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Acoustics — Experimental method for transposition of dynamic forces generated by an active component from a test bench to a receiving structure

Acoustique — Méthode expérimentale de transposition des forces dynamiques générées par un composant actif d'un banc d'essai vers une structure réceptrice

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Foreword

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This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

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

The vibroacoustic behaviour of products has become a major challenge not only in terms of user health protection through regulations, but also in terms of sound quality for safety, quality perception, and attractiveness.

At the same time, requirements on products development cycles are more and more stringent, reaching the point where component suppliers and integrators should work independently, without physical prototypes.

To master the transmission of dynamic forces (also called structure-borne noise), one needs to adapt the components to the receiving structure, and hence exchange information prior to manufacturing prototypes. This information will only be valuable for the integrator if it is clearly defined and intrinsic to the component.

This document, issued from a French experimental standard, addresses this issue. It is a user guidance to characterize an active source on a test bench and predict the effects of its integration on a passive structure. The component is characterized on its own, which makes the document complementary to the ISO 20270 that describes the measurement of “in-situ” characteristics (blocked forces), where the component is connected to its receiving structure.

The intrinsic characterization of an active source requires measuring two quantities (expressed as a function of the frequency): the first one characterizing the dynamic aspect, blocked forces, and the second one describing “static” behaviour, such as the impedance or the mobility.

The objective of this document is to help the user predict the component behaviour in a particular assembly. The theoretical background is laid in Annex A. The user is then guided (see 5.2) all along the experimental procedure enabling to reach this objective:

— Static characterization of the component, the test bench and the receiving structure.

— Force measurement: the standard proposes here direct and indirect methods. Indirect methods are generally easier to implement, but they need a particular focus on the measurement quality and matrix inversion.

— Interface integration (connecting device).

— Prediction of the behaviour of the component/receiving structure assembly.

This whole procedure is based on a general formula expressing the dynamic forces in the assembly as a function of blocked forces and static characteristics. Depending on these static characteristics, simplifications are proposed (see 5.6).

Annex B and C guide the user to measure both transfer functions and dynamic forces. It should be noted that, in general, these quantities are expressed in the 3 directions and 3 rotations, but the procedure can be applied on a number of degrees of freedom chosen by the user.

The Annex D informs about data processing. The Annex E contains a test example and the Annex F describes the method using a particular test bench (block sensor).

The data obtained and assessed in this document can be used:

— as part of a specification between suppliers and integrators;

— as input data of numerical vibroacoustic simulation models;

— to drive the modification of the physical structure or the interface in order to improve the vibroacoustic behaviour.

Acoustics — Experimental method for transposition of dynamic forces generated by an active component from a test bench to a receiving structure

1 Scope

This document specifies a method to predict the dynamic forces generated by an active component on a receiving structure from measurement on a test bench.

It sets out the requirements applicable to test benches and setup measurement conditions of dynamic forces: a criterion of validity of transfer functions measurements can be established for example.

The objective is to evaluate noise and vibrations generated by active components mounted on receiving structures, including the possibility to optimise vibration isolators.

It can be applied to different systems connected to a building, such as a compressor or a power generator, or to systems connected to a vehicle body, such as an engine powertrain or an electrical actuator, for example.

2 Normative references

There are no normative references in this document.

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
active component
active substructure which generates dynamic forces

Note 1 to entry: See Figure 1.

3.2
connecting device
mechanical interface with a specific "spring like" matrix structure which allows connecting the *active component* (3.1) to the receiving structure

Note 1 to entry: See Figure 1, Key 2.

Note 2 to entry: Insulators at fixation points are typical "spring like" connecting devices.

Note 3 to entry: A "spring like" connecting device is a structure with no internal degrees of freedom and internal mass, see 3.10.

Note 4 to entry: In the case of a connecting point, active component and receiving structure share the same location.

Note 5 to entry: In the case of seals at contact surfaces, direct connections or any other connection type, the connecting device item 2 cannot be used, and a block diagram with items 1 and 3 and 4 shall be used (see Figure 1).

Note 6 to entry: In case of direct connection, the hypothetical surface between the active component and receiving structure is called interface.

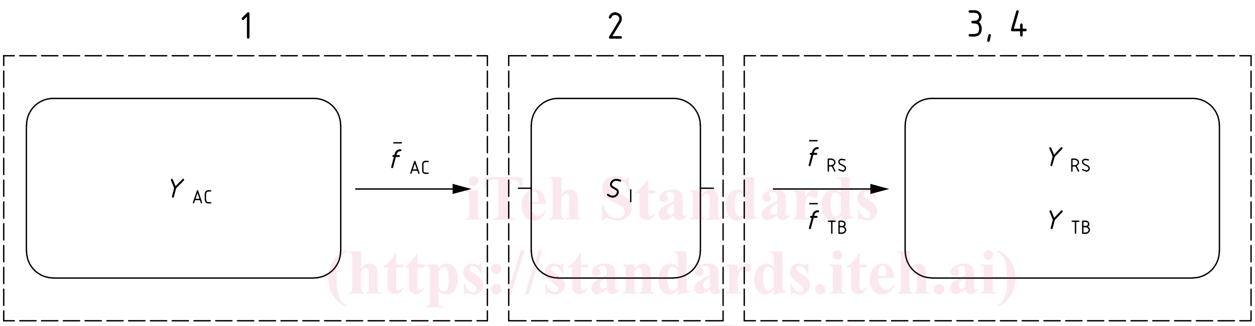
3.3
receiving structure
passive substructure to which the dynamic forces are transmitted

Note 1 to entry: See Figure 1, Key 3 and 4.

Note 2 to entry: The receiving structure can be a test bench or the structure for which the dynamic forces will be predicted.

Note 3 to entry: The "test bench" can be a specific structure designed to test the *active component* (3.1), or any other receiving structure.

Note 4 to entry: active device, connecting device and receiving structures are deformable structures.



Key

1 active component

2 connecting device

3 receiving structure

4 test bench

NOTE An active component (left) connected via a connecting device (centre) transmits dynamic forces to a receiving structure (right) which may vibrate and radiate sound.

Figure 1 — Schematic of the structure assembly

3.4
degree of freedom
n degrees of freedom through which structure-borne sound or vibration is transmitted from the *active component* (3.1) to the *receiving structure* (3.3)

EXAMPLE A connection point can have up to 6 degrees of freedom (dof).

3.5
dynamic force
$\bar{f}_{\mathrm{d}}$
complex force associated to a structure or an interface with n degrees of freedom, arranged into a $n \times 1$ vector at each frequency, according to

$$\bar{f}_{\mathrm{d}}(f) = \begin{bmatrix} \bar{f}_{\mathrm{d},1}(f) \\ \bar{f}_{\mathrm{d},2}(f) \\ \vdots \\ \vdots \\ \bar{f}_{\mathrm{d},n}(f) \end{bmatrix}$$

where $\bar{f}_{\mathrm{d},i}(f)$ is the complex Fourier transform of the i^{th} component of dynamic force at frequency f

Note 1 to entry: Forces $\bar{f}_{\mathrm{d}}$ can be considered as generalised forces, that is, including moments.

Note 2 to entry: Generalised forces units are Newtons for dynamic forces and N·m for dynamic moments

Note 3 to entry: In case pseudo-random signals, statistical tools can help into describing the dynamic forces into set of amplitude and phase force vectors.

Note 4 to entry: In Table 1, the specific dynamic forces $\bar{f}_{\mathrm{d}}$ applied at particular points used in this document are defined.

Table 1 — Dynamic forces symbols

Symbols and abbreviations	Definition
$\bar{f}_{\mathrm{AC}}$	Force generated by the active component at the interface of the connecting device in operational conditions.
$\bar{f}_{\mathrm{RS}}$ and $\bar{f}_{\mathrm{TB}}$	Forces transmitted to the receiving structure: final receiving structure (RS) or test bench (TB) in operational conditions. An additional “pred” or “meas” give indication about how the force is obtained (predicted from formulae, or directly measured): $\bar{f}_{\mathrm{RS\_pred}}$ and $\bar{f}_{\mathrm{TB\_meas}}$. In the case of no presence of a connecting device, $\bar{f}_{\mathrm{AC}} = \bar{f}_{\mathrm{RS}}$.

3.6
blocked force
dynamic force (3.5) applied by an *active component* (3.1) transmitted to a rigid *receiving structure* (3.3)

Note 1 to entry: Blocked forces indirect measurement methods are detailed in Annex F and ISO 20270.

3.7
velocity
$\boldsymbol{v}_{\mathrm{d}}$

complex vibration velocity associated to a structure or an interface with n degrees of freedom, arranged into a $n \times 1$ vector at each frequency, according to

$$\boldsymbol{v}_{\mathrm{d}}(f)=\begin{bmatrix} \boldsymbol{v}_{\mathrm{d},1}(f) \\ \boldsymbol{v}_{\mathrm{d},2}(f) \\ \vdots \\ \vdots \\ \boldsymbol{v}_{\mathrm{d},n}(f) \end{bmatrix}$$

where $\boldsymbol{v}_{\mathrm{d},i}(f)$ is the complex Fourier transform of the i^{th} velocity component at frequency f

Note 1 to entry: Velocity units are meters per second (m/s).

Note 2 to entry: Associated complex acceleration $\boldsymbol{a}_{\mathrm{d}}(f)$ can be defined via derivation of the velocity.

Note 3 to entry: Associated complex displacement $\boldsymbol{x}_{\mathrm{d}}(f)$ can be defined via integration of the velocity.

Note 4 to entry: In Table 2, the displacement, velocity and acceleration $\boldsymbol{x}_{\mathrm{d}}, \boldsymbol{v}_{\mathrm{d}}, \boldsymbol{a}_{\mathrm{d}}$ generated at particular points used in this standard are defined.

Table 2 — Velocity, displacement and acceleration definitions

Symbols and abbreviations	Definition
$\boldsymbol{x}_{\mathrm{AC}}, \boldsymbol{v}_{\mathrm{AC}}$ and $\boldsymbol{a}_{\mathrm{AC}}$	dynamic displacement, velocity and acceleration generated by the active component.
$\boldsymbol{x}_{\mathrm{RS}}, \boldsymbol{v}_{\mathrm{RS}}$ and $\boldsymbol{a}_{\mathrm{RS}}$	dynamic displacement, velocity and acceleration on the receiving structure.

3.8
frequency response function
FRF
frequency dependent ratio of the Fourier transform of the response to the Fourier transform of the excitation of a linear system

Note 1 to entry: See ISO 2041.

Note 2 to entry: The FRF denomination and associated unit depends on the two vibration quantities of the ratio (See Table 3).

Note 3 to entry: In this document, any reference to mobility Y or impedance Z is related to:

— the free mobility, $\boldsymbol{Y}_{\mathrm{free}\,ij}$, which is defined as a ratio of a dynamic velocity response in degree of freedom i to an excitation force in degree of freedom j, with all degrees of freedom free, except the one of the excitation forces; or

— the blocked impedance $\boldsymbol{Z}_{\mathrm{blocked}\,ij}$, which is defined as a ratio of the response force in degree of freedom j to the dynamic velocity in degree of freedom i, with all degrees of freedom blocked, except the one of the excitation velocity $\bar{\boldsymbol{v}}_{\mathrm{d},j}$

Table 3 — Denomination of frequency response functions FRF for various vibration quantities (displacement, *x*, velocity, *v* and acceleration, *a*)

	Dynamic Compliance	Free Mobility	Accelerance	Dynamic stiffness	Blocked impedance	Effective Mass
Denomination	$\dfrac{\boldsymbol{x}_i}{\bar{\boldsymbol{f}}_J}$	$\boldsymbol{Y}_{\mathrm{free}\,ij}=\dfrac{\boldsymbol{v}_i}{\bar{\boldsymbol{f}}_J}$	$\dfrac{\boldsymbol{a}_i}{\bar{\boldsymbol{f}}_J}$	$\dfrac{\bar{\boldsymbol{f}}_J}{\boldsymbol{x}_i}$	$\boldsymbol{Z}_{\mathrm{blocked}\,ij}=\dfrac{\bar{\boldsymbol{f}}_J}{\boldsymbol{v}_i}$	$\dfrac{\bar{\boldsymbol{f}}_J}{\boldsymbol{a}_i}$

Table 3 *(continued)*

	Dynamic Compliance	Free Mobility	Accelerance	Dynamic stiffness	Blocked impedance	Effective Mass
Unit	$\frac{\text{m}}{\text{N}}$	$\frac{\text{m}}{\text{N}\cdot\text{s}}$	$\frac{\text{m}}{\text{N}\cdot\text{s}^2}$	$\frac{\text{N}}{\text{m}}$	$\frac{\text{N}\cdot\text{s}}{\text{m}}$	$\frac{\text{N}\cdot\text{s}^2}{\text{m}}$

Note 4 to entry: Thus, in terms of matrix writing, corresponding $\boldsymbol{Y}$ and $\boldsymbol{Z}$ matrices are related:

$$\boldsymbol{Z}_{\text{blocked}} = \boldsymbol{Y}_{\text{free}}^{-1}$$

3.9
transfer matrix
set of FRF between multiple degrees of freedom systems

Note 1 to entry: In this document, the terms $\boldsymbol{Y}_{\text{AC}}$, $\boldsymbol{Y}_{\text{RS}}$ and $\boldsymbol{Y}_{\text{TB}}$ (see Table 4) can be related to free mobility, dynamic compliance or accelerances, depending of the quantities that are commonly used by the reader, with the same boundary conditions as the free mobility.

Table 4 — Main transfer matrices used in the document

Symbols and abbreviations	Definition
$\boldsymbol{Y}_{\text{AC}}$	transfer matrix of the active component
$\boldsymbol{Y}_{\text{RS}}$ and $\boldsymbol{Y}_{\text{TB}}$	transfer matrix of the receiving structure or the test bench

3.10
connecting device transfer matrix
connecting device (case of insulators at fixation points) *transfer matrix* (3.9) (see Table 5) can be obtained via different methods

Note 1 to entry: Such methods are described in ISO 10846.

Table 5 — Different expressions of connecting device transfer matrix versus dynamic stiffness matrix

Formula	Unit	Homogeneous to
$\boldsymbol{S}_{\text{I}} = \omega^2 \boldsymbol{K}_{\text{I}}^{*-1}$	$\text{m}\cdot\text{N}^{-1}\text{s}^{-2}$	accelerance
$\boldsymbol{S}_{\text{I}} = j\omega \boldsymbol{K}_{\text{I}}^{*-1}$	$\text{m}\cdot\text{N}^{-1}\text{s}^{-1}$	mobility
$\boldsymbol{S}_{\text{I}} = \boldsymbol{K}_{\text{I}}^{*-1}$	$\text{m}\cdot\text{N}^{-1}$	compliance (or receptance)
with $\boldsymbol{K}_{\text{I}}^{*}$ homogeneous to a dynamic stiffness complex matrix of the connecting device.		

3.11
operational conditions
set of conditions under which the source operates for the operational test, including speed, load and any other settings or conditions particular to the source which might affect source operation

4 Principle of the method of transposition of the dynamic force

4.1 General matters

This subclause explains how to predict the forces generated by an active component (which comes with its own sources) on a receiving structure from a series of measurements on a test bench and on specific data about the receiving structure.

Predicted or measured dynamic forces are required when

- there is no opportunity to measure directly any dynamic force of any sort (e.g. heavy and high cost electrical machine to be duplicated in a new place),
- there is only the possibility to work on a test bench, because the final receiving structure is still not available,
- the active source is provided by a component supplier to an integrator, and the integrator defines a specification on a bench, with a target to comply, and
- internal forces matrix of a specific product is needed for noise comfort prediction, or for durability purpose.

4.2 General formulae

The first Formula (1) which detail is given in Annex A can be written as follows:

$$\bar{\boldsymbol{f}}_{\mathrm{RS}} = [\boldsymbol{Y}_{\mathrm{RS}} + \boldsymbol{Y}_{\mathrm{AC}} + \boldsymbol{S}_{\mathrm{I}}]^{-1} \cdot [\boldsymbol{Y}_{\mathrm{TB}} + \boldsymbol{Y}_{\mathrm{AC}} + \boldsymbol{S}_{\mathrm{I}}] \cdot \bar{\boldsymbol{f}}_{\mathrm{TB}} \quad (1)$$

where

$\bar{\boldsymbol{f}}_{\mathrm{RS}}$ is the transmitted force vector to the receiving structure;

$\boldsymbol{Y}_{\mathrm{RS}}$ is the transfer matrix of the receiving structure;

$\boldsymbol{Y}_{\mathrm{AC}}$ is the transfer matrix of the active component;

$\boldsymbol{Y}_{\mathrm{TB}}$ is the transfer matrix of the test bench;

$\boldsymbol{S}_{\mathrm{I}}$ is the spring-like matrix representation of the connecting device;

$\bar{\boldsymbol{f}}_{\mathrm{TB}}$ is the transmitted force vector to the test bench.

The purpose of Formula (2) is to enable the prediction of a force transmitted to a receiving structure from the measurement or the estimation of 4 different FRFs matrices:

$$\bar{\boldsymbol{f}}_{\mathrm{RS\_predict}} = [\boldsymbol{Y}_{\mathrm{RS}} + \boldsymbol{Y}_{\mathrm{AC}} + \boldsymbol{S}_{\mathrm{I}}]^{-1} \cdot [\boldsymbol{Y}_{\mathrm{TB}} + \boldsymbol{Y}_{\mathrm{AC}} + \boldsymbol{S}_{\mathrm{I}}] \cdot \bar{\boldsymbol{f}}_{\mathrm{TB\_meas}} \quad (2)$$

To build this formula, there are intermediate steps that are detailed in Annex A.

Instead of a link from bench to receiving structure, in certain cases, the need is to go from receiving structure to bench; Formula (2) is then given as Formula (3):

$$\bar{\boldsymbol{f}}_{\mathrm{TB\_predict}} = [\boldsymbol{Y}_{\mathrm{TB}} + \boldsymbol{Y}_{\mathrm{AC}} + \boldsymbol{S}_{\mathrm{I}}]^{-1} \cdot [\boldsymbol{Y}_{\mathrm{RS}} + \boldsymbol{Y}_{\mathrm{AC}} + \boldsymbol{S}_{\mathrm{I}}] \cdot \bar{\boldsymbol{f}}_{\mathrm{RS\_meas}} \quad (3)$$

4.3 Geometrical considerations

Sizes and quantities handled in this document are defined in a specific coordinate system, usually the geometric coordinate system related to the receiving structure.

During FRF functions measurements (see Annex B), it can be more practical to use a local coordinate system for certain attachment points. In this case, it will be necessary to re-project in a global reference system.

5 Operating mode

5.1 General

In this subclause, an operating mode to apply this document is proposed, as an example.

This procedure is based on the general Formula (2) allowing to transpose the dynamic forces generated by an active component from a test bench to a receiving structure. Depending on the assumptions on the different transfer functions, this operating mode allows the use of simplified versions of Formula (2).

The frequency range(s) for which the formulated hypotheses and steps presented below are considered as valid or invalid shall be mentioned.

5.2 Synopsis of procedure

The various special cases discussed below can be summarized in the form of a general diagram of the procedure (see Figure 2).

5.3 Tasks and preliminary operations

A number of tasks and processes shall be performed previous to the application of this procedure:

a) During the development of the product, the component will determine the active component transfer matrix at the connecting points. There are many cases for which the active component is not only connected to its fixation points, but interacts with its environment through cables, rotation axes, hoses, pipes, friction, which do not allow to measure the transfer matrix in free conditions for all degrees of freedom. In this case, different alternatives are proposed in the document.

b) During the development of the product, the component chooses the properties of the connecting device between the component and the receiving structure. It is remarked that this connecting device matrix properties are of first order influence on the final transmitted forces: the product shall ensure a perfect decoupling in order to minimize the vibration coupling between the component and the receiving structure. Some advices are given hereunder in this operating mode.

c) To apply the methodology to predict the forces transmitted to the receiving structure in order to check compliance with the specifications, a test bench is generally developed, transmitted forces to the bench are measured. Usually, in the field of noise and vibration, an infinitely rigid bench, such as a marble, is used, but this methodology is not mandatory. Therefore, the procedure covers the case of a not infinitely rigid test bench.

The operating mode starts with the analysis of the general equation [Formula (2)] and attempts to cover the different real cases that may be encountered in practice in the fields covered by the document. The choices in the flow chart not only depend on the possibilities offered by the product, but also on the relative order of scales of different transfer matrices in Formula (2). Three different examples are described in Annexes E and F, to scan a wide range of applications.

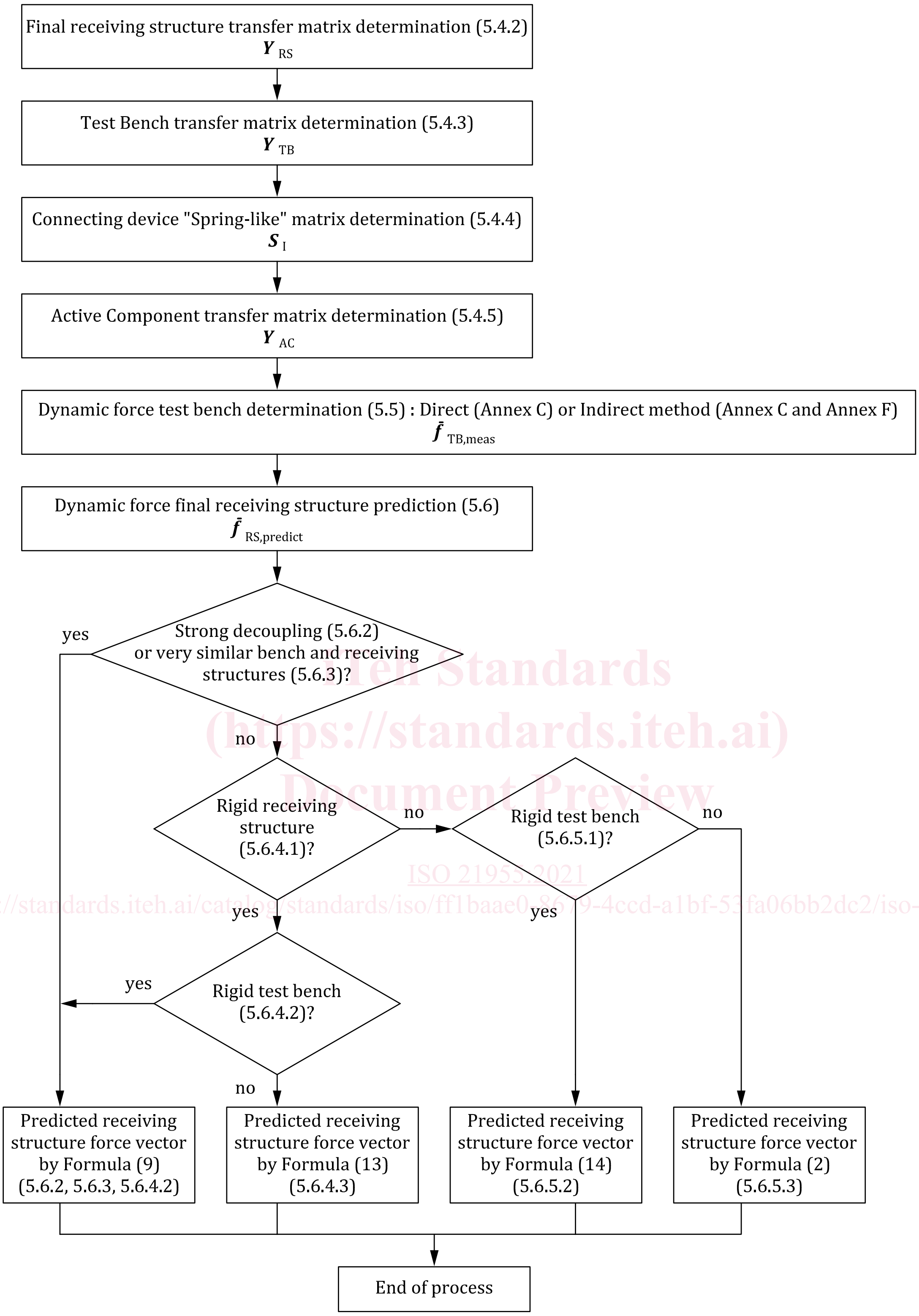


Figure 2 — Synoptic of the steps to determine predicted force