IEC 63150-1

Edition 1.0 2019-05

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Semiconductor devices – Measurement and evaluation methods of kinetic energy harvesting devices under practical vibration environment – Part 1: Arbitrary and random mechanical vibrations

Dispositifs à semiconducteurs – Methodes de mesure et d'evaluation des dispositifs de captage d'énergie cinétique dans un environnement de vibrations concret – Partie 1: Vibrations mécaniques arbitraires et aléatoires

IEC 63150-1:2019-05(en-fr)

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ICS 31.080.99 ISBN 978-2-8322-6895-7

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Part 1: Arbitrary and random mechanical vibrations

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

FDIS	Report on voting
47/2548/FDIS	47/2568/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 63150 series, published under the general title *Semiconductor devices – Measurement and evaluation methods of kinetic energy harvesting devices under practical vibration environment*, 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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- withdrawn,
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SEMICONDUCTOR DEVICES – MEASUREMENT AND EVALUATION METHODS OF KINETIC ENERGY HARVESTING DEVICES UNDER PRACTICAL VIBRATION ENVIRONMENT –

Part 1: Arbitrary and random mechanical vibrations

1 Scope

This part of IEC 63150 specifies terms and definitions, and test methods for kinetic energy harvesting devices for one-dimensional mechanical vibrations to determine the characteristic parameters under a practical vibration environment. Such vibration energy harvesting devices often have their own non-linear mechanisms to efficiently capture vibration energy in a broadband frequency range.

This document is applicable to vibration energy harvesting devices with different power generation principles (such as electromagnetic, piezoelectric, electrostatic, etc.) and with different non-linear behaviour to the external mechanical excitation.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

3.1
kinetic energy harvesting device
device to generate electrical energy from kinetic energy

3.2
rated frequency
frequency given in the specification

3.3
sinusoidal vibration
vibration with a sinusoidal acceleration waveform with a given frequency

3.4
random vibration
non-deterministic vibration with broadband frequency spectra with a constant root-mean-square (RMS) acceleration spectral density of which frequency range is specified

Note 1 to entry: See Annex B.

3.5
background noise
vibration acceleration when no driving signal is applied

3.6
transverse sensitivity ratio
ratio of the transverse vibration acceleration to the primary acceleration

4 Characteristics of kinetic energy harvesting devices

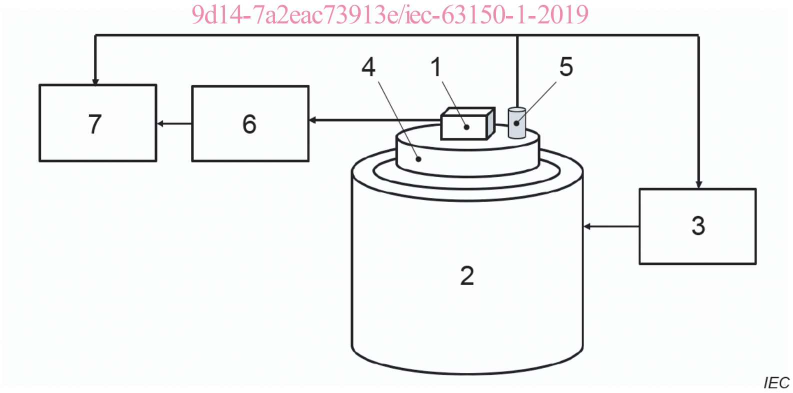
The characteristics of kinetic energy harvesting devices depend on the transduction mechanism (e.g., electromagnetic, piezoelectric, electrostatic), the device design, and the method for broadband frequency response (e.g., nonlinear spring, bistable spring, frequency up-conversion). The output voltage and power of those energy harvesting devices are characterized by measurements under three different vibration conditions, i.e., single-frequency sinusoidal vibration, vibration with frequency sweep-up/-down, and random vibration with broadband frequency spectra.

Examples of three different types of vibration energy harvesters are described in Annex A. Definition of random vibration is given in Annex B.

5 Vibration testing equipment

5.1 General

Figure 1 provides fundamental configurations with functional blocks or components for vibration testing equipment for kinetic energy harvesting devices. Details of the functional blocks or components named in the key are provided in 5.2 to 5.6.



Key

1 DUT: device under test
2 Vibration exciter
3 Vibration controller
4 Mounting fixture
5 Acceleration sensor
6 External load/read-out circuit
7 Data recorder

Figure 1 – Testing equipment for kinetic energy harvesting device for mechanical vibration

5.2 Vibration exciter

The vibration exciter shall generate vibration acceleration of the necessary frequency along with the necessary direction. In addition, the amplitude of the DUT vibration motion perpendicular to the driving direction should be small enough. The recommended value for its amplitude (transverse sensitivity ratio) is smaller than 10 % of the amplitude in the driving direction.

The vibration acceleration control can be performed by either of the following methods:

a) constant amplitude control: To maintain the vibration acceleration, by detecting and controlling the amplitude of the DUT vibration for given vibration frequency;
b) constant RMS acceleration control: To maintain the vibration acceleration, by detecting and controlling vibration acceleration directly for a given vibration frequency.

In general, when the driving voltage of the vibration exciter is kept constant, the vibration acceleration is changed with the vibration frequency. Thus, the gain of the vibration exciter for different frequencies shall be compensated with preliminary vibration tests at different frequencies or with on-line feedback control of the driving voltage based on the acceleration signal obtained with the acceleration sensor as shown in Figure 1.

5.3 Mounting fixture

The mounting fixture shall fix the kinetic energy harvesting device under test to the vibration exciter so that the generated vibration can drive the test device correctly. In addition, the direction of the vibration generated by the vibration exciter shall be within 2° from the determined direction of vibration of the tested device.

5.4 Acceleration sensor

The acceleration sensor shall measure the vibration acceleration of the bracket or the DUT.

5.5 Read-out circuit

The read-out circuit shall measure the voltage across the external load and the output power of the kinetic energy harvesting device within a 3 % measurement error. The sampling frequency of the output detector shall be high enough (at least twice as high as the highest frequency component) to capture the waveform of the output voltage accurately.

5.6 Data recorder

The test system of the kinetic energy harvesting devices shall include a data recorder to collect recording data.

6 Preparation of test bed and device

6.1 General

The kinetic energy harvesting devices for testing shall indicate the way of mounting and the direction of vibration. The device for testing shall be mounted on the vibration exciter with the mounting fixture, and its electrical output shall be connected to an external load. Prior to the actual power generation tests, preliminary evaluation of the test bed shall be made as described in 6.2 and 6.3.

6.2 Evaluation of vibration conditions

The following points should be checked prior to the test.

a) In order to avoid waveform distortion, maximum sine force F_{max} of the vibration exciter shall be higher than the required driving force, i.e.,

$$F_{max} > S\,M\,a_{max}$$

where S, M, and a_{max} are the safety factor, the total mass of the DUT and the mounting fixture, and the maximum zero-to-peak acceleration during the test. The safety ratio is the ratio between the maximum sine force of the vibration exciter and the estimated maximum sine force based on M and a_{max}. The recommended value for the safety ratio is higher than 2.

b) The background noise of the vibration acceleration shall be measured when no input voltage is applied to the vibration exciter while all the equipment is turned on.

6.3 Evaluation of electronic noise

The following preliminary measurements for evaluating electrical noise should be made prior to the test.

a) Electrical noise in the output voltage of the DUT shall be measured when no input voltage is applied to the vibration exciter while all the equipment is turned on.

b) The effect of the stray magnetic field generated by the vibration exciter shall be measured. If it is difficult to measure the stray magnetic field, the output voltage of the DUT shall be measured when the vibration exciter is operated without securing the DUT on the mounting fixture.

7 Testing methods

7.1 External load

The external load shall be a pure resistor of known value. In addition, the parasitic capacitance of the external load and the read-out circuit shall be measured.

7.2 Testing time

Testing time shall be long enough to stabilize electrical output of DUT in comparison with vibration frequency and acceleration.

7.3 Test environment

The temperature and relative humidity should be constant during the test.

7.4 Measurement conditions

Three types of measurements should be made as follows.

a) Single frequency response

The waveform of the vibration acceleration shall be sinusoidal. Vibration frequency shall be at the rated frequency. Vibration acceleration shall be constant during one set of tests. Measurements with different external loads shall be made to obtain the optimum load. Three sets of tests with different accelerations are recommended, because the response of DUT might be strongly dependent on the RMS acceleration.

b) Frequency sweeping response

The waveform of the vibration acceleration shall be sinusoidal. The lower and upper frequency of the frequency sweeping range shall be at least half and double the rated frequency. Data for sweeping in both directions (low to high or vice versa) shall be recorded. The sweep rate shall be low enough to minimize unintentional influence on the characteristics of power generation. In logarithmic sweeping, the recommended value for the sweep rate is smaller than 0,2 octave/min. Three sets of test with different accelerations are recommended, because the response of the DUT could be strongly dependent on the RMS acceleration.

c) Random vibration response

The waveform of the vibration acceleration shall be random as described in 3.4. The lower and upper frequency of the random vibration shall be at least half and double the rated frequency. Three sets of tests with different accelerations are recommended, because the response of the DUT could be strongly dependent on the RMS acceleration. The measurement time period for estimating time-averaged quantities shall be long enough. The recommended value of the time period is at least 1 000 times that of one oscillation cycle of the rated frequency.

8 Measuring procedures

8.1 General

The following three sets of measurements shall be made with the testing equipment for kinetic energy harvesting devices as provided in Figure 1. The following steps are measuring procedures:

a) set an ambient temperature and relative humidity;

b) fix the DUT on the vibration exciter with the mounting fixture;

c) set an external load to the output of the DUT;

d) apply an input voltage waveform to realize the required vibration motion as described from 8.2 to 8.4, and vibrate the DUT;

e) monitor the vibration frequency and acceleration of the DUT;

f) measure the output voltage of the DUT and compute output power;

g) repeat c) to f) for three different accelerations where required.

8.2 Single frequency response

An input voltage waveform is applied to the vibration exciter in such a way that the sinusoidal vibration of the DUT at the rated frequency and the prescribed acceleration is realized. Measurements with different external loads shall be made to obtain the optimum load.

8.3 Frequency sweeping response

An input voltage waveform is applied to the vibration exciter in such a way that the sinusoidal vibration of the DUT with a constant RMS acceleration is realized, while the vibration frequency is changed continuously at a sweep rate. Frequency shall be changed from the minimum to maximum frequencies (sweep-up) and from the maximum to minimum frequencies (sweep-down).

8.4 Random vibration response

An input voltage waveform is applied to the vibration exciter in such a way that random vibration of the DUT is realized.

9 Test report

The test report shall include at least the following information:

a) mandatory:
   1) reference to this document;
   2) shape, weight and dimensions of the tested energy harvesting device;
   3) characteristics of the read-out circuit:
      – external load;
      – sampling frequency;

- measurement accuracy;
- input impedance;
- parasitic capacitance;

4) characteristics of vibration exciter;
   - maximum sine force;
   - maximum amplitude of the DUT motion;
   - frequency range;
   - background vibration acceleration;
5) type, frequency response and accuracy of the acceleration sensor;
6) method for fixation of the energy harvesting device on the vibration exciter;
7) vibration direction with respect to the gravity direction;
8) measurement conditions:
   - external load;
   - rated frequency and vibration acceleration for rated frequency response;
   - range of frequency sweeping, sweeping rate, and vibration acceleration for vibration frequency sweeping response;
   - frequency spectrum of the vibration acceleration for random vibration;
   - measurement time;
   - measurement environment (temperature and relative humidity);
9) measurement results:
   - output voltage waveform;
   - peak-to-peak output voltage;
   - mean output power;

b) optional:
   1) purpose of testing;
   2) structure of tested device;
   3) principle of power generation;
   4) transverse sensitivity ratio of the vibration exciter;
   5) output impedance of the tested device.

Annex A
(informative)

Example of measurement for kinetic energy harvesting device

A.1 General

Annex A describes three examples of measurement for a kinetic energy harvester with different power generation principles. Clause A.2 is for an electret energy harvester with a linear spring, which exhibits a narrowband response. Clause A.3 is for an inverse-magnetostrictive energy harvester with a nonlinear spring showing significant hysteresis for frequency sweep-up/-down. Clause A.4 is for a piezoelectric energy harvester with a broadband response.

A.2 Electret energy harvester with linear spring

A.2.1 Shape, weight and dimensions of tested energy harvesting device

Figure A.1 shows the photo of the electret energy harvester. Its dimensions are 20 mm × 20 mm × 4 mm, and its weight is 3,7 g.

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Figure A.1 – Photo of the electret energy harvester

A.2.2 Characteristics of the read-out circuit

Figure A.2 shows the read-out circuit with a voltage divider. The output voltage across the load is given by

$$V = V_M \frac{R}{R_M}$$

where V_M, R, R_M are the measured voltage, the total load, and the resistance of the measurement section. The total load R is given by $R = R_M + R_H$, *and* R_M is given by the resistance of the voltage divider R_L and the input impedance of the measurement unit R_I, i.e.,

$$R_M = \frac{R_L R_I}{(R_L + R_I)}$$