{\mathrm{NOM}}} < 5\times10^{-6}$$

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

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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.

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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);

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