INTERNATIONAL STANDARD

ISO 21940-13

First edition
2012-03-15

Mechanical vibration — Rotor balancing —

Part 13:
Criteria and safeguards for the *in-situ* balancing of medium and large rotors

Vibrations mécaniques — Équilibrage des rotors —

Partie 13: Critères et sauvegardes relatifs à l'équilibrage in situ *des rotors moyens et grands*

Reference number
ISO 21940-13:2012(E)

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Foreword

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ISO 21940-13 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

This first edition of ISO 21940-13 cancels and replaces ISO 20806:2009, of which it constitutes a minor editorial revision.

ISO 21940 consists of the following parts, under the general title *Mechanical vibration — Rotor balancing*:

— *Part 1: Introduction*[1)]

— *Part 2: Vocabulary*[2)]

— *Part 11: Procedures and tolerances for rotors with rigid behaviour*[3)]

— *Part 12: Procedures and tolerances for rotors with flexible behaviour*[4)]

— *Part 13: Criteria and safeguards for the* in-situ *balancing of medium and large rotors*[5)]

— *Part 14: Procedures for assessing balance errors*[6)]

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1) Revision of ISO 19499:2007, *Mechanical vibration — Balancing — Guidance on the use and application of balancing standards*

2) Revision of ISO 1925:2001, *Mechanical vibration — Balancing — Vocabulary*

3) Revision of ISO 1940-1:2003, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances* (+ Cor.1:2005)

4) Revision of ISO 11342:1998, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors* (+ Cor.1:2000)

5) Revision of ISO 20806:2009, *Mechanical vibration — Criteria and safeguards for the* in-situ *balancing of medium and large rotors*

6) Revision of ISO 1940-2:1997, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 2: Balance errors*

— *Part 21: Description and evaluation of balancing machines*[7)]

— *Part 23: Enclosures and other protective measures for balancing machines*[8)]

— *Part 31: Susceptibility and sensitivity of machines to unbalance*[9)]

— *Part 32: Shaft and fitment key convention*[10)]

7) Revision of ISO 2953:1999, *Mechanical vibration — Balancing machines — Description and evaluation*

8) Revision of ISO 7475:2002, *Mechanical vibration — Balancing machines — Enclosures and other protective measures for the measuring station*

9) Revision of ISO 10814:1996, *Mechanical vibration — Susceptibility and sensitivity of machines to unbalance*

10) Revision of ISO 8821:1989, *Mechanical vibration — Balancing — Shaft and fitment key convention*

Introduction

Balancing is the process by which the mass distribution of a rotor is checked and, if necessary, adjusted to ensure that the residual unbalance or the vibrations of the journals or bearing supports and/or the forces at the bearings are within specified limits. Many rotors are balanced in specially designed balancing facilities prior to installation into their bearings on site. However, if remedial work is carried out locally or a balancing machine is not available, it is common to balance the rotor *in situ*.

Unlike balancing in a specially designed balancing machine, *in-situ* balancing has the advantage that the rotor is installed in its working environment. Therefore, there is no compromise with regard to the dynamic properties of its bearings and support structure, nor from the influence of other elements in the complete rotor train. However, it has the large disadvantage of restricted access and the need to operate the whole machine. Restricted access can limit the planes at which correction masses can be added, and using the whole machine has commercial penalties of both downtime and running costs. Where gross unbalance exists, it may not be possible to balance a rotor *in situ* due to limited access to correction planes and the size of correction masses available.

Mechanical vibration — Rotor balancing —

Part 13:
Criteria and safeguards for the *in-situ* balancing of medium and large rotors

1 Scope

This part of ISO 21940 specifies procedures to be adopted when balancing medium and large rotors installed in their own bearings on site. It addresses the conditions under which it is appropriate to undertake *in-situ* balancing, the instrumentation required, the safety implications and the requirements for reporting and maintaining records.

This part of ISO 21940 can be used as a basis for a contract to undertake *in-situ* balancing.

It does not provide guidance on the methods used to calculate the correction masses from measured vibration data.

NOTE The procedures covered in this part of ISO 21940 are suitable for medium and large machines. However, many of the principles are equally applicable to machines of a smaller size, where it is necessary to maintain good records of the vibration behaviour and the correction mass configurations.

2 Normative references

The following referenced documents are indispensable for the application 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 1925, *Mechanical vibration — Balancing — Vocabulary*[11)]

ISO 1940-1, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances*[12)]

ISO 2954, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity*

ISO 7919 (all parts), *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts*

ISO 10816 (all parts), *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts*

11) To become ISO 21940-2 when revised.

12) To become ISO 21940-11 when revised.

ISO 10817-1, *Rotating shaft vibration measuring systems — Part 1: Relative and absolute sensing of radial vibration*

ISO 11342, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors*[13)]

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925 apply.

4 *In-situ* balancing

4.1 General

For *in-situ* balancing, correction masses are added to the rotor at a limited number of conveniently engineered and accessible locations along the rotor. By doing this, the magnitude of shaft and/or pedestal vibrations and/or unbalance is reduced to within acceptable values, so that the machine can operate safely throughout its whole operating envelope. As part of a successful balance, transient-speed vibration might be compromised to some degree to obtain acceptable normal running speed vibration on a fixed-speed machinery train.

NOTE In certain cases, machines that are very sensitive to unbalance cannot be successfully balanced over the complete operating envelope. This usually occurs when a machine is operating at a speed close to a lightly damped system mode (see ISO 10814 to become ISO 21940-31 when revised) and has load-dependent unbalance.

Most sites have limited instrumentation and data-processing capabilities, when compared to a balancing machine, and additional instrumentation is required to undertake *in-situ* balancing in these situations. In addition, the potential safety implications of running a rotor with correction masses shall be taken into account.

4.2 Reasons for *in-situ* balancing

4.2.1 Although individual rotors might be correctly balanced, as appropriate, in a high- or low-speed balancing machine, *in-situ* balancing may be required when the rotors are coupled into the complete rotor train. This can be due to a range of differences between the real machine and the isolated environment in the balancing machine, including:

a) a difference in dynamic characteristics of the rotor supports between the balancing facility and the installed machine;

b) assembly errors that occur during installation, which cannot be reasonably found and corrected;

c) rotor systems that cannot be balanced prior to assembly;

d) a changing unbalance behaviour of the rotor under full functional operating conditions.

4.2.2 Balancing may also be required to compensate for in-service changes to the rotor, including:

a) wear;

b) loss of components, such as rotor blade erosion shields;

c) repair work, where components can be changed or replaced;

d) movement of components on the rotor train causing unbalance, such as couplings, gas turbine discs and generator end rings.

NOTE Rotor blades are normally added as balanced sets, but this can be impossible if a small number of blades are replaced.

13) To become ISO 21940-12 when revised.

4.2.3 *In-situ* balancing may be necessary due to a range of economic and technical reasons, including:

a) the investment in a balancing machine cannot be justified;

b) when a suitable balancing machine is not available in the correct location or at the required time;

c) when it is not economic to dismantle the machine and transport the rotor(s) to a suitable balancing facility.

4.2.4 Machines under normal operation or during speed variations (following remedial work, or after commissioning) can have unacceptable magnitudes of vibration when compared with common practice, contractual requirements, or International Standards such as ISO 7919 and ISO 10816. In many cases, it is possible to bring the machine within acceptable vibration magnitude by *in-situ* balancing.

4.3 Objectives of *in-situ* balancing

The reason for balancing is to reduce the vibration magnitudes to acceptable values for long-term operation. For most machines, the overall vibration magnitude limits shall either be based on common practice or the appropriate part of ISO 7919 (for shaft vibration) and ISO 10816 (for bearing housing and pedestal vibration).

Where the magnitude of unbalance is of concern, reduce the magnitude of unbalance to within permissible limits (see ISO 1940-1 and ISO 11342 for details).

5 Criteria for performing *in-situ* balancing

Prior to *in-situ* balancing, a feasibility study shall be carried out to assess if the available correction planes are suitable to influence the vibration behaviour being observed, since limited access to correction planes and measurement points on the fully built-up machine can make *in-situ* balancing impractical. Where possible, experience from previous *in-situ* balancing should be used. Sometimes modal analysis may be required.

In-situ balancing shall only be attempted in the following circumstances:

a) the reasons for the high vibrations are understood and cannot be corrected at the source;

b) after analysis of the vibration behaviour, it is judged that balancing is a safe and practical approach;

c) under the required normal operating conditions, the vibration vector is steady and repeatable prior to and during *in-situ* balancing;

d) since the addition of correction masses only affects the once-per-revolution component of vibration, *in-situ* balancing makes sense only if this is a significant component of the overall vibration magnitude.

In special circumstances, where the once-per-revolution vibration component changes during normal operation of the machine (such as thermally induced bends in generator rotors), it is possible to reach acceptable balancing results across the operating envelope by adding correction masses. Here, with the vibration magnitude at full speed, no load might be compromised to obtain an acceptable vibration magnitude at full load. Again, this shall only be attempted if the reasons for the unbalance are understood.

NOTE When systems are operating in a non-linear mode, correction masses can affect other vibration components, including both sub and high shaft speed harmonics.

The once-per-revolution component of vibration might not originate from unbalance but is generated from system forces such as those found in hydraulic pumps and electric motors. Many defects, such as shaft alignment errors and tilting bearings, can also contribute to the once-per-revolution component of vibration. Such effects should not normally be corrected by balancing, since this can mask a real system fault.

The first shaft order vectors of synchronous vibration should be sufficiently steady, such that the magnitude of the variation is not significant relative to the magnitude of the mean vibration vector.

Where sufficient design data of the rotor system are available, rotor dynamic modelling can be used to aid the choice of suitable correction planes and correction mass combinations.

6 Safeguards

WARNING — *In-situ* balancing shall only be undertaken by a skilled team, including both customer and supplier, who understand the consequences of adding trial and correction masses and have experience of operating the machine. Failure to do this can place the whole machine and staff at risk.

6.1 Safety of personnel while operating close to a rotating shaft

While undertaking *in-situ* balancing, the machine is operated under special conditions, allowing access to rotating components to add trial and final correction masses. Strict safety procedures shall be in place to ensure that the machine cannot be rotated while personnel have access to the shaft and that no temporary equipment can become entwined when the shaft is rotated.

6.2 Special operating envelope for *in-situ* balancing

Machines may be quickly run up and run down many times and can have unusual loading conditions during the *in-situ* balancing exercise, which can be outside the normal operating envelope of a machine. Examples for specific machine types that shall be taken into account are given in Annex A. It shall be established that such operations are not detrimental to the integrity or the life of the whole machine.

However, as no general list of machine types can cover all situations, it is necessary to review individually the integrity requirements for each *in-situ* balance.

6.3 Integrity and design of the correction masses and their attachments

When trial and correction masses are added, it shall be confirmed that they are securely attached and their mountings are capable of carrying the required loads. The correction masses shall not interfere with normal operation, such as coming into contact with stationary components due to shaft expansion. The correction masses should be fitted in accordance with the manufacturer's instructions, if available.

Correction masses are often attached with bolts or by welding. It shall be ensured that neither the bolt holes nor the welding process compromise the integrity of the rotor component to which the correction masses are attached, or the function of the component, such as cooling. Furthermore, correction masses shall be compatible with their operating environment, such as temperature and chemical composition of the atmosphere.

Where possible, the total mass of the correction masses on each plane shall be minimized by consolidating those added from previous balancing exercises. However, correction masses that have been added for specific reasons (such as to balance the individual disc or counteract for blade root eccentricity errors) should not be changed.

When correction masses are added to non-integral rotating components, these parts should be match marked so that the proper assembly orientation can be maintained.

6.4 Machinery-specific safety implications

General safety requirements associated with *in-situ* balancing are discussed in 6.1 to 6.3, but precautions and safeguards for specific machine types, given in Annex A, shall be taken into account. However, as no general list of safety precautions can cover all machinery and all situations, it is necessary to review individually the safety requirements for each *in-situ* balance.

7 Measurements

7.1 Vibration measurement equipment

Basic procedures for the evaluation of vibration by means of measurements made directly on the rotating shaft shall conform to ISO 7919-1 and the measurement system shall conform to ISO 10817-1. Measurement procedures for transducers mounted on the pedestal shall conform to ISO 10816-1 and the measurement system shall conform to ISO 2954. Either system shall have sufficient frequency range to capture data for the full speed range over which the machine is to be balanced. The transducers shall have the necessary sensitivity and shall be located at the appropriate positions to measure the effects of the correction masses.

On flexible support structures, pedestal measurements can give the best results. On rigid supports, shaft relative transducers can be more responsive. Guidance as to the most suitable measurement system can also be gained from previous experience or rotor dynamic modelling. When eddy current non-contact transducers are used to measure the shaft relative motion, the signal can be compromised by electrical and/or mechanical runout of the measurement track (for details, see ISO 7919-1 and ISO 10817-1). Where these effects significantly influence the true reading, the source should be isolated and appropriate corrections made. If available, shaft absolute measurement can be used, which provides a shaft position independent of the pedestal movement.

ISO 7919 and ISO 10816 are concerned with acceptable overall vibration values for machinery operating under steady-state conditions. For balancing, the vibration measurement equipment shall have the additional facility to extract the once-per-revolution component of vibration, giving both magnitude and phase angle. Furthermore, ISO 7919 and ISO 10816 apply to the radial measurement directions on all bearings and the axial direction for only the thrust bearing. However, in some special conditions, axial measurements on other bearings shall be carried out where necessary.

In-situ balancing is normally carried out to reduce the vibration magnitude at the operating speed and while passing through the system resonances, during run up and run down. The measurement equipment shall have sufficient dynamic range to measure both magnitude and phase over the full speed and operating ranges under consideration.

Vibration shall be measured at selected locations where it is necessary to reduce its magnitude. However, balancing can improve the vibration magnitude at some locations or directions at the expense of others. Therefore, it is recommended to have additional transducers on adjacent rotors or bearings. Whilst, for monitoring purposes, measurements in only one direction may be sufficient, for an *in-situ* balance it is advisable to measure in two orthogonal directions, where possible.

Where permanently installed transducers are used, it is advisable to check their calibration, in both magnitude and phase, immediately prior to balancing. Permanently installed shaft relative transducers are not normally checked for calibration, but a phase and shaft runout check is advisable. It is normally sufficient to check the phase of the shaft transducers by ensuring the signal has the correct polarity. Where accessible, pedestal transducers shall be checked against portable equipment.

In some cases, it can be useful to measure the full orbit of vibration and in this instance it is necessary to have pairs of transducers at selected axial measurement locations along the shaft. Strictly, it is only necessary to have two non-parallel transducers to describe the orbit; however, orthogonal pairs are usually used.

7.2 Measurement errors

Any measurement is subject to error, which is the difference between the measured value and the true value. The difference is called the error of measurement and, in balancing, this is caused by a combination of systematic, randomly variable and scalar errors. Systematic errors are those when both magnitude and phase angle of the unbalance can be evaluated by either calculation or measurement. Random errors are those when both the magnitude and phase of the unbalance can vary unpredictably, and scalar errors occur when the magnitude of the unbalance can be evaluated or estimated but the angle is undefined.

ISO 21940-14 gives examples of typical errors that can occur in the field of balancing and provides procedures for their determination. Some of the examples presented are for the balancing facility, but many are also applicable to *in-situ* balancing.

The limit for these errors shall be matched to the acceptance criteria of the *in-situ* balancing, as agreed between the supplier and customer (see 4.3).

7.3 Phase reference signals

7.3.1 General

A phase reference mark, such as a keyway or reflective tape, is usually placed on the shaft or any synchronous part, and is detected by a transducer mounted on a non-rotating component, e.g. a bearing pedestal. This provides a once-per-revolution signal from which the phase of the vibration can be measured.

Sometimes the reference mark is permanently installed. The reference mark, such as a keyway or markings on the shaft, shall be clearly documented and, if possible, shall be visible to allow correction masses to be accurately placed.

In addition, the direction of shaft rotation shall be established so that phase angles, with or against rotation, can be translated into the appropriate correction mass locations. Measured angles with rotation (phase lead) require correction masses to be located in the direction of rotation from the leading edge of the phase mark. Angles measured against rotation (phase lag) require the correction mass to be located against the direction of rotation from the leading edge of the phase mark.

Alternative phase definitions may be adopted, but the system used shall be clearly defined. It is good practice to ensure that the phase angle used for the location of the correction mass is consistent with the phase angle of the once-per-revolution vibration.

7.3.2 Information required for reproducible phase reference data

The position of the shaft phase reference shall be consistently defined to provide accurate records so that previous and future *in-situ* balancing data can be compared (see Clause 9). The pulse generated by the shaft mark shall be sharp so that different trigger levels do not lead to inaccurate phase measurements. The sinusoidal type signal (see Figure 1) can give a trigger time dependent on the level of the trigger setting, but the sharp pulse (see Figure 2) gives a trigger time independent of the trigger level. Triggering shall be from the leading edge of the pulse, for either negative or positive going pulses (either negative or positive slope). Triggering on the trailing edge can lead to significant phase errors, since the pulse width might not reflect the width of the phase mark and depends on the pulse signal conditioning.

7.3.3 Phase data when using trial masses as the phase reference

If the *in-situ* balancing process adopted uses a trial mass or set of masses as the initial run, and all subsequent runs are compared with this, it may not be necessary to have detailed knowledge of the phase reference signal, as described in 7.3.2. All correction mass locations are relative to the position of the initial trial mass(es) and errors introduced by the measurement system have less significance.

However, using the trial mass(es) phase reference approach, the same or equivalent equipment and trigger settings shall be used throughout the whole *in-situ* balancing exercise and the phase data collected will have no significance relative to previous or future data. In addition, the position of the initial trial mass(es) can increase the vibration magnitude. This can be unacceptable for a machine that is already operating at a high vibration magnitude.

