INTERNATIONAL STANDARD

ISO 23670

First edition
2021-09

Space systems — Vibration testing

Systèmes spatiaux — Essais de vibration

Reference number
ISO 23670:2021(E)

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Foreword

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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 vehicle*, 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

Vibration testing is one of the most important test items of space systems. The primary goals of vibration testing are to verify the design and to detect manufacturing issues of spacecraft, subsystems and units that could result in in-flight failures. In design, material selection, manufacture, assembly and integration phase, the test aims on exposing defects and non-conformances existing and eliminating potential quality problems. With regard to the launch phase, it also serves to prevent structural failure of a space system, loosening of fasteners and connectors, failure of electronic components, leakage of sealing elements or malfunction of mechanical system.

During vibration testing, over-testing can result in unnecessary destruction of the test specimen. In the 1990s, at the Jet Propulsion Laboratory, Mr. Terry Scharton elaborated the methodology of force notching for qualification of satellites and spacecraft to mitigate unnecessary over-testing. Since then, several attempts have been made to establish this methodology for a broader range of application. This document includes the methodology of force-based testing.

Space systems — Vibration testing

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This document provides guidance and requirements for test providers and interested parties to implement vibration testing.

This document specifies methods, including the force limiting approach, to mitigate unnecessary over-testing of spacecraft, subsystems and units for space application.

The technical requirements in this document can be tailored to meet the actual test objectives.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitute 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 15864:2021, *Space systems — General test methods for space craft, subsystems and units*

ISO 19924:2017, *Space systems — Acoustic testing*

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:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
notching
reduction of the input level or spectrum in a vibration testing to limit structural responses at resonant frequencies according to qualification or acceptance loads to avoid over-testing.

3.2
response limited vibration testing
reduction of input acceleration in a vibration testing to maintain the measured response at or below a specified value

3.3
force limited vibration testing
reduction of reaction force in a vibration testing to specified values, which are usually the interface forces predicted for flight, plus a desired margin.

3.4
statistical DOF
number of independent variables in a statistical estimate of a probability

Note 1 to entry: The number of degrees of freedom determines the statistical accuracy of an estimate.

[SOURCE: ISO 2041:2018, 3.5.16, modified — The term has been changed from "statistical degrees of freedom" to "statistical DOF".]

4 Abbreviated terms

For the purposes of this document, the abbreviated terms described in Table 1 apply.

Table 1 — Abbreviated terms

DOF	degree of freedom
FEA	finite element analysis
FLV	force limited vibration
FLVT	force limited vibration test
FMD	force measurement device
FRF	frequency response function
POGO	propulsion generated oscillations
PSD	power spectral density
RMS	root mean square
TDFS	two-degree of freedom system

5 General

Vibration testing is distinguished between sinusoidal vibration testing and random vibration testing.

Sinusoidal vibration testing is intended to simulate the vibration environment produce by unstable combustion, by coupling of structural resonant frequencies (POGO), by imbalances in rotating equipment. Sinusoidal vibration testing is also to simulate ground transportation and handling, due to resonant responses of tires and suspension systems of the transporters.

Random vibrations are generated by the launcher engines and by acoustic and aerodynamic excitation of the launch vehicle and spacecraft fairing. During flight or ground transportation and handling, broad band vibration environment is imposed on the spacecraft. ISO 15864 recommends either vibration or acoustic testing, whichever is more appropriate, with the other one left optional. Generally, if acoustic testing is performed, random vibration may be skipped. For a small compact spacecraft, acoustic testing does not provide adequate environmental simulation, and random vibration may replace the acoustic test. To take this decision it is important to consider:

— vibration testing do not reach high frequency contents;

— whether the structure is sensitive to acoustic loads;

— whether the structure is sensitive to acoustic loads where the units are mounted.

Information for random vibration and acoustic test tailoring is provided in Annex A.

Conventional acceleration control during vibration testing may lead to the so-called over-testing problem due to the difference of the interface impedance of the mounting structure and the shaker. In order to overcome this problem, the force limited vibration (FLV) testing technique was developed. In the FLV testing, in addition to the acceleration specification, the specification of the reaction force between fixture and test specimen shall be defined. Using the FLV technique, both the acceleration and force at the interface of test specimen and fixture are limited so that the vibration environment characterizes the real situation more precisely.

6 Test technical requirements

6.1 Test specification

The test specification shall meet the requirements of the respective launch vehicle user manual.

The test specification generally includes testing level, frequency range, test direction and test duration. The duration of sinusoidal vibration testing is determined by the sweep rate and frequency range. The duration of random vibration testing is expressed in seconds or minutes. The test directions usually correspond with the three orthogonal axes, one of which is in accordance with the launch direction.

If FLVT will be applied, the test specifications shall be extended with the FLVT requirements.

When needed to re-check workmanship by dynamic mechanical environmental test for flight units that have undergone rework and that required random vibration testing at acceptance test, the minimum retesting shall be random vibration testing at workmanship screening level to be agreed with the customer. However, if the most effective single axis of workmanship screening re-test for all the reworked areas is determined, re-test excitation can be based just on that axis.

6.2 Tolerances

The tolerances shall be determined based on the design standard. If not specified otherwise, the following test level tolerances can be used.

a) Sinusoidal vibration

Frequency: −2 % to +2 % (or −1 Hz to +1 Hz, whichever is greater)

Acceleration amplitude: −10 % to +10 %

b) Random vibration

Acceleration spectral density (frequency resolution better than 10 Hz)

10 Hz to 100 Hz (analysis bandwidth 10 Hz or narrower): −3 dB to +3 dB

100 Hz to 1 000 Hz (analysis bandwidth is 10 % or narrower of the central frequency): −3 dB to +3 dB

1 000 Hz to 2 000 Hz (analysis bandwidth 100 Hz or narrower): −3 dB to +3 dB

Statistical DOF: not less than 100

Overall grms.: −10 % to +10 %

Test duration: −0 % to +10 %

6.3 Test control

6.3.1 Control strategy

6.3.1.1 General

The control strategy shall provide the required vibration at the required locations in or on the test specimen. This depends on the kind of vibration to be generated and on the test specimen/shaker interaction. Generally, a single strategy is appropriate (e.g. only acceleration input control strategy is used). There are cases where multiple strategies are used simultaneously (e.g. acceleration input control strategy and force limited vibration testing strategy are used simultaneously).

6.3.1.2 Acceleration input control

Acceleration input control is the basic method of vibration testing. The control accelerometers shall be mounted on the fixture at the test specimen mounting points. Shaker motion shall be controlled with feedback from the control accelerometer(s) to provide defined vibration levels at the fixture/ test specimen interface.

6.3.1.3 Notching

Notching is a general accepted practice in full-level vibration testing to avoid over-testing. Implementation of notching shall be subject to customer approval and relevant to Launcher authority approval. Refer to Annex B for an example of the notching calculate method. The following requirements apply.

a) The force on the main structure shall not be higher than the design value of quasi-static load plus a desired margin.

b) The vibration level shall not be less than the level of coupling analysis result for the interface between spacecraft and launcher, unless agreed by the launcher authority.

c) The response of key equipment fixed position shall not be higher than the equipment vibration testing level.

6.3.1.4 Force limited vibration testing

For force limited vibration testing, the vibration level is defined by acceleration. In addition, the reaction force between fixture and test specimen shall be measured and limited. Dynamic force gauges are mounted between the fixture and the test specimen. If the force achieves the limited value, the exciter motion shall be controlled with feedback from the force gages.

Force limiting is most useful for test specimens that exhibit distinct, lightly damped resonances on the shaker. The amount of relief available from force limiting is greatest when the structural impedance of the test specimen is equal to, or greater than that of the mounting structure in the actual mounting situation.

The force limit value shall be slightly larger than the real reaction force of the interface during launch, plus the desired margin. Force limits value can be determined in several ways including simple and complex TDFS Method, semi-empirical method, FEA method, quasi-static-load method, apparent masses envelope method and design/flight loads method. A non-exhaustive list of force limit method is specified in Annex C.

6.3.1.5 Response limited vibration testing

For response limited vibration testing, the vibration level is defined by acceleration. In addition, vibration response limits at specific points on the test specimen shall be defined. Monitoring accelerometers shall be located at these points. The test specimen shall be excited using control point accelerometer signals to control the exciters. The control inputs shall be automatically modified as needed to limit responses at the monitoring accelerometers to the predefined limits. This strategy is used to avoid damage to the specific equipment or lower level assembly.

6.3.2 Control point

The control accelerometer(s) shall be mounted on the test fixture near the specimen attachment points. For multiple-point control, an even distribution should be adopted. In case specific requirements exist, the positions of the control points shall be determined accordingly. If more than one control accelerometer is used, the test levels may be controlled by a control scheme either based on the average response or on the response extremes. The control scheme shall be consistent with the test requirement.

6.4 Specimen configuration requirements

The specimen configuration shall be as described in ISO 15864:2021, 7.13.3 and 7.14.3.

6.5 Response measurement point

The test requirements shall specify the number, installation position and orientation, type and measurement range of test sensors, as well as the processing modes and requirements for data measurement. See more detailed requirements in 7.2.5.

6.6 Test success criteria

It is presupposed that an accomplished test is formally compliant with the contract requirements.

For the test provider, if not specified otherwise, the following requirements shall apply.

— All vibration testing shall be applied at the right test level.

— The acquisition of test specimen vibration response data shall be complete and valid.

For the specimen provider, if not specified otherwise, the following requirements shall apply.

— The intended test purposes shall be achieved.

— There shall be no visual damage to the test specimen.

— The characteristic response curve (which includes the resonance frequencies and the amplification ratio) shall be the same before and after each full level vibration testing (see 8.2.3 a)) under consideration of the specified tolerance bands.

— The test specimen performance after the test shall be specified by the customer.

7 Test system

7.1 Test facility requirements

A vibration testing facility includes a vibration excitation system, a vibration control system, a measuring system and auxiliary equipment. An example of a vibration testing facility is shown in Figure 1.

For FLVT, dynamic force gauges are mounted between the shaker/fixture and the test specimen. The force at the interface is measured by the force gauges and is fed back to the control system to implement response limiting.