IEC 62047-43

Edition 1.0 2024-03

# INTERNATIONAL STANDARD





## Semiconductor devices – Micro-electromechanical devices – Part 43: Test method of electrical characteristics after cyclic bending deformation for flexible micro-electromechanical devices

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# FOREWORD





IEC 62047-43 has been prepared by subcommittee 47F: Micro-electromechanical devices, of IEC technical committee 47: Semiconductor devices. It is an International Standard.

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

| Draft | Report on voting |
|---|---|
| 47F/459/FDIS | 47F/464/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/publications.

A list of all parts in the IEC 62047 series, published under the general title *Semiconductor devices – Micro-electromechanical devices*, 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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# INTRODUCTION

In the recent trend toward ubiquitous sensor society and the world of internet of things, demand and thus the market for softer electronic devices are quickly expanding. That is what flexible micro-electromechanical devices are for, some of which are already released into the market. Even a so-called foldable device is under development and will soon appear in the market. However, to operate trillions of such devices for the comfort and safety of human beings, the reliability of the individual devices is a critical concern. Especially in the case of flexible devices, robustness against bending deformation is an important issue which will be shared among all the producers and users of such devices. In addition, since such devices are bent usually not only once but some numbers of cycles, information on performance deterioration along with the number of cycles is also important.

In order to understand how safe a situation is, even after numbers of cycles, performance deterioration behaviour of those devices as a function of loading levels and cycles needs to be evaluated so as to ensure secure operation during expected service periods. This standard procedure of testing is designed with the emphasis on such points and with the applicability not only to already emerging flexible devices but also to so-called foldable devices which still function even when the device is folded.

# SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

## Part 43: Test method of electrical characteristics after cyclic bending deformation for flexible micro-electromechanical devices



## 1 Scope

This part of IEC 62047 specifies the test method of electrical characteristics after cyclic bending deformation for flexible electromechanical devices. These devices include passive micro components and active micro components on the flexible film or embedded in the flexible film. The desired in-plane dimensions of the device for the test method ranges typically from 1 mm to 300 mm and the thickness ranges from 10 µm to 1 mm, but these are not limiting values. The test method is so designed as to understand and further visualize the entire performance deterioration behaviour after cyclic bending deformation in a concept of 3D (P-S-N: Performance – Severity of bending – Number of cycles) plot over the loading space of severity of bending and number of repeated cycles. This document is essential to estimate safety margin over the operation period under a certain level of cyclic bending deformation and indispensable for reliable design of the product employing these devices.

## 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 62047-35:2019, *Semiconductor devices – Micro-electromechanical devices – Part 35: Test method of electrical characteristics under bending deformation for flexible electro-mechanical devices*

## 3 Terms and definitions

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

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

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

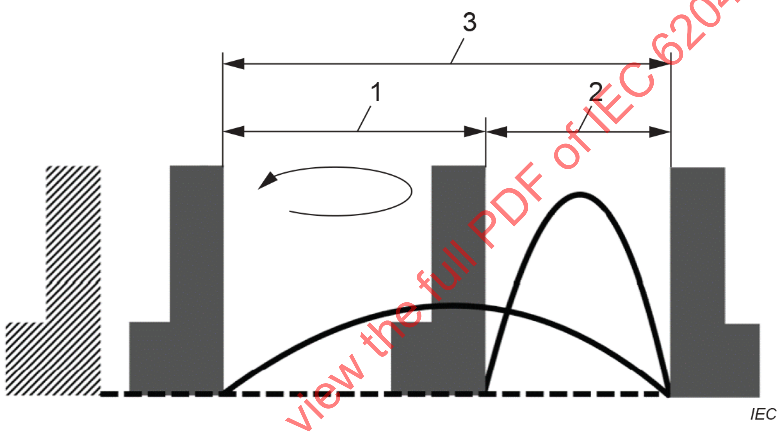
**3.1**
$d_{max}$
**maximum folding distance**
maximum distance between two loading walls, representing severity of bending, i.e. loading level, applied to the device, as indicated in Figure 1

**3.2**
$d_{min}$
**minimum folding distance**
minimum distance between two loading walls, representing severity of bending, i.e. loading level, applied to the device, as indicated in Figure 1

Note 1 to entry: The degree of bending given to the device is here represented by the distance between two walls approaching close to each other to bend the device, which is denoted as folding distance.

Note 2 to entry: This measure may be optionally converted to the radius of curvature *r* and also converted to the bending strain ε given around a bending axis. The strain is one of the suitable parameters for estimating the damage of materials through cyclic mechanical loading. But here it may not be uniform between the two walls especially when the rigidity distribution around the bending axis is not homogeneous due to the heterogeneity of structures. The nominal value of the radius is proportional to the distance, and the bending strain is in inverse proportion to the radius. Thus, the maximum of nominal bending strain occurs at the minimum folding distance.

**3.3**
**shuttle range**
travel distance of moving wall, as indicated in Figure 1




1 shuttle range

2 minimum folding distance

3 maximum folding distance

**Figure 1 – Schematic explanation of cyclic bending test**



# 4 Test piece

## 4.1 General

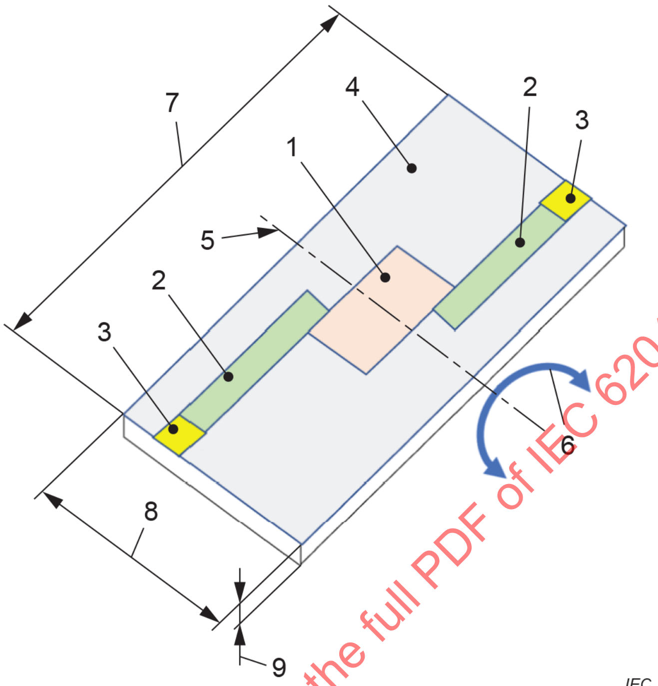
Flexible MEMS device, which is bent in use, can be in principle a test piece as it is and subjected to the evaluation of this document. In principle, this test-method is applicable without restriction on size and shape of devices. However, for the ease of load application, it may be cut into a rectangular shape with target parts to be loaded at the centre as mentioned in 4.2.

## 4.2 Shape of a test piece

A rectangular shape of test piece should be used for the ease of experiment as shown in Figure 2. It can be necessary to cut out a part of devices for the test, especially when the target part to be tested, which determines its own functional feature, is not located in the centre of the device. In this case, the test piece shall be prepared in a rectangular form by cutting a part out of the entire device with the target part located at the centre of two parallel edges which should also be parallel to the bending axis. This is because the point to be loaded to the end is limited in this test method only along the bending axis likely coming out at the centre due to the loading scheme explained in 5.1.

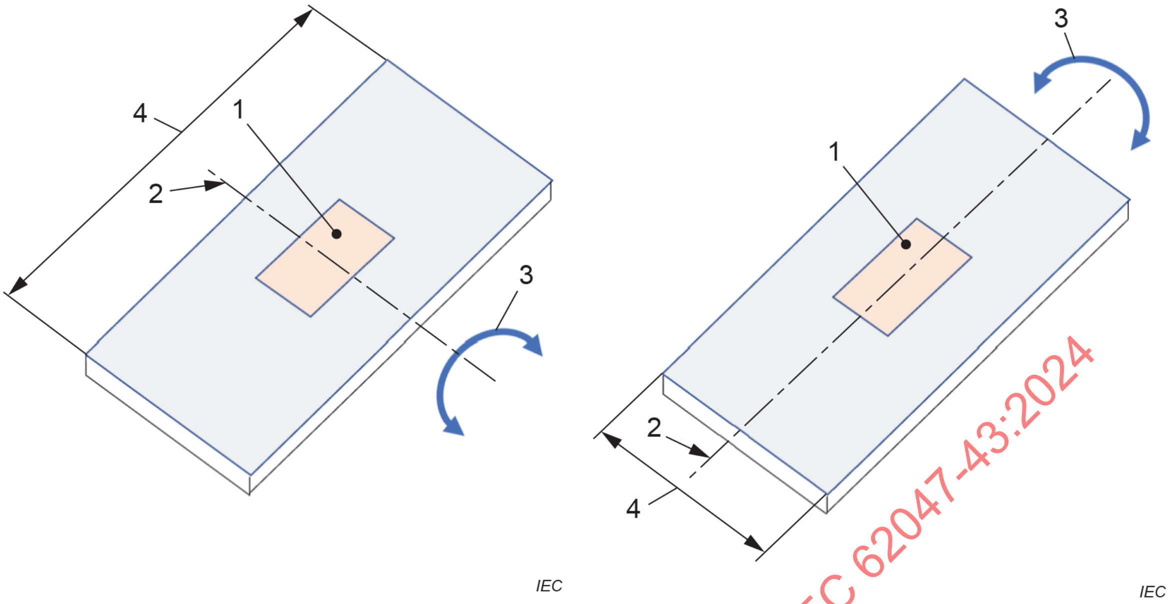
In this document, the length $l$ and the width $w$ of test piece is the dimension of the test piece in perpendicular and parallel direction to the bending axis, respectively. Because of the structures assembled on or embedded in the flexible substrate, the thickness can be not uniform over the entire device and hence depends on the location.

NOTE Length and width could be interchangeable when bending axis is rotated by 90 degrees, which are symbolically illustrated in Figure 3.




1 target part
2 interconnects
3 electrodes
4 flexible substrate
5 bending axis
6 bending direction
7 length
8 width
9 thickness

**Figure 2 – Schematic illustration of flexible MEMS test piece**




a) **0-degree condition** b) **90-degree condition**

**Key**

1 target part

2 bending axis

3 bending direction

4 length

**Figure 3 – Selection of bending axis**

# 5 Test method

## 5.1 Principle

Principles of loading to the test piece are illustrated in Figure 4. The device shall be inserted between two walls sliding closer to each other as illustrated in Figure 4 a). Then let the distance between two walls, i.e. folding distance $d$, be gradually shorter as shown in Figure 4 b) until finally reaching minimum folding distance in between as in Figure 4 c). Then let the two walls go backward to the maximum folding distance in Figure 4 a) and keep on cyclic loading between the minimum and maximum folding distances, i.e., in the shuttle range. After a certain number of cycles, evaluate the device performance at the minimum folding distance and consecutive maximum folding distance.


a) Apogee b) in-between c) Perigee

**Key**

1 folding distance $d$

2 test piece

**Figure 4 – Folding procedures**



## 5.2 Test apparatus and instrumentation

### 5.2.1 Test apparatus

The apparatus of measurement used in this cyclic test shall conform to the apparatus described in IEC 62047-35. There is no special requirement on the configuration of test apparatus in this document, so far as with which the device can be folded to the end of possibility. However, the width and height of walls shall be longer preferably at least by 5 % than the width and half the length of the test piece, respectively, so that the whole test piece is firmly pressed by the walls. The surface flatness and parallelism of walls is carefully prepared so as not to touch each other before the end of test. The variance of gap between walls shall be smaller than the thickness of test piece. The surface roughness and flatness of walls are recommended to be less than 1/10 of the thickness of test piece so as not to distort test piece by bumps of wall except for the intended bending deformation. Either wall or both walls are shifted by a motor drive system, or a manually-actuated linear stage. Both ends of test piece shall be fixed so as to follow the motion of walls, on condition that the ends of test piece can smoothly rotate.

Folding distance shall be measured to the appropriate accuracy relative to the folding distance itself. Because it is sometimes difficult to keep the same level of accuracy over the entire range of folding distance, it is recommended to secure 1 % when the folding distance is more than the half of specimen length, 3 % when less than one third, and 5 % when less than one tenth. Therefore, it can be suggested to use a number of different tools, e.g. a scale for millimetre range, a micrometer gauge for submillimetre range, or a laser displacement meter or microscopy for micron and sub-micron range.

### 5.2.2 Instrumentation

Set the test piece on the apparatus and evaluate the initial performance before bending. Then, let the two walls come closer to the minimum folding distance. Stop the apparatus at the minimum folding distance and evaluate the performance. Then let the two walls go backward to the maximum folding distance and keep on cyclic loading between the minimum and maximum folding distances. After a certain number of cycles, evaluate the device performance at the minimum folding distance and consecutive maximum folding distance.

Device performance and its accuracy of measurement strongly depend on individual devices. Therefore, nothing is normatively specified in this part. Instead, users of this procedure should be responsible for adequate evaluation for the performance of their devices and reporting accuracy of instrumentation in the test report as described in Clause 6.

It is also advised that connection of lead wires to the device must be carefully prepared in order to avoid artifacts possibly caused by the failure of wirings (especially the connection points) during repeated loading process.

Not an absolute error for full range measurement but a relative error on folding distance is of importance to maintain the reproducibility in bending deformation, especially around the end of test, because the nominal curvature can be approximated by $2/d$ under the bending deformation as shown in Figure 4 b). In addition, the value of $d$ ranges from $l$, e.g. more than a hundred millimetres, to $2t$, e.g. less than submillimetres. The dimension with such a wide range is difficult to measure with the accuracy of less than 1 % by a ready-made apparatus. That's why the accuracy of folding distance is noted in terms of the relative value with the accuracy of 5 % for the ease of experiment in this document.

## 5.3 Procedure

### 5.3.1 Testing conditions

Since this document is to see the deterioration behaviour of device performance after cyclic bending deformation, it cannot always be easy to find testing speed adequately corresponding to the conditions of actual device operation. Therefore, evaluation of time-dependent deformation behaviour such as visco-elasticity is regarded here as out of scope, and loading speed (frequency of cyclic load) is not particularly specified here. Load frequency is determined by the user of this document and shall be included in the test report. Attention should be paid to time-dependent behaviour of the devices since flexible MEMS are often made of polymeric materials and their deformation should be in principle more or less time-dependent. Therefore, the loading frequency, i.e. speed of deformation, should be determined, to the extent possible, to the actual operating condition of the device and non-elastic deformation should be reported, if any noticed, as mentioned in Clause 6. Detailed survey about the time-dependent behaviour of devices over a range of loading speed is out of requirement of this document.



A cyclic bending test shall be performed between the specified minimum and maximum folding distances which should not be changed during the test on a test piece. A number of tests shall be performed by changing the maximum and minimum folding distances so as to draw a curvilinear surface of performance deterioration as mentioned in 3.2. Maximum folding distance should also be changed even for the same minimum folding distance because the performance deterioration behaviour changes depending on both folding distances as mentioned in 3.2. Details are explained in Annex A. For devices developed exclusively for a particular operation condition, it is enough to perform cyclic bending test with that specified values of minimum and maximum folding distance.

Required minimum value of minimum folding distance is the situation defined as the end of test in IEC 62047-35.

Other conditions for testing, such as temperature and humidity, etc., shall be as far as possible the same as those where the devices are operated in actual use.

NOTE Since the objective of this document is to see the deterioration behaviour of device performance against monotonic bending to the end of possible curvature, it can be not always easy to find testing conditions (especially speed) which adequately correspond to those of actual device operation. In such cases, the users are responsible to determine the conditions and report them appropriately as mentioned in 6.5.

### 5.3.2 Selection of bending direction

Set the test piece on the test apparatus, with the surface to be loaded in convex facing upward in Figure 3. Choice of bending direction whether the surface with devices is loaded in tension or compression should follow in principle the condition in which the device is actually bent during its service. However, in order to explore possible failure modes, both the two bending directions may be examined regardless of how the device is actually used.

NOTE When a test piece as shown in Figure 2 is set on the test apparatus with the target part facing upward, the test piece is loaded in convex and the target part is strained in tension. On the other hand, for the test under the opposite bending direction, the test piece is set with the target part facing downward and the target part is strained in compression.

### 5.3.3 Determination of bending axes

Select a characteristic axis of individual devices to be tested. In addition, at least another direction in 90 degrees to it should also be tested as shown in Figure 3. Actual selections of directions are left to suppliers and users. It is here noted that the actual bending axes appearing in the end of the test can be somehow not exactly at the position expected, likely because of possible error in test piece preparation and inhomogeneous stiffness distribution over the device. Therefore, fine adjustment of bending axis location may be necessary during the loading process. Possible methods for the precise control for this adjustment are suggested in Annex B of IEC 62047-35:2019.

### 5.3.4 Measurement of test piece dimensions

Length and width of the test piece shall be measured and recorded for each test piece. Measurement of the length of device is critical because of the loading scheme explained in 5.1 and 5.2. It shall be measured to the accuracy of 1 % relative to the length itself. Dimensions in the direction parallel to the bending axis is not important but may also be measured in the same way. Thickness can vary among different points over the test piece due to its inhomogeneous structures. Therefore it shall also be measured at a number of typical points, e.g. both the substrate part and the target part. A profilometer can measure the local thickness of test piece with sufficient accuracy. The same accuracy suggested in 5.2.1 for the folding distance may be applied also for the thickness measurement.

NOTE 1 Since preferable methods and accuracy in measurement strongly depend on individual devices, users of this procedure are responsible for choosing adequate methods for their devices and reporting accuracy in the test report as described later.

NOTE 2 Since the distribution of thickness strongly depends on the structures on individual devices subjected to the test, selection of measuring points is left to the users.

NOTE 3 It is optional to report the dimensions except for length because the width and the thickness are just a supporting information for the design of the test apparatus for this document.

### 5.3.5 Measurement of folding distance

Distance between two walls is measured and recorded as the folding distance at each measurement of device performance. It shall be measured to the accuracy of 5 % relative to the folding distance itself. These measurements can be made using a scale for millimetre range, a micrometer gauge for submillimetre range, or a laser displacement meter or microscopy for micron range.

### 5.3.6 Number of testing

A number of different positions shall be tested in the same way, i.e., a number of different locations of bending axes shall be loaded in this document. This is because the point of the device to be loaded to the end is limited only along the bending axes, and because the device can be bent at an arbitrary position in the actual use.

The total number of test pieces is more than three. The individual conditions of cyclic bending should be designed so as to draw visibly P-S-N curvilinear surface. And, as regards the information on reproducibility, more than two specimens should be tested under the same condition from the view point of statistics and the number shall be stated in the test report.

NOTE When the performance (P) is plotted over the spaces of severity of bending (S) and number of cycles (N), there comes up a curvilinear surface which visually presents performance deterioration behaviour. It is noteworthy that this surface is a function not only of minimum folding distance but also maximum folding distance, which means as if the surface would split depending on both the minimum and maximum folding distances. Further details of this concept are visually explained in Annex A with figures.

### 5.3.7 Instrumentation

Set the test piece on the apparatus and evaluate the initial performance before bending. Then, let the two walls come closer to the minimum folding distance. Stop the apparatus at the minimum folding distance and evaluate the performance. Then let the two walls go backward to the maximum folding distance and keep on cyclic loading between the minimum and maximum folding distances. After a certain number of cycles, evaluate the device performance at the minimum folding distance and consecutive maximum folding distance.

Device performance and its accuracy of measurement strongly depend on individual devices. Therefore, nothing is normatively specified in this part. Instead, users of this procedure should be responsible for adequate evaluation for the performance of their devices and reporting accuracy of instrumentation in the test report as described in Clause 6.

### 5.3.8 End of testing

The cyclic bending test should be kept doing at least $10^4$ cycles. If the performance after $10^4$ cycles decreases from the initial value to less than 10 %, the test can be stopped. If not, the test should continue to apply cyclic load $10^5$, $10^6$ and more till the deterioration behaviour appears clearly.



## 6 Test report

### 6.1 General

The information provided in 6.2 to 6.5 shall be included in the test report of this document. Testing conditions determined by users as mentioned in 5.3.1 shall also be included as well.

### 6.2 Bending direction(s) and in-plane locations of bending axes

Bending direction(s) and detailed locations of bending axes on the device shall be reported, preferably with figures as illustrated in Figure 3 as an example. In case a test piece was bent with more than one axis in a single test, it is highly recommended to dispose the result and try the test again with shorter length of test piece.

Methods and accuracy of measurement for these parameters should be included in the test report, though they are not normatively specified since they strongly depend on individual devices.

### 6.3 Dimensions of the test piece

At least the length of the test piece shall be reported. However, additional report on other dimensions such as width and thickness should be appreciated. Since a device is deformed by pushing its ends to come closer to each other for the case of test shown in Figure 4, the distance between two ends, i.e., length, dominates its deformation against folding distance in the early stage of testing [Figure 4 a)]. Therefore, length is the most essential parameter to be informed for each test. In the meantime, although deformation is determined only by the folding distance and independent of test piece dimensions in the middle stage [Figure 4 b], the folding distance in the last stage [Figure 4 c)] is intimately correlated with thickness distribution over the entire length and width of the test piece. Thus width and thickness should also be reported in addition to length, in order to fully inform the geometrical characteristics of the test piece.

### 6.4 Performance degradation characteristics with the folding distance

Supply in a graphical manner the relationship between the device performance plotted along the ordinate, the minimum folding distance and the number of cycles along two abscissae. Example is shown in Figure 5. Parameters along the ordinate can be selected in an arbitrary manner depending on the device function to be examined, i.e. voltage, current or resistance. On the contrary, there are several candidates for the parameter to indicate folding distance along the abscissa. They may optionally be either the absolute distance between two walls which is the original meaning of folding distance, the distance between two walls normalized by the length of the test piece, or the average radius of curvature calculated with the assumption of uniform bending deformation between the two walls. How the loading parameter along the abscissa is defined shall be clearly stated in the report.

In addition to the mandatory graphical presentation above, from the view point of more accurate information in quantities, it is also recommended to include in the report a table where the source of graphical representation explained above is shown in numbers. It can also be helpful to show two-dimensional plots, i.e. cross sections of the three-dimensional plot along the planes of users' interests, for a clearer recognition of test results. An example of such two-dimensional plot is presented in Figure A.4.

NOTE P-S-N plot changes depending also on the maximum folding distance. That means P-S-N curvilinear surface eventually splits with different shuttle ranges even if the minimum folding distance is the same. See Annex A for more details.



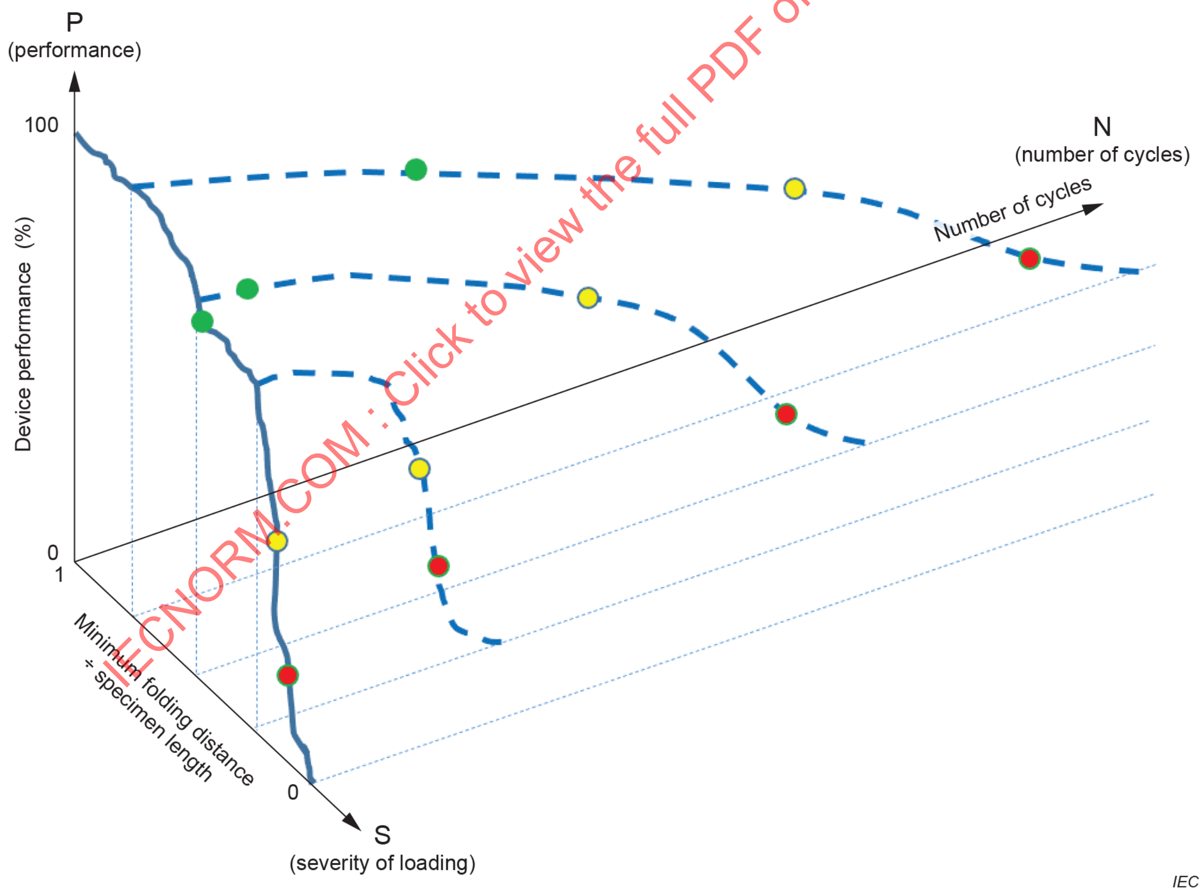



**Figure 5 – 3-dimensional P-S-N plot**

### 6.5 Testing conditions

Holding time between two loading steps before starting instrumentation as well as loading speed itself is determined by user and included in a test report, e.g. round trip motion of moving wall with a frequency of 1 Hz and 1 min holding time per each measurement. Other conditions for testing, such as temperature and humidity etc., shall also be reported.

Since substrates for flexible MEMS are often made of polymeric materials, deformation behaviour should be in principle more or less time-dependent. Non-elastic time-dependent behaviour should be mentioned in the test report, if any noticed.