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**Environmental testing - Part 2: Test methods - Test Fx and
guidance: Multi input multi output vibration test**

环境试验 第2部分：试验方法 试验 Fx 和导则：多输入和多输出振
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Environmental testing - Part 2: Test methods - Test Fx and guidance: Multi input multi output vibration test

1 Scope

This part of GB/T 2423 specifies the terms and definitions test methods, test equipment, test methods and conditions, information requirements, test implementation, results analysis requirements of multi input multi output vibration (hereinafter referred to as: MIMO).

This Part applies to the determination or verification of mechanical weaknesses and/or degradation of properties of samples, after subjected to excitation by multiple exciters. This test method can also be used to verify the mechanical structural and functional integrity of samples AND to study their dynamic properties.

2 Terms and definitions

2.1

Multi input single output; MISO

In the multi-DOF structure, multiple driving signals are input to the excitation system; AND in the single-DOF structure, the single-parameter measurement output is obtained from the fixture or sample.

Note: This professional term is mostly used in the measurement data processing, in the case of multiple input measurement combined with single output.

2.2

Multi input multi output; MIMO

In multi-DOF structures, multi-driving signals are input to the excitation system; AND in multi-DOF structures, multi-measurement outputs are obtained from fixtures or samples.

Note: Generally, there is no one-to-one correspondence between input and output; the input No. is also different from the output No.

2.3

3.2 Multi-excitation vibration test system

3.2.1 Exciter

Determine the configuration of the exciter AND select the exciter, according to the required test type, test frequency range, low frequency displacement, test magnitude, the size and mass of the sample and fixture. The exciter can be electric or hydraulic.

The multi-excitation system mainly consists of three parts: Exciter, fixture, controller. The exciters operate in the same plane as required. They can also be independent of each other, provide sufficient displacement, to carry out the test of the corresponding sample mass and acceleration magnitude. When using a multi-excitation system, it is important to consider the use of gain control for each exciter, so that the difference of the control loop can be limited, thereby obtaining the control effect satisfying the given limit range. Shorten the update time of the control loop; extend the record length; improve the control accuracy. Statistical precision, which is defined in degrees of freedom, is important to the calculation results. The value of the degrees of freedom depends on the pre-test magnitude (-6 dB, -3 dB, 0 dB, etc.), before reaching the full scale value. As the test value gets closer and closer to the full value, the value of the degrees of freedom becomes larger and larger. The value of the degrees of freedom shall satisfy that, at the 99% confidence level, it can obtain the results within 5% deviation of the specified value, or the -3 dB value can reach the 95% confidence level. With the real-time closed-loop control method, the statistical accuracy will continue to improve, as the test progresses.

3.2.2 Test fixture

The design of the fixture shall meet the requirements of the vibration standard. In practice, the design of the fixture shall also consider the frequency response and the ability to withstand the reaction force. It is necessary to consider the potential for large loads during multi-point and multi-axis tests, resulting in simultaneous occurrence of acceleration at multiple degrees of freedom. The test fixture requirements are as follows:

In addition to the general test fixture design requirements, refer to Appendix A for the design of multiaxial test fixtures.

Test fixtures are critical, when specifying test requirements for multiple exciter. The fixture simulates the structural support during product use, as much as possible, so as to reproduce the dynamic load and structural dynamic response characteristics of the product, during use.

The shape and size of the fixtures can vary widely, depending on the differences of product and test method. Rigid and flexible connection devices can be considered, as follows:

- a) Connected with a coupler (commonly known as "bullhead") or directly connected to the structure;
- b) Direct connection with flexible drive rod and blade support;
- c) Connections by shafts, spherical joints, etc., which have limited freedom of movement as required;
- d) Use a slide with the above device.

To aid in the selection and evaluation of fixtures and control strategies, the various dynamic response characteristics of the following products shall be considered. The vibration test fixture, test spectrum, control strategy shall be reasonably determined, according to the dynamic complexity and size of the product, as follows:

- a) Flexible symmetrical dynamic structures with different aspect ratios;
- b) Rigid kinetic structures with flexible ends;
- c) Dynamically and geometrically asymmetric structures;
- d) For large rigid structures, thrust is the main problem;
- e) All containers for transport and storage in the above categories.

Consideration shall be given to the layout of the main supports of the sample to be tested. In principle, the fixture itself shall have sufficient stiffness, to support the sample, whilst minimizing the coupling effects of the orthogonal axis and the off-axis effects of the exciter. Unintended orthogonal axis motion shall be minimized. Special attention shall be paid to the rigid body mode, when designing the fixture; however, with the improvement of the control algorithm, this problem may be solved. It shall also be considered that there are displacement differences within the product, AND how this difference affects the exciter. The control system cannot adapt to an unreasonable fixture design in all cases.

3.2.3 Test device

Multi-excitation vibration test requires that the test configuration can constrain the degrees of freedom, which is not controlled by the exciter, whilst leaving the controlled degrees of freedom unconstrained. Motion evaluation shall be performed, after completing the test platform installation, to determine suitable couplings and decoupling devices, etc., thereby ensuring that undue loads and motions are not transmitted to the sample.

The measurement accuracy of the test and control portion largely depends on the test fixtures, fixation devices, measurement systems, exciter control strategies. In order to meet the tolerance requirements proposed in 4.6, it shall carefully design the test

control strategy depends on the existing field vibration data, OR the vibration data to be collected that meets the requirements of the test program. The need for testing and control strategies, control points, cross-coupling information will affect field data collection requirements.

3.3.4 Control limits

Vibration control limits are set, in terms of spectral type, magnitude, partial coherence, phase, or cross-spectral density. Vibration control is achieved, using spectral shape and amplitude control limits.

In addition to the specification of the test axis, it is also required to specify the control limits of the orthogonal axis. When partial coherence and phase and cross-spectral density are specified, it needs to determine the optimal control limits for the test.

3.3.5 Cross-spectral data

Phase, partial coherence, cross-spectral density normalization have important implications for test and analysis. If data on product use cannot be provided, the cross-correlation coefficient shall be obtained, through laboratory tests. If there is a lack of product usage data, there will be discrepancies between the data obtained by the laboratory and the usage data of the product. Therefore, when formulating test specifications, two sets of data shall be compared; if the difference is large, a detailed analysis shall be carried out.

It is recommended to compare the coherence, phase, cross-spectral densities, between two structures with different configurations; then decide whether to specify partial coherence and phase; OR to define the items as 1 and 0, respectively. Clearly, a comparison of product usage data with pre-test data is required. Another method is to use the coherence, phase, cross-spectral densities of a laboratory test configuration, which once again shows the importance of upfront test.

When the cross-coupling matrix is inverse, it generally should optimize it. If the test engineer has the ability to do this, it will improve the ability to make judgments, when specifying important parameters and optimizing the control strategy adopted.

3.4 Vibration measurement system

3.4.1 Overview

In general, it is necessary to measure the acceleration of certain points on the sample, to meet the test specification. It is necessary to ensure that, the acceleration information measured in the test corresponds to the acceleration information measured in the field, AND is used to determine the needs of the multiple input multiple output test. This requires that, the position of the accelerometer installed on the sample shall be the same

as the position on the field measurement sample. In the case of multiple degrees of freedom, the phase and polarity between instrument channels become the key test parameters. In order to maintain the phase accuracy requirements, it is recommended to use the same sampling A/D converter. It is recommended that the data acquisition instruments in the laboratory and the field, use the same data format as the controller; otherwise, the reference data may need to be preprocessed, before starting the test.

3.4.2 Vibration measuring instrument

The vibration measuring instrument shall meet the requirements of measuring, recording, processing, analyzing the vibration response of the vibration measuring point. It shall also meet the following conditions:

- a) The number of measurement channels shall be able to meet the measurement requirements;
- b) Record data continuously;
- c) During synchronous sampling, the phase difference between channels is not more than 0.5° ;
- d) Use the same sampling frequency as the controller, to achieve synchronous sampling with the controller;
- e) Generally, it shall include analysis functions, such as time domain, FFT, self-spectral density, cross-spectral density, coherence, phase, frequency response.

3.4.3 Accelerometer

The accelerometer shall meet the following requirements:

- a) The lateral sensitivity is not more than 5%;
- b) The linearity of the amplitude is within 3%;
- c) Within the measurement frequency range, the accuracy of frequency response amplitude is within $\pm 5\%$;
- d) It has sufficient sensitivity, to ensure that the relative phase between the control responses is accurate and reliable;
- e) If necessary, equip the sensor with a reasonable conditioning amplifier.

The control strategy of vibration test depends on the vibration test data, that can be provided, to achieve the purpose of vibration test. When independent spectral density, partial coherence, phase and cross-spectral density can be provided, a multi-exciter control strategy is possible. When the partial coherence, phase, cross-spectral density cannot be provided enough, it is necessary to adopt the single axial target spectrum control strategy firstly, in the vibration test. In some cases, limit control needs to be applied to its orthogonal axis, in order to protect the exciter. Limit control also requires outfield spectral envelopes. Typical test and control strategies include:

- a) Single spectrum: Determined according to operational data or specifications;
- b) Multiple self-spectral densities: Determined according to operating data or related specifications;
- c) Multiple self-spectral densities and partial coherence: Determined according to operational data or laboratory test configuration data;
- d) Multiple self-spectral densities and phases: Determined according to operational data or laboratory configuration data;
- e) Multiple self-spectral densities, partial coherence, phases: Determined according to operational data or laboratory configuration data;
- f) Multiple self-spectral densities, partial coherence, phase, self-spectral densities at other positions: Determined according to operational data or laboratory configuration data;
- g) Multiple self-spectral densities, cross-spectral densities, other related parameters: Determined according to operating data or laboratory configuration data;
- h) Control limits using both magnitude and envelope based on operational data.

4.3.2 Control method

The choice of test method is controlled by many factors, including the external vibration environment and product type. Control functions for multiple exciter tests include:

- a) Sine: Same sine and magnitude; multiple sine components and phases; magnitude and phase in variable directions.
- b) Random: Multiple exciter, single axis, single control target spectrum; multiple exciter, multiple axis, multiple control target spectrum; controllable coherence and phase difference.

4.3.3 Test plan

For the first test of a more complex structure or a new product, a test plan shall be prepared. The test plan generally includes:

- a) Selection of test equipment: Reasonably select test equipment, according to the basic parameters of the sample and test requirements;
- b) Test fixture scheme: It is designed according to the basic parameters and test requirements of the sample and the selected test equipment; the test fixture shall meet the test requirements;
- c) Control scheme: Initially determine the control method, according to the structural characteristics and fixture scheme;
- d) Test installation: Formulate a complete test installation plan, according to the test situation, the size of the test site, the specific conditions of the test equipment.

4.4 Determine the test conditions

4.4.1 Overview

Usually, the multi-excitation vibration test needs to determine the test conditions, according to the measurement data of the vibration response of the sample work site. Therefore, it is necessary to obtain sufficient field data, to describe the test conditions and working states of the multi-excitation vibration test. These data are generally time histories. If the power spectrum is required, the measured data need to be estimated by auto-power spectrum and cross-power spectrum density, to determine the test conditions. Of course, when the field data is insufficient, the multi-excitation test process may determine the test conditions, through theoretical analysis of the samples AND laboratory measurement data.

For the time-domain reproduction multi-excitation test, field test data is required; the correlation, between experimental control and field data, cannot be determined without field test data.

In general, there will always be differences between the field environment and the laboratory environment, due to the influence of impedance and boundary conditions. This difference may require further analysis, to determine whether the difference is significant enough to affect the results of the test.

4.4.2 Sufficiency of field data

When performing a multi-excitation vibration test, the basic parameters to be specified in the test specification are as follows:

- a) Frequency range, sampling frequency, tolerance, power spectral density (spectral type and frequency value), cross-coupling and error minimization, partial coherence, phase;
- b) Temperature, humidity, air pressure, electromagnetic field, etc.;

- 3) If the amplitude exceeds the range of $\pm 10\%$ of the specified value, the cumulative frequency bandwidth shall not exceed 5% of the test frequency.

b) Random vibration:

- 1) Amplitude: If not more than 500 Hz: ± 3 dB;
- 2) Amplitude: If greater than 500 Hz, ± 6 dB;
- 3) If the amplitude exceeds the range of ± 3 dB from the specified value, the cumulative frequency bandwidth shall not exceed 5% of the test frequency;
- 4) Root mean square value: ± 2 dB.

When the structure is complex, the requirements can be appropriately relaxed; however, when the tolerance is exceeded, it shall be recorded and reflected in the report.

5 Information requirements

5.1 Overview

In order to adequately conduct and document dynamic performance tests, at least the following information needs to be provided. The schedule is designed according to the actual situation; adjustments can be made, by adding or removing some items if necessary. Modal analysis testing of fixtures and samples is recommended. These data are useful for evaluating trial results and assessing the product's ability to adapt to changing needs or new applications. These data will be very valuable for future planning, to highlight new application areas for existing products (resonance searches can provide very useful information, when modal detection is not considered, due to test procedures).

5.2 Information required before testing

The following information is required, in order to successfully carry out the multi-point excitation vibration test.

- a) Select the test process and test system (test item/platform configuration); the detailed information includes:
 - 1) Test reference conditions, time history or power spectrum and correlation coefficient;
 - 2) Installation position of the control sensor;
 - 3) Installation location of monitoring/limiting sensor (if any);

- 4) Acceptable pre-test magnitudes to achieve proper compensation of the exciter system;
 - 5) Test tolerance criteria, including the previously determined multi-point excitation test tolerance range;
 - 6) Vibration control strategy.
- b) Environmental requirements for the test, such as temperature, humidity, electromagnetic field, etc.;
 - c) Failure criteria and testing methods of samples;
 - d) Information about the modal measurement of the test fixture;
 - e) Test interruption procedure.

5.3 Information required in the test

The following information shall be collected during the test:

- a) Test debugging records;
- b) Testing records of the appearance and performance of the samples;
- c) Analysis and discussion records of the test process;
- d) Additional environmental conditions, such as temperature records;
- e) Records of any out-of-tolerance conditions associated with control measurement points;
- f) Records of test interruption, test failure, handling of test failure;
- g) Appropriately processed monitoring/limitation time history information, in numerical form;
- h) Record of number of tests and the duration of the tests.

5.4 Information required after the test

The following information shall be recorded after the test:

- a) Testing record of the appearance and performance of the sample, after the test;
- b) Vibration measurement data analysis and performance inspection analysis;

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