

Experimental determination of mechanical mobility

**Part 5. Measurement using impact
excitation with an exciter which is not
attached to the structure**

Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee GME/21, Mechanical vibration and shock, upon which the following bodies were represented:

- Federation of Civil Engineering Contractors
- Imperial College of Science and Technology
- Institute of Sound and Vibration Research
- Institution of Mechanical Engineers
- Lloyd's Register of Shipping
- Ministry of Defence
- Open University
- Power Generation Contractors' Association (PGCA (BEAMA Ltd.))
- Railway Industry Association of Great Britain
- Sira Test and Certification Ltd.
- Society of British Aerospace Companies Limited
- Society of Environmental Engineers

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- British Coal Corporation
- Electricity Association
- Health and Safety Executive
- University of Cranfield

This British Standard, having been prepared under the direction of the Engineering Sector Board (E/-), was published under the authority of the Standards Board and comes into effect on 15 March 1995

© BSI 1995

The following BSI references relate to the work on this standard:
Committee reference GME/21
Draft for comment 91/70504 DC

ISBN 0 580 23924 1

Amendments issued since publication

Amd. No.	Date	Text affected

Contents

	Page
Committees responsible	Inside front cover
National foreword	ii
Introduction	iii
Method	
1 Scope	1
2 Normative references	1
3 Definitions	1
4 General characteristics of impact measurements	2
5 Support of the structure under test	4
6 Application of the excitation	5
7 Transducer system	10
8 Processing of the transducer signals	10
9 Tests for validity of the measurements	20
Annexes	
A (informative) Correction of mobility measurements for the effects of exponential windowing	21
B (informative) Bibliography	22
Figures	
1 Instrumentation block diagram for impact excitation	3
2 Typical impactor	5
3 Typical force pulse and spectrum	7
4 Effects of low-pass filtering on the force pulse of figure 3a) and its spectrum	8
5 Spectrum effects of two impacts in the force record	9
6 Transient captured force-time history with pre-trigger	11
7 The effect of 'force windowing'	13
8 Leakage errors caused by a force window	14
9 Unwindowed response and frequency-response function	16
10 Exponentially windowed response and frequency-response function	18

National foreword

This British Standard has been prepared by Technical Committee GME/21. It is identical with ISO 7626-5 : 1994 *Vibration and shock — Experimental determination of mechanical mobility — Part 5 : Measurements using impact excitation with an exciter which is not attached to the structure*, published by the International Organization for Standardization (ISO).

ISO 7626-5 was prepared by Technical Committee ISO/TC 108, Mechanical vibration and shock, in which the UK played an active part.

Cross-references

International standard	Corresponding British Standard
ISO 2041 : 1990	BS 3015 : 1991 <i>Glossary of terms relating to mechanical vibration and shock</i> (Identical)
ISO 7626-1 : 1986	BS 6897 <i>Experimental determination of mechanical mobility</i> Part 1 : 1987 <i>Specification for transducers</i> (Identical)
ISO 7626-2 : 1990	Part 2 : 1990 <i>Measurements using single-point translation excitation with an attached vibration exciter</i> (Identical)

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Introduction

General introduction to ISO 7626 on mobility measurement

Dynamic characteristics of structures can be determined as a function of frequency from mobility measurements or measurements of the related frequency-response functions, known as accelerance and dynamic compliance. Each of these frequency-response functions is the phasor of the motion response at a point on a structure due to a unit force (or moment) excitation. The magnitude and the phase of these functions are frequency dependent.

Accelerance and dynamic compliance differ from mobility only in that the motion response is expressed in terms of acceleration or displacement, respectively, instead of in terms of velocity. In order to simplify the various parts of ISO 7626, only the term "mobility" will be used. It is understood that all test procedures and requirements described are also applicable to the determination of accelerance and dynamic compliance.

Typical applications for mobility measurements are for:

- a) predicting the dynamic response of structures to known or assumed input excitation;
- b) determining the modal properties of a structure (natural frequencies, mode shapes and damping ratios);
- c) predicting the dynamic interaction of interconnected structures;
- d) checking the validity and improving the accuracy of mathematical models of structures;
- e) determining dynamic properties (i.e. the complex modulus of elasticity) of materials in pure or composite forms.

For some applications, a complete description of the dynamic characteristics may be required using measurements of translational forces and motions along three mutually perpendicular axes as well as measurements of moments and rotational motions about these three axes. This set of measurements results in a 6×6 mobility matrix for each location of interest. For N locations on a structure, the system thus has an overall mobility matrix of size $6N \times 6N$.

For most practical applications, it is not necessary to know the entire $6N \times 6N$ matrix. Often it is sufficient to measure the driving-point mobility and a few transfer mobilities by exciting with a force at a single point in a single direction and measuring the translational response motions at key points on the structure. In other applications, only rotational mobilities may be of interest.

In order to simplify the use of the various parts of ISO 7626 in the various mobility measurement tasks encountered in practice, ISO 7626 will be published as a set of five separate parts:

ISO 7626-1 covers basic definitions and transducers. The information in ISO 7626-1 is common to most mobility measurement tasks.

ISO 7626-2 covers mobility measurements using single-point translational excitation with an attached exciter.

ISO 7626-3 covers mobility measurements using single-point rotational excitation with an attached exciter. This information is primarily intended for rotor system rotational resonance predictions.

ISO 7626-4 covers measurements of the entire mobility matrix using attached exciters. This includes the translational, rotational and combination terms required for the 6×6 matrix for each location on the structure.

ISO 7626-5 (this part of ISO 7626) covers mobility measurements using impact excitation with an exciter which is not attached to the structure.

Mechanical mobility is defined as the frequency-response function formed by the ratio of the phasor of the translational or rotational response velocity to the phasor of the applied force or moment excitation. If the response is measured with an accelerometer, conversion to velocity is required to obtain the mobility. Alternatively, the ratio of acceleration to force, known as accelerance, may be used to characterize a structure. In other cases, dynamic compliance, the ratio of displacement to force, may be used.

NOTE 1 Historically, frequency-response functions of structures have often been expressed in terms of the *reciprocal* of one of the above-named dynamic characteristics. The arithmetic reciprocal of mechanical mobility has often been called mechanical impedance. It should be noted, however, that this is misleading because the arithmetic reciprocal of mobility does *not*, in general, represent any of the elements of the impedance matrix of the structure. Mobility test data cannot be used directly as part of an analytic impedance model of the structure. To achieve compatibility of the data and the model, the impedance matrix of the model must be inverted to a mobility matrix, or vice versa. This point is elaborated upon in annex A of ISO 7626-1:1986.

Introduction to this part of ISO 7626

Impact excitation has become a popular method for measuring the frequency response of structures because of its inherent speed and relatively low cost to implement. However, the accuracy of mobility measurements made by using impact excitation is highly dependent upon both the characteristics of the test structure and on the experimental techniques employed. With impact excitation, it may be difficult or impossible in certain cases to obtain the accuracy which is attainable using continuous excitation with an attached exciter, and the impact method carries an increased danger of gross measurement errors. (See ref. [7]). In spite of these limitations, impact testing can be an extremely useful excitation technique when applied properly.

This part of ISO 7626 provides a guide to the use of impact excitation for mobility measurements. Accurate mobility measurements always require careful attention to equipment selection and to the measurement techniques employed; these factors are especially important when using impact excitation. Furthermore, the characteristics of the test structure, especially its degree of nonlinearity, will limit the accuracy which can be achieved. Subclause 4.2 describes these limitations on the use of impact excitation.

Because the exciter is not attached to the structure, this method makes it practical to measure a series of transfer mobilities of a structure by moving the excitation successively to each desired point on the structure, while the response motion transducer remains at a single fixed location and direction. Due to the principle of dynamic reciprocity, such measurements should be equal, assuming linearity, to the results obtained using an attached exciter at the same fixed location and direction with the response transducer relocated to each desired point on the structure. However, it may be difficult to impact the structure in all desired directions at certain locations, and in such cases it may be more practical to use impact excitation at the fixed location and direction and relocate a multi-axis response transducer to the desired response locations.

NOTE 2 The use of a multi-axis response transducer at a fixed location does not provide information about the multi-axis response at other locations. For example, if a fixed response transducer is used in performing measurements for a modal test, and if the impact is applied in only a single direction at each point, then only the mode shape components in that direction are obtained.

Vibration and shock — Experimental determination of mechanical mobility —

Part 5:

Measurements using impact excitation with an exciter which is not attached to the structure

1 Scope

This part of ISO 7626 specifies procedures for measuring mechanical mobility and other frequency-response functions of structures excited by means of a translational impulsive force generated by an exciter which is not attached to the structure under test.

It is applicable to the measurement of mobility, accelerance or dynamic compliance, either as a driving point measurement or as a transfer measurement, using impact excitation. Other excitation methods, such as step relaxation and transient random, lead to signal-processing requirements similar to those of impact data. However, such methods are outside the scope of this part of ISO 7626 because they involve the use of an exciter which is attached to the structure.

The signal analysis methods covered are all based on the discrete Fourier transform. This restriction in scope is based solely on the wide availability of equipment which implements these methods and on the large base of experience in using these methods. It is not intended to exclude the use of other methods currently under development.

Impact excitation is also widely used to obtain uncalibrated frequency-response information. For example, a quick impact test which obtains approximate natural frequencies and mode shapes can be quite helpful in planning a random or sinusoidal test for accurate mobility measurements. However, these uses of impact excitation to obtain qualitative results should not be confused with its use for mobility measurements.

This part of ISO 7626 is limited to the use of impact excitation techniques for making accurate mobility measurements.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 7626. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 7626 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2041:1990, *Vibration and shock — Vocabulary*.

ISO 7626-1:1986, *Vibration and shock — Experimental determination of mechanical mobility — Part 1: Basic definitions and transducers*.

ISO 7626-2:1990, *Vibration and shock — Experimental determination of mechanical mobility — Part 2: Measurements using single-point translation excitation with an attached vibration exciter*.

3 Definitions

For the purposes of this part of ISO 7626, the definitions given in ISO 2041 apply. For convenience, the most important definitions used in this part of ISO 7626 are given below.

3.1 frequency-response function: The frequency-dependent ratio of the motion-response phasor to the phasor of the excitation force.

NOTES

3 Frequency-response functions are properties of linear dynamic systems which do not depend on the type of excitation function. Excitation can be harmonic, random or transient functions of time. The test results obtained with one type of excitation can thus be used for predicting the response of the system to any other type of excitation.

4 Linearity of the system is a condition which, in practice, will be met only approximately, depending on the type of system and on the magnitude of the input. Care has to be taken to avoid nonlinear effects, particularly when applying impulse excitation. Structures which are known to be nonlinear (for example, certain riveted structures) should not be tested with impulse excitation and great care is required when using random excitation for testing such structures.

5 Motion may be expressed in terms of either velocity, acceleration or displacement; the corresponding frequency-response function designations are mobility, acceleration and dynamic compliance or impedance, effective mass and dynamic stiffness, respectively.

[ISO 2041, 1.48]

6 Assuming linearity, the frequency-response function may be defined equivalently for transient excitation as the complex ratio of the Fourier transform of the motion response to the Fourier transform of the excitation force. In actual practice, the discrete Fourier transform (DFT) is used as an approximation of the continuous Fourier transform. The errors of this approximation can be reduced to levels below those of other measurement errors. Hence, the use of the DFT does not necessarily limit the accuracy of the measurement.

3.2 frequency range of interest: Span, in hertz, from the lowest frequency to the highest frequency at which mobility data are to be obtained in a given test series.

[ISO 2041, 1.49]

3.3 direct (mechanical) mobility; driving-point (mechanical) mobility, Y_{jj} : The complex ratio of velocity and force taken at the same point in a mechanical system during simple harmonic motion.

NOTES

7 Driving-point mobility is the frequency-response function formed by the ratio, in metres per newton second, of the velocity-response phasor at point j to the excitation force phasor applied at the same point with all other measurement points on the structure allowed to respond freely without any constraints other than those constraints which represent the normal support of the structure in its intended application.

8 The term "point" designates a location and a direction. The term "coordinate" has also been used with the same meaning as "point".

[ISO 2041, 1.51]

3.4 frequency-averaged mobility magnitude: The r.m.s. value of the ratio, in metres per newton second, of the magnitude of the velocity response at point i to the magnitude of the exciting force at the same point, averaged over specified frequency bands.

[ISO 2041, 1.52]

3.5 transfer (mechanical) mobility: The complex ratio of the velocity, taken at one point in a mechanical system, to the force, taken at another point in the same system, during simple harmonic motion.

NOTE 9 Transfer mobility is the frequency-response function formed by the ratio, in metres per newton second, of the velocity-response phasor at points i to the excitation force phasor applied at point j with all points other than j allowed to respond freely without any constraints other than those constraints which represent the normal support of the structure in its intended application.

[ISO 2041, 1.53]

3.6 energy spectral density: The power spectral density multiplied by the length, in seconds, of the record which is used in the spectrum calculation of a transient signal.

NOTE 10 This definition assumes that the transient signal is entirely contained within the record. This normalization is needed in order to obtain a spectral magnitude which is independent of the record length used in the finite Fourier transform.

4 General characteristics of impact measurements

4.1 General description

The instrumentation required for mobility measurements using impact excitation consists of an impactor with built-in force transducer, one or more motion-response transducers with their associated signal conditioners, and a digital Fourier transform analysis system or analyser having at least two simultaneous input channels. The instrumentation system is shown schematically in figure 1. This part of ISO 7626 provides information on the selection and use of these components.

The force and response signals from each impact are anti-aliasing filtered and then digitally sampled using