
Space systems — Micro-vibration testing

Systèmes spatiaux — Essais de microvibration

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Foreword

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

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

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Spacecraft on-orbit experience a micro-vibration environment which can induce severe disturbances to sensitive payload with high pointing stability and/or position stability. It can affect mission success of payload equipment, e.g. earth observation, space telescopes, optical experiments, telecommunication.

For such applications, it is necessary to verify their resistance to the micro-vibration environment on-orbit. This verification may be supported by spacecraft level micro-vibration tests on ground. In that case:

- the vibration transmissibility from the disturbance sources to the sensitive payloads should be investigated;
- the performance of these payloads under the influence of the relevant disturbance sources should be identified by response measurements;
- the modal parameters of the spacecraft should be extracted to update the analysis model.

This document specifies contents to meet test requirements. It includes test purpose, general test information, test equipment, test requirements and recommendations, test flow and procedure, test interruption and handling, test data and result evaluation, and test reports for spacecraft level micro-vibration tests.

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Space systems — Micro-vibration testing

1 Scope

This document specifies requirements for the implementation of spacecraft level micro-vibration tests on space systems to be considered by test providers, including test designers and test engineers. It also gives guidance for spacecraft designers and interested parties.

The spacecraft level micro-vibration test is applicable to space systems which contain payload equipment sensitive to the micro-vibration environment which only induced by the internal disturbance sources on-orbit, e.g. for the purpose of earth observation, space telescopes, optical experiments, telecommunication.

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.

ISO 14620-1, *Space systems — Safety requirements — Part 1: System safety*

ISO 15864:2021, *Space systems — General test methods for spacecraft, subsystems and units*

ISO 17566:2011, *Space systems — General test documentation*

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:

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

3.1

micro-vibration environment

dynamic environment on-orbit which is characterized by very low acceleration level compared with the usual dynamic environment during launch

Note 1 to entry: Micro-vibration environment affects the normal performance or function of sensitive payload equipment of the spacecraft on-orbit.

Note 2 to entry: Generally, the micro-vibration environment of the sensitive payload equipment on-orbit is in the range of micro-g's to milli-g's, and the frequency range is from a few hertz up to a few hundred hertz^[1].

3.2

background noise

noise coming from sources other than the test signal

[SOURCE: ISO 13472-1:2022, 3.8]

3.3

signal-to-noise ratio

S/N

difference between the level of the nominal useful signal and the level of the *background noise* (3.2) at the moment of detection of the useful event

Note 1 to entry: The signal-to-noise ratio is given in decibels.

[SOURCE: ISO 13472-1:2022, 3.9]

3.4

design safety factor

factor by which limit loads are multiplied in order to account for uncertainties and variations that cannot be analysed or accounted for explicitly in a rational manner

Note 1 to entry: Design safety factor is sometimes referred to as design factor of safety, factor of safety or just safety factor.

[SOURCE: ISO 10786:2011, 3.15]

4 Symbols and abbreviated terms

FFT	fast Fourier transform
FM	flight model
LoS	line-of-sight
RMS	root mean square
<i>S/N</i>	signal-to-noise ratio
SADA	solar array drive assembly
SM	structural model
STM	structural/thermal model

5 Test purpose

The main purpose of the spacecraft level micro-vibration test is to verify the dynamic characteristics in micro-vibration environment. This is achieved by:

- obtaining transfer characteristics from disturbance source to the sensitive payload to verify the transfer path design through transfer function measurements;
- obtaining modal parameters of the spacecraft through a modal survey test, in order to update the analysis model;
- obtaining the micro-vibration response of sensitive payload equipment through response measurements.

Usually, the verification of the dynamic characteristics in a micro-vibration environment is based on a combination of analytical prediction and test.

6 General test information

6.1 Tailoring

Requirements of this document may be tailored to fulfil the objectives of the test.

6.2 Disturbance sources

Disturbance sources can be classified as external sources and internal sources. External sources can be found in the space environment, e.g. eclipse entry and exit. Internal sources can be found from within the spacecraft.

[Annex A](#) presents typical internal disturbance sources and their characteristics.

6.3 Preliminary analysis

A preliminary micro-vibration analysis shall be conducted before the spacecraft level micro-vibration test. The objectives of the preliminary analysis are:

- a) to identify the payloads sensitive to micro-vibration;
- b) to identify the main disturbance sources on-orbit;
- c) to decide whether a spacecraft level micro-vibration test for a specified spacecraft is necessary.

[Annex B](#) may be considered to decide whether spacecraft level micro-vibration tests are necessary or not for the spacecraft with pointing stability as the sensitive index, depending on the nature and characteristics of the mission.

In cases where spacecraft level micro-vibration testing is decided to be necessary, modelling and analysis of spacecraft dynamics should be done before test for test planning and the following tasks shall be executed:

- Obtain the prediction results to be used for test planning and specification.
- Define the configuration of the test article under the consideration that the test configuration can differ from the flight configuration.
- Determine the dynamic characteristics of the disturbance sources to be replaced by analogue exciters in the test configuration.
- Define the test frequency range according to the sensitive frequency range of the sensitive payloads.
- Evaluate the influence of boundary simulation equipment.

7 Test equipment

7.1 Test configuration for transfer function measurement and modal survey test

The test configuration for the transfer function measurement and modal survey test shall:

- a) provide approximated “free-free” boundary conditions for the test article;
- b) apply the excitation force to the pre-defined excitation points in the test article;
- c) measure, acquire and process response signals;
- d) obtain transfer functions from the response signals with the excitation signal as the reference;

- e) obtain modal parameters based on the transfer functions, so as to update the analysis model if needed or requested.

NOTE The “free-free” boundary conditions can be chosen and justified so that it remains representative of the dynamic characteristics of the test article on orbit flight conditions.

An example of test configuration is shown in [Figure 1](#).

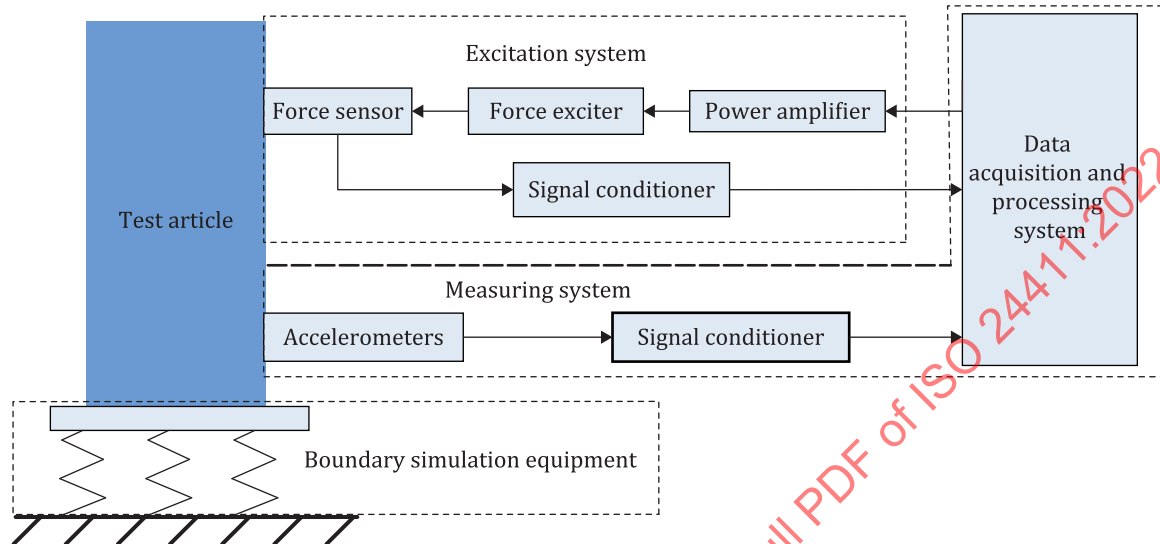


Figure 1 — Test configuration for transfer function measurements and modal survey test

7.2 Test configuration for response measurement

The test configuration for response measurement shall:

- provide approximated “free-free” boundary conditions for the test article;
- excite the test article by disturbance sources or analogue exciters;
- measure, acquire and process response signals (typical sensors are accelerometers, displacement sensors, force sensors, angular sensors).

NOTE The “free-free” boundary conditions can be chosen and justified so that it remains representative of the dynamic characteristics of the test article on orbit flight conditions.

An example of test configuration is shown in [Figure 2](#).

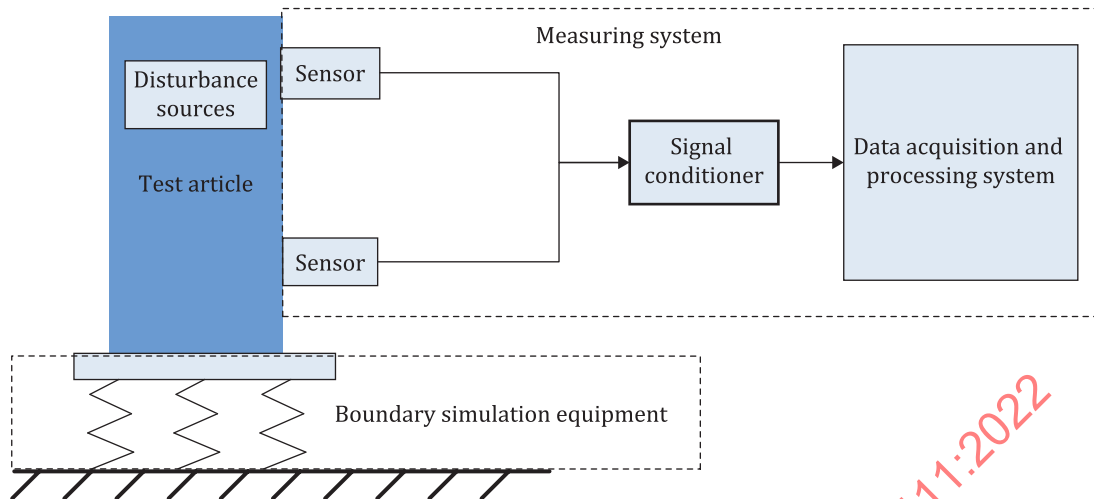


Figure 2 — Test configuration for response measurement of micro-vibration

7.3 Test equipment functional requirements and recommendations

7.3.1 Boundary simulation

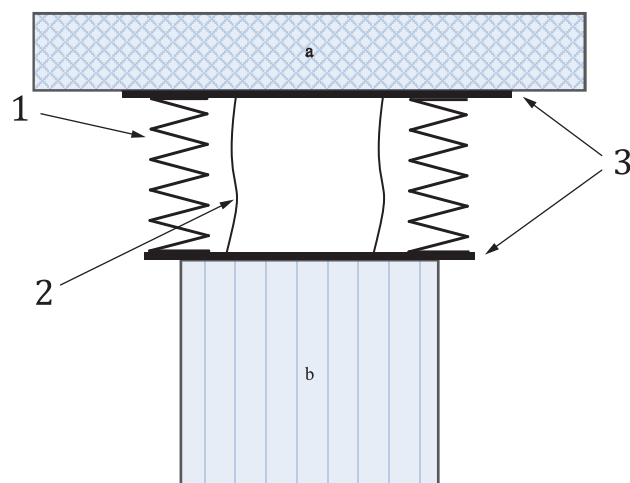
The test configuration shall simulate the on-orbit dynamic conditions as close as possible in order to get reliable estimates for the expected on-orbit performances. In particular, the test article shall be in a quasi “free-free” boundary condition and the gravity forces acting on the structure and surrounding air effects shall be minimized.

The requirements and recommendations for the boundary simulation equipment are as follows:

- The boundary simulation equipment shall provide the function of suspension and safety protection for the test article.
- Suspension frequencies, which are the first six rigid body frequencies of the system composed of boundary simulation equipment and the test article, should be lower than 25 % of the first elastic modal frequency of the test article under the free-free boundary condition.
- The attached mass moving synchronously with the test article should be sufficiently less than the mass of the test article (e.g. less than 5 % of the mass of the test article) to ensure that its dynamic characteristics are unchanged as far as possible.
- The influence of the boundary simulation equipment on the dynamic characteristics of the test article shall be analysed.
- The design safety factor of boundary simulation equipment under static load induced by the gravity force of the test article shall meet the requirements of the customers.
- One end of the boundary simulation equipment shall match the interface of the test article, and the other end shall match the ground base or coping of the laboratory.

NOTE The “free-free” boundary conditions can be chosen and justified so that it remains representative of the dynamic characteristics of the test article on orbit flight conditions.

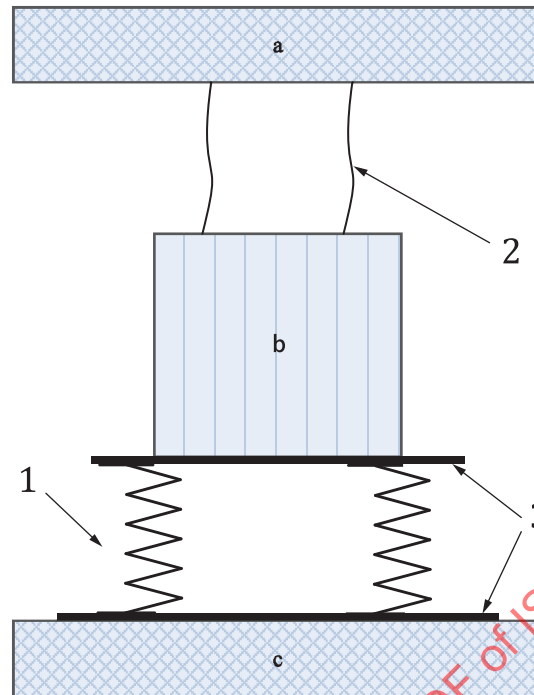
Examples for typical boundary simulation equipment are shown in [Figures 3](#) and [4](#).



Key

- 1 flexible suspension component
- 2 safety protection component
- 3 mechanical interface component
- a Coping of the testing laboratory or structural frame.
- b Test article.

Figure 3 — Suspending-fashion boundary simulation equipment

**Key**

- 1 flexible suspension component
- 2 safety protection component
- 3 mechanical interface component
- a Coping of the testing laboratory or structural frame
- b Test article.
- c Ground base of the testing laboratory.

Figure 4 — Supporting-fashion boundary simulation equipment

7.3.2 Excitation

The test configuration shall be able to excite the test article at the defined excitation points as specified in the test specification.

The following requirements apply for excitation:

- a) The excitation force of excitation equipment shall meet the test requirements.
- b) Excitation equipment should be as small as possible to minimize the noise.
- c) Sensors and signal conditioners shall meet the requirements specified in [7.3.3](#).

7.3.3 Measurement, data acquisition and processing

7.3.3.1 General

The test configuration shall provide measurement and data acquisition means capable of meeting test requirements.

7.3.3.2 Measurement sensors

The following requirements apply for measurement sensors:

- a) Sensor resolution shall be sufficient to distinguish between low amplitude signals and noise.
- b) Sensor mass should be as small as possible to minimize the influence of additional mass.
- c) Sensor frequency response range shall meet the test requirements.
- d) Sensor wiring shall be fixed according to practices to reduce induced physical constraint and noise.

7.3.3.3 Signal conditioning

The following requirement and recommendation apply for signal conditioning:

- a) Signal conditioners shall cover the overall frequency range and shall have flat frequency response properties.
- b) Signal conditioners should be capable of signal filtering, power supplying for sensors and signal amplification.

7.3.3.4 Data acquisition and processing

The following requirements apply for data acquisition and processing:

- a) The data acquisition and processing system shall have enough channels to meet the test requirements.
- b) The S/N of the data acquisition and processing system shall meet the test requirements.
- c) The data acquisition and processing system shall be capable of measuring the overall frequency range and shall have flat frequency response properties.
- d) The sampling rate of the data acquisition system shall meet the test requirements.
- e) The data acquisition and processing system shall be capable of recording time domain signals and post processing the data according to the characteristics of the signal.

The measurement equipment used for tests shall be calibrated and used within the valid calibration period.

8 Test requirements and recommendations

8.1 General test requirements and recommendations

8.1.1 General

Spacecraft level micro-vibration test is typically composed of the following activities:

- a) transfer function measurement (see [8.1.2](#));
- b) modal survey test (see [8.1.3](#));
- c) micro-vibration response measurement (see [8.1.4](#)).

8.1.2 Transfer function measurement

The following recommendations apply:

- a) If not specified otherwise, the mechanical interface location of each disturbance source should be excited one at a time.
- b) The corresponding transfer functions between the disturbance sources and the sensitive payloads should be extracted.
- c) During the test, the test article should be excited with different levels of excitation force to verify the linearity of the transfer function.

NOTE The transfer functions can be used in the design, optimization and verification of the micro-vibration attenuation of the test article.

8.1.3 Modal survey test

The following requirements apply:

- a) In the modal survey test, the test article shall be excited on specific and well-defined points.
- b) The test article's transfer functions shall be extracted from the excitation and response data.
- c) The modal parameters of the test article shall be identified according to the transfer functions.

NOTE The modal parameters can be used to update the analysis model.

8.1.4 Micro-vibration response measurement

During the micro-vibration response measurement, the micro-vibration response of the key locations shall be measured when different disturbance sources work separately or work together.

NOTE Typical key locations for micro-vibration response measurement are disturbance source locations, sensitive payload locations and the transfer path.

8.2 Pre-conditions

The following items shall be specified before the test:

- a) the frequency range for measurement;
- b) the target modes;
- c) the measurement point plan;
- d) the applicable exciter positions and allowable force levels;
- e) the test cases.

8.3 Test article configuration

The test article can be the SM, STM and/or FM. Layout and state of the units on-board should be consistent with the flight state. If the real state of a unit is difficult to achieve, it may be simplified or represented by an equivalent mass.

Payloads sensitive to disturbance and their interface state should be present in their actual flight configuration. The main disturbance sources should participate in the micro-vibration test. Disturbance sources may be replaced by analogue exciters if it is difficult to include the real disturbance source into the test configuration.

8.4 Test environment

8.4.1 Laboratory environment requirements

The laboratory environment shall comply with the customer's requirements including temperature, relative humidity, atmospheric pressure, cleanliness and other requirements.

8.4.2 Background noise requirements

Background noise shall be minimized. The S/N should be higher than 10 dB. The calculation formula of S/N is shown by [Formula \(1\)](#):

$$S/N = 10 \log_{10} \left(\frac{P_s}{P_n} \right) \quad (1)$$

where

P_s is the signal power;

P_n is the noise power.

8.5 Measurement

The recommendations are as follows:

- a) Response measurement should be performed with acceleration and/or displacement and/or force and/or angular displacement sensors.
- b) If required, measurement for LoS distortion of optical instruments may be performed.
- c) Different operational modes of disturbance sources should be applied for measurement.

8.6 Safety

The following requirements apply for safety:

- a) Test operators shall be technically trained and qualified.
- b) Technical and safety status of the test article shall be confirmed before the test.
- c) Test operators shall follow the test article handling requirements as well as the facility and customer safety requirements.
- d) Test operators shall manipulate test equipment according to the relevant operating rules and technical safety rules.
- e) Test article placement, transporting and installation shall comply with customer requirements.
- f) The load introduced by the excitation signal shall not damage the test article.
- g) The test article shall be electrically grounded.

The safety requirements of ISO 14620-1 shall be considered in planning and executing the test activities.

9 Test flow and procedure

9.1 Test flow

The micro-vibration test includes three stages, as shown in [Figure 5](#):

- before the test (see [9.2.2](#));
- test implementation (see [9.2.3](#));
- after the test (see [9.2.4](#)).

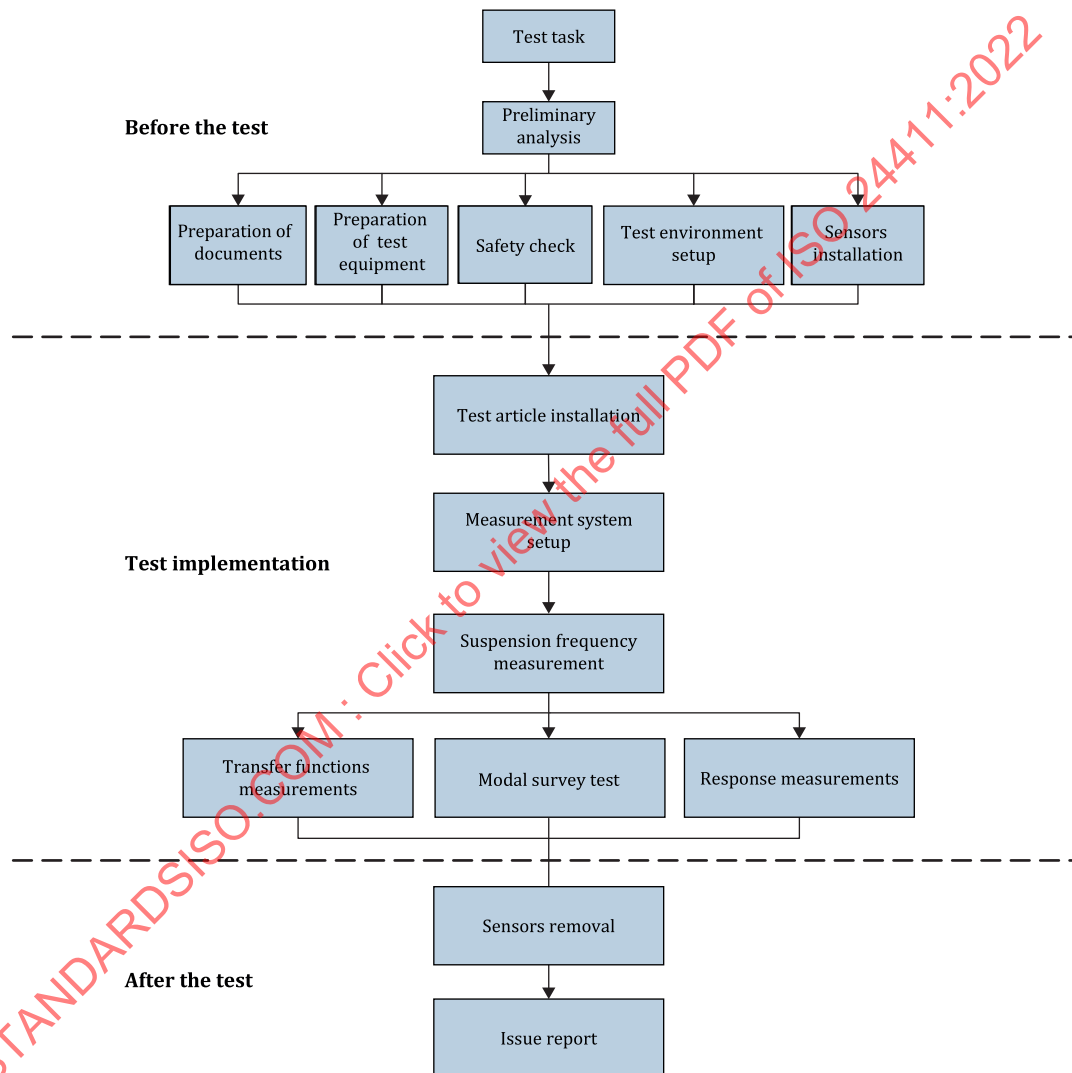


Figure 5 — Test flow

9.2 Test procedure

9.2.1 General

If not specified otherwise, the following procedures should be applied.

9.2.2 Before the test

9.2.2.1 Preliminary analysis

A preliminary analysis as specified in 6.3 shall be performed.

9.2.2.2 Preparation of test documents

The test documents shall be prepared in accordance with ISO 15864:2021, 4.9. The test documents should be reviewed by the customer.

9.2.2.3 Preparation of test equipment

The following requirements apply:

- a) The test equipment shall be set up according to the test requirements.
- b) The performance capability of the test equipment shall be ensured to meet the test requirements.
- c) All the instruments shall be calibrated before the test and used in the valid period.

9.2.2.4 Safety check

The following requirements apply:

- a) Functional check of the emergency power supply system of the laboratory shall be performed.
- b) Safety check of the test equipment shall be performed.

9.2.2.5 Test environment setup

The test environment shall be set up according to the test requirements. The ground vibration, acoustic noise and electromagnetic noise shall be considered comprehensively. Some measures to reduce the noise can be considered, such as perform the test at night to avoid road traffic, turn off air-conditioning, reduce human activity, apply ground vibration isolation system, remove light source.

9.2.2.6 Installation of sensors

Sensors shall be installed and checked according to the test procedures.

9.2.3 Test implementation

9.2.3.1 General

The following procedures should be applied.

9.2.3.2 Test article installation

The test article shall be installed on the boundary simulation equipment according to test procedures.

9.2.3.3 Measurement system setup

The parameters of the measurement system shall be set and the readiness of all systems for the test shall be confirmed.

9.2.3.4 Suspension frequencies measurement

The suspension frequencies should be measured. Suspension frequencies measurement method refers to [Annex C](#).

9.2.3.5 Transfer functions measurements

The following requirements and recommendations apply:

- a) The excitation point shall be chosen according to the test requirements.
- b) The excitation system shall be installed.
- c) The test parameters setting shall be checked.
- d) The excitation and response data shall be acquired after applying excitation. The excitation should be performed at different levels.
- e) The data shall be processed and the transfer functions shall be estimated.

9.2.3.6 Modal survey test

The following requirements and recommendations apply:

- a) The geometry model of the test article shall be established.
- b) The excitation point shall be chosen to make sure the desired modes can be excited.
- c) The excitation system shall be installed.
- d) The test parameters setting shall be checked.
- e) The excitation and response data shall be acquired after applying excitation.
- f) The data shall be processed and the modal parameters shall be extracted.
- g) The modal parameters should be verified.

9.2.3.7 Micro-vibration response measurements

The following requirements and recommendations apply:

- a) The background noise of the test environment shall be measured and confirmed to meet the test requirements.
- b) The micro-vibration response shall be measured according to the test cases required in the test documents. When the actual disturbance source is difficult to work (e.g. antenna fixed point mechanism, SADA), analogue exciters can be used to simulate the disturbance signal.
- c) Test data should be processed according to the test requirements. The test data processing should conform to ISO 18431-1.

In order to ensure high data quality for post-processing, the following important aspects shall be considered for micro-vibration response measurements:

- The low level of the signals requires a careful data check to avoid errors in the measured data caused by limited measurement time and limited amplitude resolution.
- The measured data contains expected and unexpected signals (noise) that shall be separated.
- The S/N of each channel shall be acquired.

9.2.4 After the test

The following requirements and recommendations apply:

- a) The measurement cables, measurement system and other equipment shall be removed.
- b) The test article shall be removed from the boundary simulation equipment.
- c) The data shall be processed, and the test reports should be issued.

10 Test interruption and handling

10.1 Test interruption

If either of the following situations appears, the test shall be interrupted:

- a) The technical requirements cannot be met.
- b) Test articles or test equipment failure.
- c) Safety requirements are not met.

10.2 Interruption handling

Interruptions should be handled as follows:

- a) If a test is interrupted because the technical requirements cannot be met, the test should be performed again after finding out the reasons and implementing corrective measures.
- b) If the test is interrupted because of test articles or test equipment failure, the test should only be continued after the interference or failure has been eliminated.
- c) If the test is interrupted because of safety, the test should be performed after finding out the reasons and implementing corrective measures.

11 Test data and result evaluation

11.1 Test data

Typically, test data includes the following items:

- a) status data of the test article;
- b) status data of the equipment;
- c) transfer function curves;
- d) response curves of the micro-vibration measurements;
- e) modal characteristics of the test article such as the natural frequency, mode shapes and modal damping ratio;
- f) environment data of the laboratory.

Test data shall conform to ISO 15864:2021, 4.9.5.

11.2 Result evaluation

After the test, the results should be evaluated according to the following criteria:

- a) Conformance of the measurement results with the test requirements.
- b) Conformance of the overall results with the test objectives.

12 Test report

Test documentation shall conform to ISO 17566:2011, 3.4.

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Annex A (informative)

Typical internal disturbance sources and characteristics

Typical internal disturbance sources and characteristics are shown in [Table A.1](#).

Table A.1 — Typical internal disturbance sources and characteristics

Source	Characteristics
Reaction wheel	Harmonic
Control momentum gyros	Harmonic
Gyroscopes	Harmonic
Solar array drive mechanisms	Harmonic or transient
Antenna pointing mechanisms	Transient
Mirror scan mechanisms	Transient
Cryogenic coolers	Harmonic
Micro-thrusters	Transient
Latch valve	Transient
Heat pipe	Harmonic
Relay	Transient
Sudden stress release	Transient

Annex B (informative)

Guideline of the necessity of spacecraft level micro-vibration test

Micro-vibration can be described by micro linear vibration and micro angular vibration. Correspondingly, the requirements of position stability or pointing stability for the spacecraft can be described as the sensitive index.

Once the sensitive index is required by the mission, whether spacecraft level micro-vibration tests are necessary or not shall be decided.

This decision can be made according to the experiences of identical or similar spacecraft. When there is a lack of such experience, for the spacecraft with pointing stability as the sensitive index, the guideline in [Table B.1](#) can be considered at the present stage^[1].

Table B.1 — Guideline for micro-vibration tests

Stability level (RMS per axis, 1-sigma values)	Spacecraft level micro-vibration test
> 100 arc-second	Not required ^a
10 to 100 arc-second	Optional ^{b e}
0,1 to 10 arc-second	Optional ^{c e}
< 0,1 arc-second	Required ^d
^a It is not a micro-vibration challenge. A spacecraft level micro-vibration test is not really necessary. ^b The payload equipment can be affected by micro-vibration, and subsystem/unit-level test should be carried out to modify the analysis model. A spacecraft level micro-vibration test is optional. ^c Micro-vibration is a difficult problem to the mission requirement. A subsystem/unit-level micro-vibration test is necessary. A spacecraft level micro-vibration test should be carried out if possible. ^d Micro-vibration is very difficult problem to the mission requirement. A subsystem/unit-level micro-vibration test is necessary. A spacecraft level micro-vibration test shall be carried out to verify the mission performance in a micro-vibration environment. ^e For these categories, further analysis is needed to decide the necessity of spacecraft level micro-vibration test. In the process of analysis: — When it is unable to obtain or accurately obtain the disturbance characteristic of some equipment by analysis or unit-level test, a spacecraft level micro vibration test should be carried out. — When there is a lack of a reliable analysing method for some complex parts such as joints with multiple interfaces, a spacecraft level micro-vibration test should be carried out. — When the economic or time cost of analysis is far overweighting the cost of the test, a spacecraft level micro-vibration test should be carried out.	

Annex C (informative)

Suspension frequencies measurement

C.1 Principle

To simulate the free-free boundary configuration of the spacecraft on orbit, the test article is suspended by boundary simulation equipment. The first six rigid body frequencies of the system composed of boundary simulation equipment and test article are called “suspension frequencies”.

Suspension frequencies measurement is performed by application of external force and torque along the X/Y and Z direction of the test article coordinate system to make the test article deviate from the static balance position. Then the applied force is removed to make the system freely oscillate, and the free oscillation response of the system is measured. The oscillation period is extracted by analysing the measured response curves.

Examples are shown in [Figures C.1 to C.4](#). [Figure C.1](#) and [C.3](#) show the applied X-direction (horizontal) force to obtain suspension frequencies of the bending and rocking modes of the system in the X-direction (similarly, Y-direction force is applied to obtain suspension frequencies of the bending and rocking mode of the system in the Y-direction). [Figure C.2](#) and [C.4](#) show the applied torque around the Z-direction to obtain suspension frequency of the torsional mode of the system around the Z-direction.

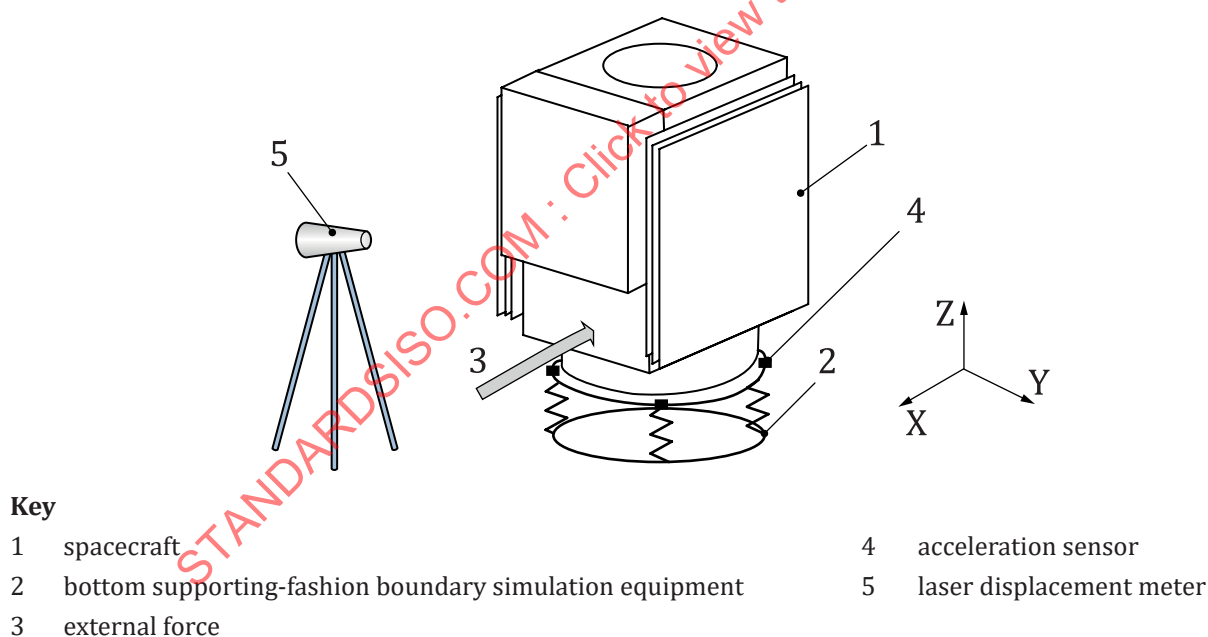


Figure C.1 — Applied X-direction (horizontal) force to get suspension frequencies of the system in X-direction