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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*

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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.

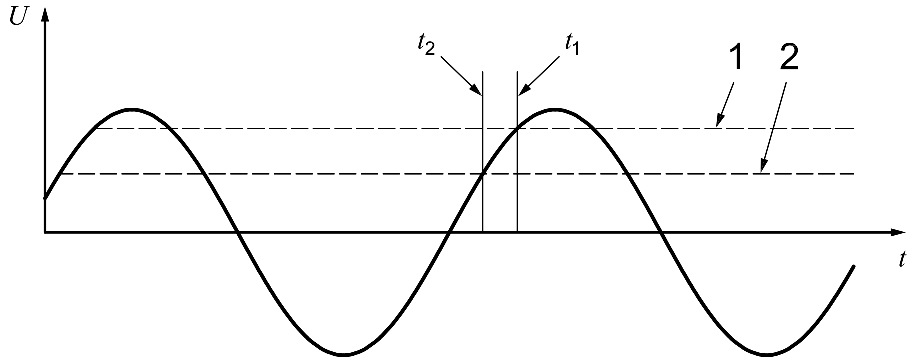
7.3.2 Information required for reproducible phase reference data

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.



Key

t time

t_1 time of trigger level 1

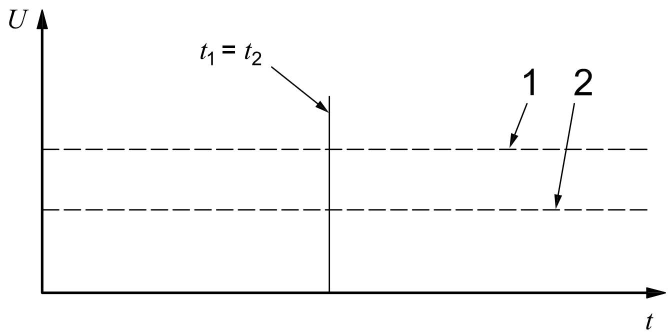
t_2 time of trigger level 2

U tachometer signal

1 trigger level 1

2 trigger level 2

Figure 1 — Bad phase reference signal



Key

t time

t_1 time of trigger level 1

t_2 time of trigger level 2

U tachometer signal

1 trigger level 1

2 trigger level 2

Figure 2 — Good phase reference signal

8 Operational conditions

Vibration data for the balancing runs shall only be collected under sufficiently steady and repeatable operating conditions that influence the vibration, such as active power, fluid flow, electrical current, and pressure. This may require pre-balance tests to determine the effects related to the operating conditions; e.g. machines can have thermal transients during initial start-up and it may be necessary to run for a sufficient time to reach normal operating conditions prior to taking the vibration values.

NOTE 1 Additional testing may also be required when a non-linear behaviour is suspected. Under this condition, the first shaft order vibration vector change is not linearly related to the position and magnitude of the correction mass.

NOTE 2 When vibration data are collected under transient speed conditions, the rate of change of speed (increasing or decreasing speed) can influence the values of vibration measured.

9 Reporting

9.1 General

The level of reporting depends on the type of machine being balanced. This clause specifies information that shall be reported. Table 1 provides broad guidance on normally acceptable levels of reporting related to the type of machine being balanced. Examples of balancing reports for a fan and a large turbine generator set are given in Annexes B and C, respectively.

Balancing shall be accurately reported to maintain records of the correction masses added to the rotors. This is especially important when rotors are removed for remedial work, so that the correction masses added to correct for defects in the rotor train can be distinguished from those added for individual rotors.

Good balancing records are also required to assist in understanding the behaviour of the machine, enabling its response to be predicted in relation to additions of correction masses. This simplifies further balancing procedures and aids the identification of fault locations when problems occur.

Even on smaller, low-cost machines, records and patterns of additions of correction masses shall be maintained to identify generic or rogue plant problems.

Before *in-situ* balancing is undertaken, the need to add correction masses shall be understood. If possible, the report should include the reasons for the unbalance and the information used to reach this conclusion.

Table 1 — Levels of reporting for *in-situ* balancing reports

Type of machine	Size MW	Background	Machine details	Instrumentation details	Results			
					Correction mass(es)	Tabular	Graphical	
	Subclause				Subclause			
							Vectors	Signatures
		9.2.1	9.2.3	9.3	9.4 2	9.4.3	9.4.4.1	9.4.4.2
Boiler fans	≤1	Yes	—	—	Yes	Yes	—	—
	>1	Yes	—	Yes[a]	Yes	Yes	Yes	—
Main boiler feed pumps	≤1	Yes	—	—	Yes	Yes	—	—
	>1	Yes	—	Yes[a]	Yes	Yes	Yes	—
Electric motors	≤1	Yes	—	—	Yes	Yes	—	—
	>1	Yes	Yes	Yes	Yes	Yes	Yes	—
Gas turbines	≤50	Yes	Yes	Yes	Yes	Yes	Yes	—
	>50	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Steam turbines	≤50	Yes	Yes	Yes	Yes	Yes	Yes	—
	>50	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Electrical generators	≤10	Yes	Yes	Yes	Yes	Yes	Yes	—
	>10	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[a] If a supplementary installation is used to perform the balance, the instrumentation details shall be reported.

9.2 Report introduction

9.2.1 Background

Any relevant machine history shall be highlighted, with particular consideration being given to the recent operating regime and maintenance work.

9.2.2 Objective

Reports for all classes of machine shall clearly outline the objective for the *in-situ* balancing exercise. Normally the reason for balancing is to reduce the vibration to acceptable magnitudes but, in special circumstances, it may be necessary to reduce the unbalance to permissible limits.

9.2.3 Machine details

A schematic diagram of the whole machine being balanced should be provided, indicating all the rotors and the location of the thrust and support bearings. All vibration transducer locations and directions shall be clearly shown, plus the position and orientation of the phase reference mark. The direction of shaft rotation shall also be included with respect to the viewing direction along the shaft.

NOTE Information on conventions for bearing housing designation and identifying vibration transducer locations and directions on rotor trains is given in ISO 13373-1:2002[1], Annex D.

Where more complex features that affect the balance condition are incorporated in the machine design, these shall be highlighted.

9.3 Vibration measurement equipment

Details of all equipment used for the vibration measurements shall be recorded. Transducers used shall be clearly documented, showing their type, serial numbers, sensitivities, calibration dates, locations and orientations.

9.4 Results

9.4.1 Measurement units

All data provided shall be presented with their measurement units, e.g.:

a) vibration peak-to-peak displacement — micrometres (μm);

NOTE Sometimes the displacement amplitude (zero to peak) is presented.

b) vibration root mean sqaure (r.m.s.) velocity — millimetres per second (mm/s);

c) correction mass — grams (g) or kilograms (kg);

d) correction mass radius — millimetres (mm) or metres (m).

9.4.2 Correction masses

The complete configuration of each correction mass shall be presented, giving:

a) axial location along the shaft;

b) radial location;

c) magnitude of the installed correction mass;

d) angle relative to the phase reference position.

These data can be presented in either a pictorial or tabular form, as appropriate, identifying any existing masses, where these are present. Mass data for the final configuration shall always be provided; but with complex balancing exercises, where a number of runs took place, it may be appropriate to present the correction mass configurations for each run, subject to agreement between the supplier and the customer.

The phase angle convention (lead or lag) for the attachment of the correction masses shall be defined.

9.4.3 Tabular data: Vibration results and correction mass configurations

Vibration measurements for the initial run and at least the final run shall be presented in tabular form. This shall include the overall magnitude of the vibration and its once-per-revolution magnitude and phase at each measurement location. This shall be provided at the normal operating speed and at any other speed where the vibration is of concern, normally while passing through resonance speeds. With complex balancing exercises, where a number of runs are required, it may be appropriate to present all the vibration data together with correction mass configurations for each run, subject to agreement between the supplier and the customer.

The phase angle convention (lead or lag) for the attachment of the correction masses and for vibration vectors shall be defined.

9.4.4 Graphical data

9.4.4.1 Vibration vector changes

Depending on the size and type of machine (see Table 1), polar plots, showing the vector changes from the initial to the final balancing run of the once-per-revolution vibration, in magnitude and phase may complement the tabular data for each relevant measurement position. Where multiple balancing runs are used, progressive vector changes may be appropriate, subject to agreement between the supplier and the customer. For constant-speed machines, the vibration vector changes (from the initial to final balance runs) at the normal operating speed shall be shown. However, if other speeds are important, such as passing through shaft resonance speeds, it may be necessary to include these vector changes as well.

Influence coefficients may be required in special circumstances, subject to agreement between the supplier and the customer.

9.4.4.2 Vibration signatures

Wherever possible, pre- and post-balancing data showing the once-per-revolution vibration, in magnitude and phase, should be included for relevant measurement locations over the full operating envelope, run up, loading, steady-state, and run down. In addition, it is normally necessary to present the overall vibration magnitude to confirm that the reduction in the once-per-revolution magnitude has been sufficient to ensure that the overall acceptance criteria have been satisfied.

9.5 Text information

9.5.1 General

The quantity of descriptive text required for the reporting should be minimal, but sufficient to explain the data presented.

9.5.2 Discussion

A discussion shall be included to explain and summarize the steps taken to add the correction masses and highlight significant events that took place during the balancing runs.

9.5.3 Conclusion

Significant results shall be stated and the post-balancing results compared to the appropriate acceptance criteria.

9.5.4 Recommendations

Any recommended actions resulting from the *in-situ* balancing shall be highlighted.

Annex A
(normative)

Precautions and safeguards for specific machine types during *in-situ* balancing

It is not possible to define all safety precautions associated with operating rotating machines for *in-situ* balancing, however, some key considerations that shall be taken into account are highlighted in Table A.1 for specific machine types.

Table A.1 — Precautions for specific machine types

Machine type	Examples	Considerations
Turbines	Steam and gas turbines	Before a turbine shaft is stopped to add correction masses or establish phase signal references, it shall be confirmed that the correct procedures are undertaken to prevent bending of the shaft. This normally involves barring for a period of time to reduce the shaft temperature. The rotor life can be related to the number of machine starts and this needs to be taken into account in relation to the starts required for the *in-situ* balancing runs.
Electric motors	Motors for large fans	Some electric motors have restrictions on the number of starts per hour and this shall not be exceeded. Electric motors can run from zero to full speed with no intermediate control. Trial masses shall be of a size that does not cause damage to the machine, even if placed in the wrong position.
Pumps	Main boiler feed pumps	Some pumps need to be full of fluid for their safe operation and *in-situ* balancing runs are not generally an exception.
Large fans	Large induced and forced draft fans	During the *in-situ* balancing runs, the flow induced by the fan shall be correctly accommodated; e.g. dampers may need to be shut and this can place the fan under stall conditions. Fans can be delivering hot or hazardous fluids and personnel shall not be allowed to enter the fan to add correction masses until conditions are safe.
Electrical generators	Large hydrogen-cooled electrical generators driven by steam or gas turbines	The considerations related to the turbines apply also to the generators. For easy access to the internal *in-situ* correction planes, it may be necessary to run the generator in air instead of hydrogen. However, most generators have restrictions on the maximum running speed and duration of the in air runs, even at no-voltage and no-load. These restrictions shall not be exceeded. It shall be established that the seal oil system provides adequate lubrication of the gland seals when the generator is running in air. For easy access to the internal *in-situ* correction planes, it may be necessary to dismantle some of the internal baffling of the cooling circuit. The effect on generator cooling and cleanness shall be taken into account when making such modifications.

Annex B
(informative)

Example of an *in-situ* balancing report for a boiler fan ≤1 MW

		Ref:
		Date:
To:	**Mr J Smith** **Station Manager, Power Station X**	
Prepared by:	**Mr D Brown** **Z Balancing Services Ltd**	
Approved by:	**Mr S Daves** **Turbine Generator Group Manager**	
Subject:	**Power Station X, Unit 2** **2A “PA” (primary air) boiler fan** ***In-situ* balancing, YYYY-MM-DD**	
Conclusion:		
The *in-situ* balancing of unit 2A PA boiler fan was successful in reducing the vibration magnitude to within zone B of ISO 10816-3, group 2, rigid foundations.		
Copies to:	**Power Station X**	
		Task number:
		Number of pages: 4
		Number of tables: 4
		Number of figures: 1

Background

Unit 2A PA fan has had a history of blade tip erosion, leading to debris accumulating inside the blade section. The fan has now been cleaned and the blade tips repaired and balancing is required to correct for unbalance introduced by this work.

Objective

To reduce the vibration magnitudes, as measured on the pedestals, to values that are suitable for continuous long-term operation.

Instrumentation

Portable instrumentation was used to undertake this balancing, with a single transducer being used for all locations.

Vibration transducers

Manufacturer	Type	Serial number	Sensitivity	Calibration date	Location (if applicable)	Orientation

Phase reference transducers

Manufacturer	Type	Serial number	Location	Orientation

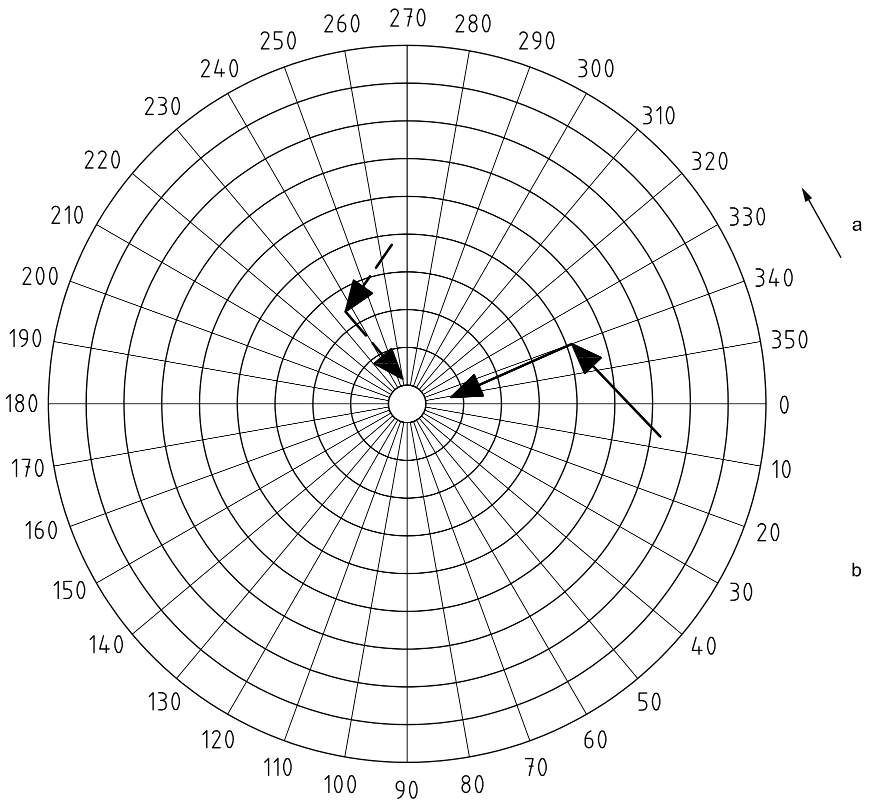
Analysis system

Manufacturer	Type	Serial number	Date of last calibration

Results — Vibration data from the balancing of 2A PA fan

Date	Time	Speed	Non-drive end pedestal						Drive end pedestal						Correction mass	
			Vertical			Horizontal			Vertical			Horizontal			Mass at centre span 0,7 m radius	
			Overall	First shaft order		Overall	First shaft order		Overall	First shaft order		Overall	First shaft order			
		r/min	mm/s (r.m.s.)	mm/s (r.m.s.)	Phase lag degrees	mm/s (r.m.s.)	mm/s (r.m.s.)	Phase lag degrees	mm/s (r.m.s.)	mm/s (r.m.s.)	Phase lag degrees	mm/s (r.m.s.)	mm/s (r.m.s.)	Phase lag degrees	kg	Phase lag degrees
2002-01-10	20:05	600	13,5	13,3	8	8,9	8,7	264	12,9	12,6	9	8,1	7,9	264	—	—
2002-01-10	21:50	600	9,3	9,2	343	7,2	7,0	236	9,1	9,0	340	6,3	6,1	235	3	220
2002-01-10	23:30	600	2,4	2,3	7	1,8	1,6	265	1,7	1,6	11	1,0	0,9	262	5	180

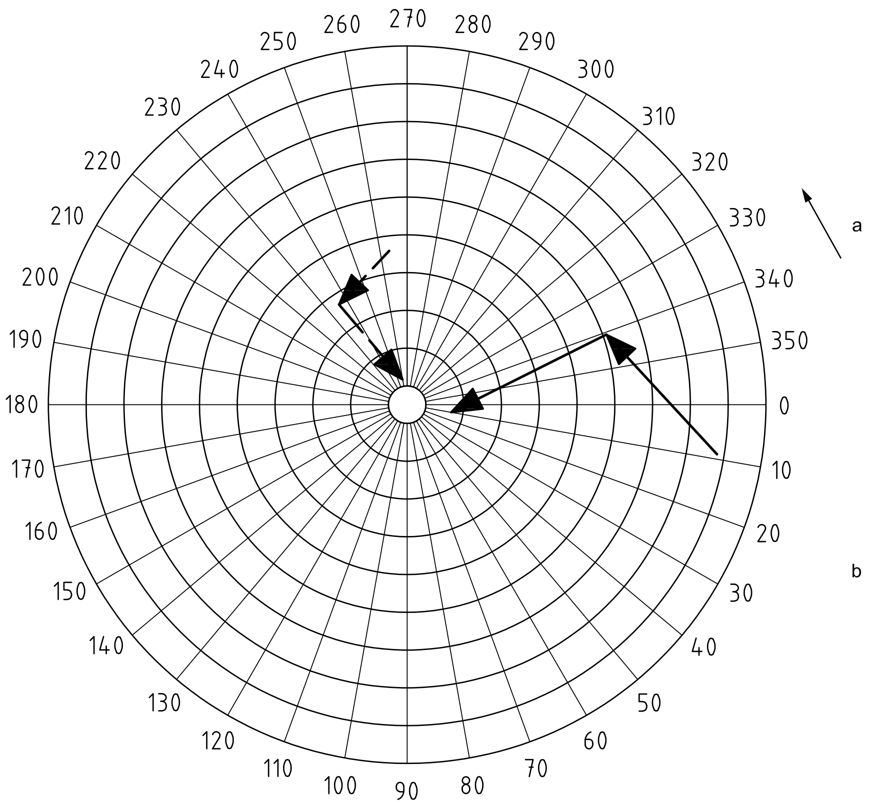
The phase reference signal and horizontal vibration transducers were measured in the same direction.



Key

drive end vertical (solid arrow)

drive end horizontal (dashed arrow)



Key

non-drive end vertical (solid arrow)

non-drive end horizontal (dashed arrow)

The maximum radius is 15 mm/s (r.m.s.).

Graphical presentations are not generally necessary for fans of this size. Vectors show the progressive changes from the datum run, the first run and on to the final run.

[a] Rotation.

[b] Angle (phase lag).

Drive end and non-drive end pedestal vibrations

Annex C
(informative)

Example of an *in-situ* balancing report for a large >50 MW turbine generator set

		Ref:
		Date:
To:	**Mr J Smith** **Station Manager, Power Station X**	
Prepared by:	**Mr D Brown** **Z Balancing Services Ltd**	
Approved by:	**Mr S Daves** **Turbine Generator Group Manager**	
Subject:	**Power Station X, Unit 2** **Turbine generator set** ***In-situ* balancing following return to service, YYYY-MM-DD**	
Conclusion:		

The *in-situ* balancing was successfully carried out reducing the vibration magnitude on the LP pedestal bearings to within zone B of ISO 10816-2.

Copies to:	**Power Station X**		
		Task number:	
		Number of pages:	6
		Number of tables:	3
		Number of figures:	3

Background

Unit 2 turbine generator set at Power Station X returned from a major overhaul. During the overhaul, the LP (low-pressure) rotors had work carried out on their last stage blades. Although these rotors were low-speed balanced, higher than acceptable vibration magnitudes were measured on the bearings supporting the LP rotors. Such behaviour is common on this class of machine and is normally attributed to concentricity errors associated with an unsupported dumbbell shaft joining the two LP rotors. An *in-situ* balance exercise was requested to correct for the unbalance introduced by this concentricity error.

Objective

To reduce the vibration magnitudes, as measured on the pedestals, to values that are suitable for continuous long-term operation at normal operating speed. Vibration magnitudes while passing through system resonances under transient speed conditions should also remain within acceptable limits.

Machine details

The 350 MW, 3 000 r/min machine comprises an HP (high-pressure turbine), IP (intermediate-pressure turbine) and two LPs (low-pressure turbines) coupled to a hydrogen-cooled generator and an exciter. The bearings monitored during the return to service were:

Bearing number	Machine position as seen from the high-pressure turbine
4	IP rear (between IP and LP1)
5	LP1 forward (between IP and LP1)
6	LP1 rear (between LP1 and LP2)
7	LP2 forward (between LP1 and LP2)
8	LP2 rear (between LP2 and generator)
9	Generator forward (between LP2 and generator)

Instrumentation

Vibration data from temporary installed velocity transducers were analysed and stored using a portable data collector. This provided both real time and archive facilities, giving the overall magnitude of vibration and the once-per-revolution magnitude and phase.

A permanently installed shaft reference was used, which is installed at the exciter in a horizontal direction on the right hand of the machine, looking from the HP end. The direction of rotation is counterclockwise looking from the same end.

Analyser type: _______________ Analyser serial number:________________ Date of last calibration:______________

Vibration transducers

Channel	Manufacturer	Type	Serial number	Sensitivity	Calibration date	Location Bearing No.	Orientation[a]
1						4	Vertical
2						4	Horizontal
3						5	Vertical
4						5	Horizontal
5						6	Vertical
6						6	Horizontal
7						7	Vertical
8						7	Horizontal
9						8	Vertical
10						8	Horizontal
11						9	Vertical
12						9	Horizontal

[a] Horizontal is at the half joint on the right-hand side of the machine as viewed from the HP end and the phase reference transducer is in this same direction. The vertical position is on the top of the bearing.

Phase reference transducer

Manufacturer	Type	Serial number	Location	Orientation
			Adjacent to the exciter bearing	Horizontal

Results

Correction masses

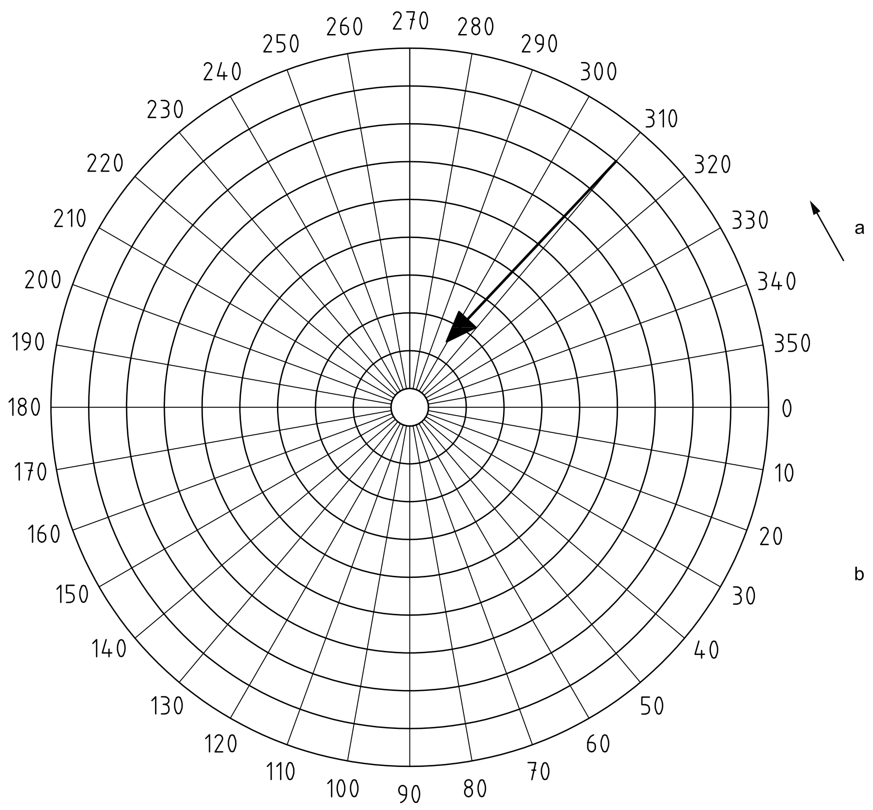
The final correction mass configuration was 0,6 kg at a 300 mm radius on the bearing 6 end dumbbell coupling and 2 kg at a 300 mm radius on the bearing 7 end, both at zero phase relative to the shaft marker. No previous correction masses were found.

NOTE Only sample results are presented for this example, not the complete set as would be expected in the full report.

Tabular data

Date	Time	Condition	Speed	Bearing 7					
				Vertical			Horizontal		
				Overall	First shaft order		Overall	First shaft order	
			r/min	mm/s (r.m.s.)	mm/s (r.m.s.)	Phase lag degrees	mm/s (r.m.s.)	mm/s (r.m.s.)	Phase lag degrees
2002-01-10	20:05	Initial	3 000	14,0	13,7	310			
2002-01-11	8:50	Final	3 000	3,7	3,3	302			

Vector changes



Key

⟶ bearing 7, vertical

The maximum radius is 15 mm/s (r.m.s.).

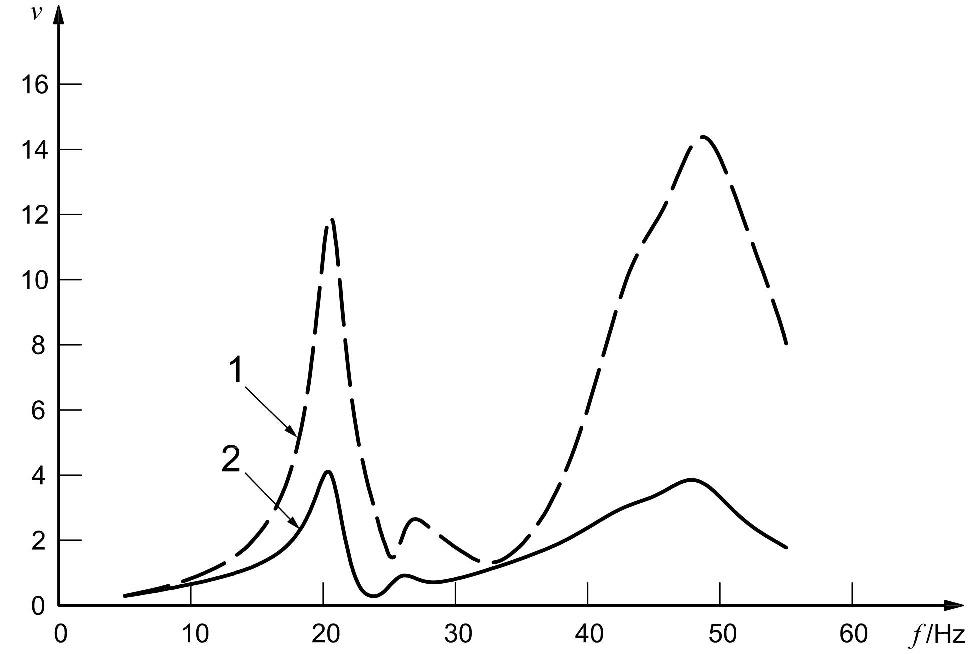
[a] Rotation.

[b] Angle (phase lag).

Vibration vector change for bearing 7, vertical

Vibration signatures

In some circumstances, it may be necessary to show changes in vibration during a full loading cycle, including the run up, rise to full operational load at normal operational speed and the subsequent run down. Here only the run down is presented.



Key

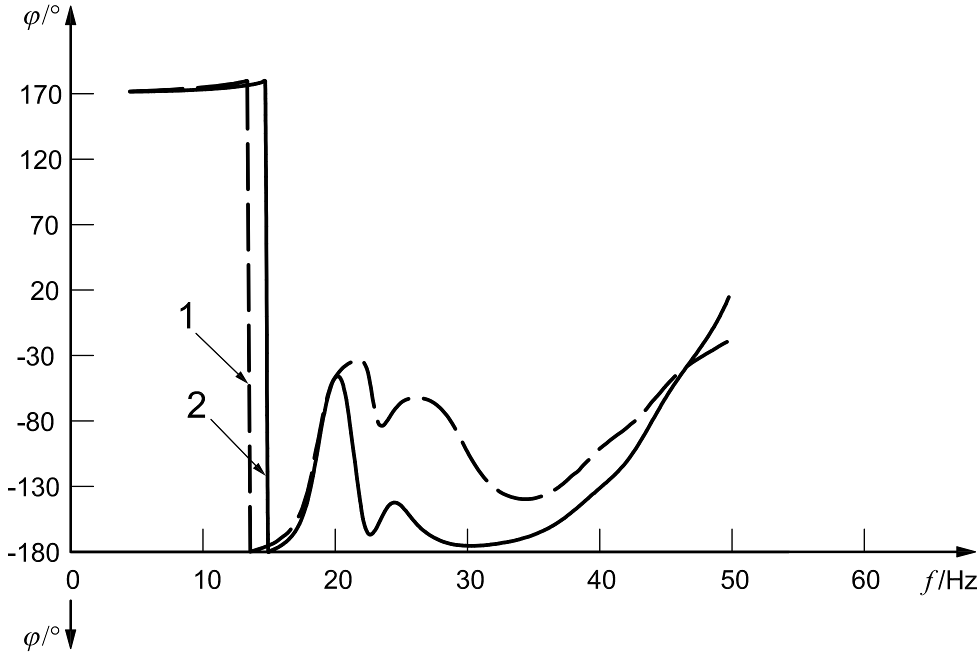
f frequency

v magnitude, mm/s (r.m.s.)

1 unbalanced

2 balanced

Vibration magnitude during run down from bearing 7, vertical



Key

f frequency

φ phase

1 unbalanced

2 balanced

Vibration phase during run down from bearing 7, vertical

Discussion

The key problem of this machine was the high magnitudes of vibration during run down at around 1 200 r/min (20 Hz) and 2 880 r/min (48 Hz). The *in-situ* balancing successfully reduced the magnitude of vibration at both these peaks and at the normal operating speed of 3 000 r/min (50 Hz).

Bibliography

[1] ISO 13373-1:2002, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*

ICS 21.120.40

Price based on 23 pages