INTERNATIONAL STANDARD

ISO 13373-5

First edition
2020-06

Condition monitoring and diagnostics of machines — Vibration condition monitoring —

Part 5:
Diagnostic techniques for fans and blowers

Surveillance et diagnostic d'état des machines — Surveillance des vibrations —

Partie 5: Techniques de diagnostic pour ventilateurs et souffleurs

Reference number
ISO 13373-5:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document 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*.

A list of all parts in the ISO 13373 series can be found on the ISO website.

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

This document defines the procedures to be considered when carrying out vibration diagnostics of fans and blowers. It is intended to be used by vibration practitioners, engineers and technicians and it provides them with useful diagnostic tools. These tools include the use of diagnostic flow charts, process tables and fault tables. The material contained in this document presents the most basic, logical and intelligent steps that should be taken when diagnosing problems associated with these particular types of machines.

The ISO 7919 (rotating shafts), ISO 10816 (non-rotating parts) and ISO 20816 (both rotating shafts and non-rotating parts) series of International Standards contain acceptable vibration values and zones for various types and sizes of machines, ranging from new and well-running machines to machines that are in danger of failing.

ISO 13373-1 presents the basic procedures for vibration narrow-band signal analysis. It includes the types of transducers used, their ranges and their recommended locations on various types of machines; on-line and periodic vibration monitoring systems; and potential machinery problems.

ISO 13373-2 includes descriptions of the signal conditioning equipment that is required; time and frequency domain techniques; and the waveforms and signatures that represent the most common machinery operating phenomena or machinery faults that are encountered when performing vibration signature analysis.

ISO 13373-3 provides some procedures to determine the causes of vibration problems common to all types of rotating machines. It includes systematic approaches to characterize vibration effects; the diagnostic tools available; which tools are needed for particular applications; and recommendations on how the tools are to be applied to different machine types and components. However, this does not preclude the use of other diagnostic techniques.

ISO 17359 indicates that diagnostics:

— can be started as a succeeding activity after detection of an anomaly during monitoring; or

— can be executed synchronously with monitoring from the beginning.

This document considers only the former, in which diagnostics are performed after an anomaly has been detected. Moreover, it focuses mainly on the use of flow charts and process tables as diagnostic tools, as well as fault tables, since it is felt that these are the tools that are most appropriate for use by practitioners, engineers and technicians in the field.

The flow-chart and diagnostic process table methodology presents a structured procedure for a person in the field to diagnose a fault and find its cause. This step-by-step procedure aims at guiding the practitioner in the vibration diagnostics of the machine anomaly, in order to reach the probable root cause of this anomaly.

The fault tables present a list of the most common faults in machinery, as well as their manifestations in the vibration data. When used with the flow charts, the tables assist with the identification of machinery faults.

When approaching a machinery problem that manifests itself as a high or erratic vibration signal, the diagnosis of the problem should be performed in a well thought out, systematic manner. This document, together with ISO 13373-3, achieves that purpose by providing to the analyst guidance on the selection of the proper measuring tools, the analysis tools and their use, and the step-by-step recommended procedures for the diagnosis of problems associated with various types of fans and blowers.

Condition monitoring and diagnostics of machines — Vibration condition monitoring —

Part 5: Diagnostic techniques for fans and blowers

1 Scope

This document sets out the specific procedures to be considered when carrying out vibration diagnostics of various types of fans and blowers.

This document is intended to be used by condition monitoring practitioners, engineers and technicians and provides a practical, step-by-step, vibration-based approach to fault diagnosis. In addition, it gives a number of examples for a range of machine and component types and their associated fault symptoms.

The approach given in this document is based on established good practice, put together by experienced users, although it is acknowledged that other approaches can exist. Recommended actions for a particular diagnosis depend on individual circumstances, the degree of confidence in the fault diagnosis (e.g. has the same diagnosis been made correctly before for this machine), the experience of the practitioner, the fault type and severity as well as on safety and commercial considerations. It is neither possible nor the aim of this document to recommend actions for all circumstances.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

ISO 13372, *Condition monitoring and diagnostics of machines — Vocabulary*

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

ISO 13373-2, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 2: Processing, analysis and presentation of vibration data*

ISO 13373-3:2015, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 3: Guidelines for vibration diagnosis*

ISO 21940-2, *Mechanical vibration — Rotor balancing — Part 2: Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041, ISO 13372 and ISO 21940-2 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 http://www.electropedia.org/

4 Measurements

4.1 Vibration measurements

Vibration measurements may be obtained using two main categories of transducers:

— non-contacting, e.g. inductive, capacitive and eddy current probes used on rotating shafts; and

— seismic transducers, e.g. accelerometers or velocity transducers used on non-rotating parts, such as bearing housings.

International Standards are available to help assess the vibration severity for the described types of measurement, in particular the ISO 7919, ISO 10816 and ISO 20816 series.

Descriptions of transducer and measurement systems as well as specification of techniques are given in ISO 13373-1 and ISO 13373-2, which shall be considered for appropriate selection.

4.2 Machine operational parameter measurements

Machine operational parameter measurements are operational parameters, e.g. rotational speed, load, fan orientation (vertical or horizontal), mounting configuration (solid or flexible support arrangement) and temperatures, that can have an influence on the machine vibration characteristics and are therefore important to acquire in order to arrive at an appropriate diagnosis. For a given machine, these parameters can be associated with a range of steady-state and transient operating conditions.

5 Initial analysis

An initial analysis shall be performed in accordance with ISO 13373-3:2015, Annex A. This analysis should identify safety concerns, the presence of high vibration and, if so, its vibration severity, past history, effects of operating parameters, consequences of not taking corrective actions and the need for a fan shutdown. Other factors such as mounting configuration, position relative to other rotating machines, building structure, environment, etc. should be considered during an initial analysis. See also ISO 13373-3:2015, Annexes B to D, for common faults such as from installation and bearing defects.

6 Specific analysis of fans and blowers

This document covers vibration diagnosis information for the most common types of fans and blowers. Symptoms of the most prevalent fan and blower defects that cause excessive vibration magnitudes are given in Annex A, which shall be used. This annex does not cover fan or blower vibration from hydrodynamic bearing or rolling element bearing problems, which are addressed in ISO 13373-3:2015, Annexes C and D, respectively.

The systematic procedure used in the ISO 13373 series includes usage of fault tables and a step-by-step methodology of vibration diagnosis of faults. For this document, the fault table for the diagnosis of fans and blowers to be used is given by Table A.1, while the methodology of vibration diagnosis is presented in Annex B. Examples of the use of the fault table and methodology of vibration diagnosis of fans and blowers are given in Annex C.

Different designs of fans are presented in ISO 14694 and ISO 14695, as well as VDI 3839 Part 4. These include coupling driven fans and belt driven fans. In addition, overhung and centrally-hung fans are described. The user is advised to consult these standards for various fan designs.

Annex A
(normative)

Systematic approach to vibration analysis of fans and blowers

A.1 Fault table

The systematic approach to vibration analysis of fans and blowers is given by the fault table in Table A.1. The fault table includes mainly installation faults. For faults regarding fan or blower bearings, see ISO 13373-3:2015, Annexes C and D. Several faults can give similar indications and further investigation would be necessary to distinguish between them.

Table A.1 — Fault table for fans and blowers

Fault	Vibration characteristics	Other descriptors	Comment
Shaft misalignment/ concentricity errors	1x, or 1x and 2x, sometimes 1x and 2x and 3x.	Directional force 180° phase shift across coupling. Offset misalignment tends to produce phase shift across the coupling in the radial direction, while angular misalignment tends to produce the phase shift in the axial direction.	There are two types of misalignment: parallel and angular, and in most cases there would be a combination of the two.
Looseness	Usually a series of peaks at rotational speed and integer harmonics of rotational speed, generally the amplitude of these peaks decreasing with higher harmonic numbers.	Looseness can be at bearings or skid, or anchor bolts. Check for difference in amplitude and/ or phase at the interface to discern position of looseness.	Looseness can be at the bearing housing (sometimes due to the bearing installation), and/or at the pedestal or the skid.
Excessive bearing clearance	1x. With low amplitude harmonics in rolling element bearings.	Directional.	Can be due to wear, in both fluid film and rolling element bearings.
Piping strain	1x	Directional, wave clipping in time waveform.	Piping flanges should match without jacking.
Soft foot	1x, plus 2x line frequency in the electric motor	Soft foot test.	Soft foot is the condition that exists when all feet are not correctly supporting the machine.
Shaft rubbing	Clipping in time waveform, with 1x and multiple harmonics in spectrum. Light rubbing can cause rotating vectors (spiral vibration).		Not commonly observed on fans.
NOTE ODS stands for operational deflection shape.			

Table A.1 *(continued)*

Fault	Vibration characteristics	Other descriptors	Comment
Unbalance	1x	Phase shift across coupling depends on the mode. Cylindrical modes tend to have 0° phase shift across the coupling, while conical modes tend to have 180° phase shift. Usually, 90° phase shift between the horizontal and vertical measurements at the same bearing location.	Unbalance is often due to erosion, or deposits on blades. Overhung fans may require a couple balance, while centre-hung fans can generally be balanced in a single-plane.
Bent shaft	1x similar to unbalance, manifests itself at slow roll speed.	Can cancel with unbalance at particular rotational speeds.	Rarely seen on fans.
Casing distortion	1x, sometimes 2x.	180° phase shift from end to end.	Only important where bearings are integral with the casings.
Resonance	High vibration at a particular frequency.	Resonance testing indicates natural frequency.	Avoid operating close to a resonant frequency e.g. by changing speed, or by changing resonant frequency, e.g. by stiffening machine or adding mass. Sometimes damping can be needed.
Tilting foundation	High 1x vibration levels that cannot be explained by unbalance, misalignment, bent shaft or eccentricity.	Rocking motion in 1x ODS.	ODS study to analyse problem in more depth.
Aerodynamic forces	Blade passing frequency.	Can have high noise.	Usually caused when fan is operating off best efficiency point.
Belt faults	Belt Passing frequency.	Less than 1x.	Typically due to belt wear, misalignment and/or incorrect tension.
Belt resonance	Belt resonance frequency.	Usually less than 1x.	Usually due to lack of belt tension.
Excessive belt tension	1x	Directional.	Similar symptoms to misalignment
Belt pulley eccentricity	Usually directional 1x, sometimes 1x and 2x.	Sometimes visually observed as wobbly motion.	
NOTE ODS stands for operational deflection shape.			

Table A.2 — Observable symptoms of typical faults

Fault type	Elevated vibration signals					Vibration phase, etc.				Other diagnostic discriminating factors		Typical corrective action to be considered
	Sub 1x	1x	2x shaft speed	2x electrical supply	>2x	90° V - H	180° shift at coupling	ODS findings	Time wave clipping	Soft foot test	Other observations	
Shaft misalignment/concentricity errors		●	○		○		●				Phase shift across coupling in axial or radial direction	Align machine
Looseness	○	●	●		●						Locate looseness by vibration - test #2 below	Check source of looseness and remedy – e.g. tighten bolts
Excessive bearing clearance		●	○		○							Repair or replace bearing
Piping strain		●							●		Disconnect pipes - does gap appear? Vibration may be directional	Adjust pipes to fit without jacking
Soft foot		●		○							2x electrical supply frequency indicates distortion of motor stator or frame	Measure clearance and fit shims or packing or as appropriate
Rubbing		●	●		●				●			Identify root cause and rectify it.
Unbalance		●				○					Usually 90 deg phase shift between vertical and horizontal measurements at same bearing location	Check cause, remedy e.g. by cleaning fan blades, re-balance if still required
Bent shaft		●									Axial vibration, phase shift between the bearings	Difficult to balance an overhung rotor with bent shaft
Casing distortion		●	○				●					Relieve distortion

This table is not exhaustive but contains the most prevalent faults associated with fans and blowers.

● indicates symptom almost certain to be seen if fault occurs.

○ indicates symptom may or may not be seen.

Table A.2 *(continued)*

Fault type	Elevated vibration signals					Vibration phase, etc.				Other diagnostic discriminating factors		Typical corrective action to be considered
	Sub 1x	1x	2x shaft speed	2x electrical supply	>2x	90° V - H	180° shift at coupling	ODS findings	Time wave clipping	Soft foot test	Other observations	
Resonance	○	●			○			●			High vibration at a frequency that is NOT an obvious multiple of shaft speed	Change speed, or change natural frequency by changing stiffness or mass
Tilting foundation		●						●			Usually result of uneven isolation and uneven mass distribution or poor soil conditions	Requires civil engineering solution
Skid not level		●						●				Level up skid
Aerodynamic forces			●								May be at blade pass frequency or random	Correct flow, e.g., by changing damper angle
Belt faults	●	○									Belt pass frequency	Replace belt, align, and tension correctly
Belt resonance	●										Belt resonance frequency	Usually resolved by setting to correct tension
Belts too tight	○	●									1x directional	Tension correctly
Belt sheave eccentricity		●	○								1x directional	Correct sheave eccentricity and align
Belt misalignment		●									Axial	Align sheaves

This table is not exhaustive but contains the most prevalent faults associated with fans and blowers.

● indicates symptom almost certain to be seen if fault occurs.

○ indicates symptom may or may not be seen.

A.2 Descriptions of tests related to Table A.2

A.2.1 Soft foot test

Loosen holding down bolts one at a time, checking for gaps opening up under the base and measuring with a feeler gauge if appropriate. Retighten the loose bolt before loosening another bolt. If one or more feet show a gap, it implies that the machine casing has been distorted when tightened down. Filling the gap with the appropriate thickness of shims and then re-tightening is a typical route to correcting this problem.

A.2.2 Looseness location vibration test

Measurements of vibration magnitude and phase are taken at a range of locations, from the bearing housings and machine casing, through the bearing holding down bolts, machine holding down bolts, support frame holding down bolts and skid holding down bolts, looking for the place where the vibration magnitude and/or phase are significantly different at the two sides of the interface. This indicates the location of the looseness.

A.2.3 ODS Test

Measure amplitudes and phase angles at several points to find the operation deflection shapes of the system. Investigate the possible causes for high mobility or high flexibility of the system.

A.3 Descriptions of faults related to Table A.2

A.3.1 Excessive bearing clearance

This refers to several possible situations.

— Journal bearing, where the clearance between the shaft and the bearing is too large (oil gap).

— Rolling element bearing, where the bearing race is loose in the bearing housing.

— Rolling element bearing, where the clearances between the rolling elements and the races is too large, e.g. the wrong specification of bearing was selected, or serious wear has occurred to the races and rolling elements.

Annex B
(informative)

Methodology of vibration diagnosis of faults in fans and blowers

Fans and blowers are amongst the simplest machines. Most fans and blowers are driven either through a coupling or a belt, whilst other fans and blowers are driven by a gearbox.

NOTE Gearbox-related faults are to be covered by ISO 13373-11.

The most common faults for fans and blowers can be categorized into four main types:

a) installation faults,

b) bearing faults,

c) unbalance, and

d) aerodynamic forces.

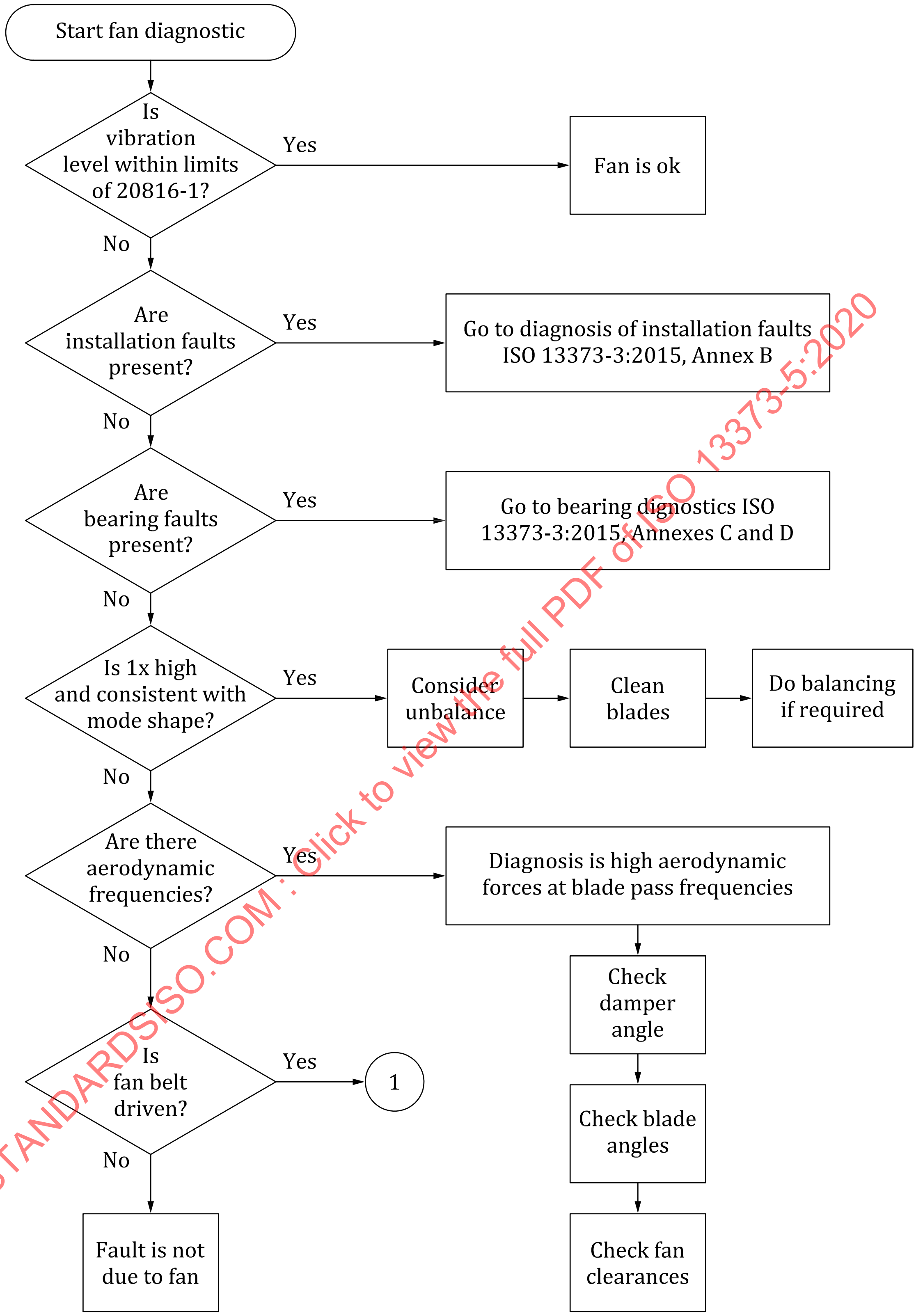
The methodology shown in the flow chart of Figure B.1 guides the user through the steps taken in the diagnosis process. For an installation faults step-by-step methodology, see ISO 13373-3:2015, Annex B, and for a bearing faults step-by-step approach, see ISO 13373-3:2015, Annexes C and D.

In many industries, particularly the cement industry, fans require frequent balancing. Fan unbalance is depicted by high 1x radial vibration and 0° phase across the coupling. Usually, 90° phase shift between the horizontal and vertical measurements at the same bearing location confirms the unbalance condition. Sometimes 1x axial vibration appears in overhung fans due to unbalance. Cleaning fan blades is recommended before balancing. Users should eliminate all other sources of 1x vibration, e.g. misalignment, looseness, bearing clearance, before attempting to balance fans and blowers.

In some machines, a high vibration component at the blade passing frequency (*n*x vibration, where *n* is the number of blades) occurs. This is usually due to aerodynamic forces and is usually attributed to an incorrect air damper positioning. This can be corrected by using a suitable damper angle.

In belt driven fans (see Figure B.2), particular faults occur. Belt faults appear at frequencies less than 1x, and in this case, the belt should be replaced. Belt tension problems can have adverse effects. A low belt tension can cause a belt resonance, usually below 1x, and may be corrected by increasing the belt tension. Excessive belt tension, on the other hand, results in directional 1x vibration, and in this case, belt tension may be corrected to resolve the problem.

In some cases, with belt driven machines, sheave problems occur. Usually, sheave problems appear as a misalignment, and either 1x or 1x and 2x vibration appear in the spectrum. If possible, visual observation can confirm sheave problems.



Key

1 go to Figure B.2

Figure B.1 — Flow chart for the diagnosis of faults in fans and blowers

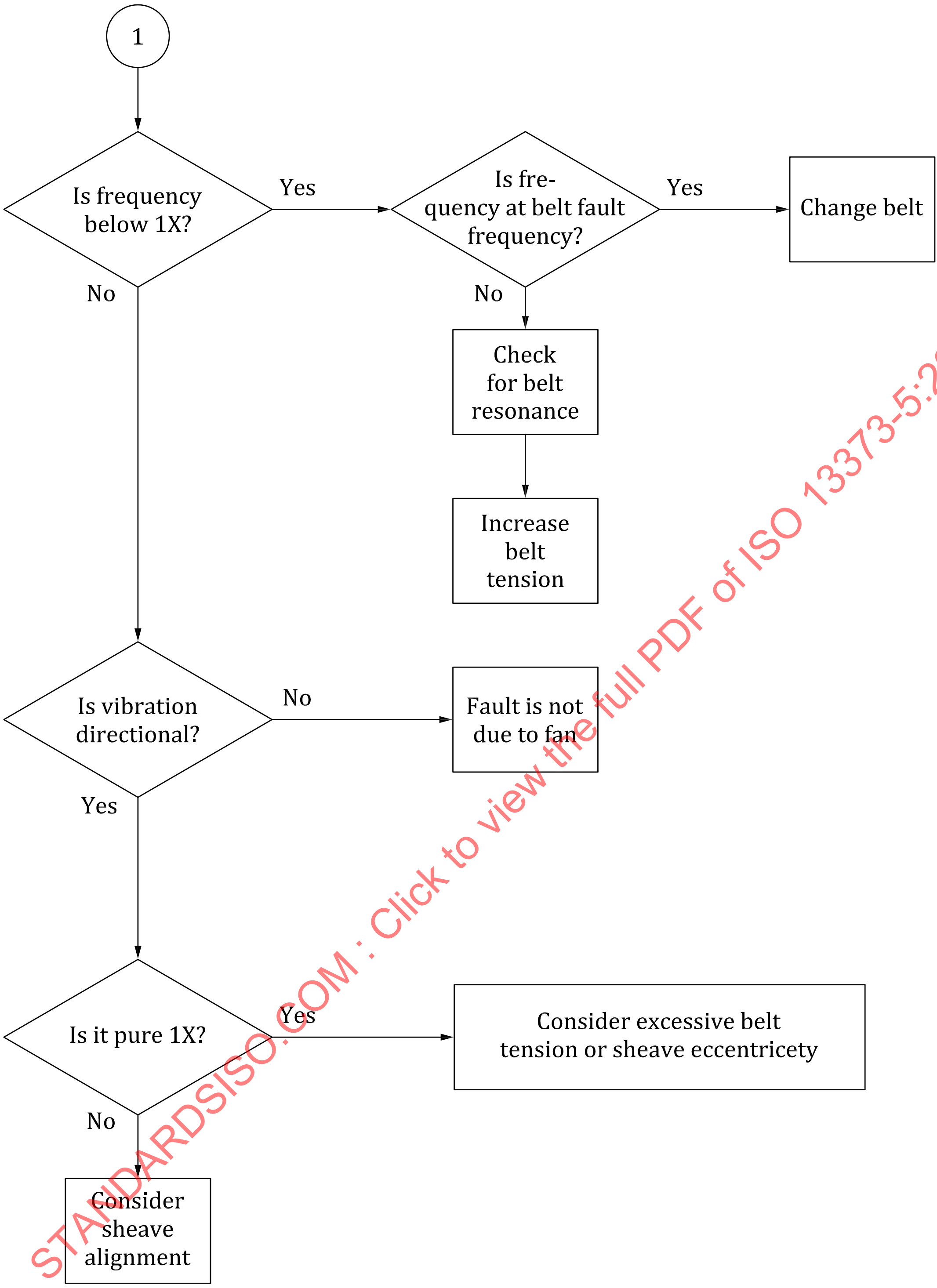


Figure B.2 — Flow chart for the diagnosis of faults in fans and blowers with belt drive

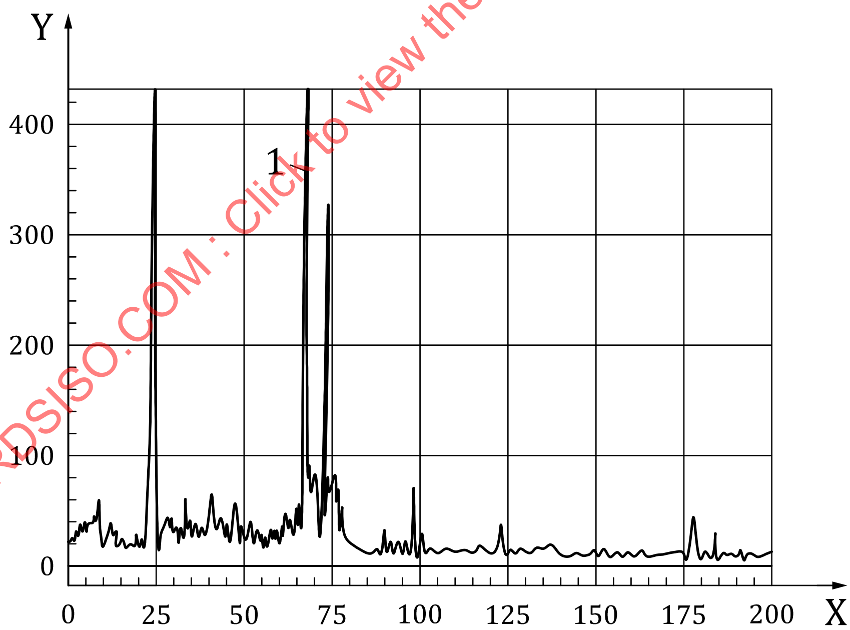
Annex C
(informative)

Examples of vibration problems in fans and blowers

C.1 Example of spectral analysis

The main air blower in a sulphur plant had been experiencing frequent motor bearing failure for the last two years. The 600 kW AC motor operating at 1 500 r/min was mounted on two rolling element bearings. The axial load was taken on the non-drive end angular contact bearing, while the drive end bearing was the one experiencing the frequent failures. Most failures were in the form of a shearing cage. The motor was torn apart several times, but no cause was found for this problem.

Upon investigating this machine, the bearing failure rate was at a rate of once every two to three weeks. Spectral measurement on the machine confirmed that the motor had no malfunction, but the axial vibration was relatively high at the speed of the blower. Figure C.1 shows the spectrum of the motor drive end bearing with high vibration at the speed of the blower. The motor was driving through a flexible coupling and a speed increaser gearbox mounted on journal bearings. The gearbox was driving the blower at 4 000 r/min through a flexible coupling. The blower was overhung and mounted on two journal bearings. A survey of the blower and the gearbox showed a high axial component at both the gearbox and blower bearings at the speed of the blower.



Key

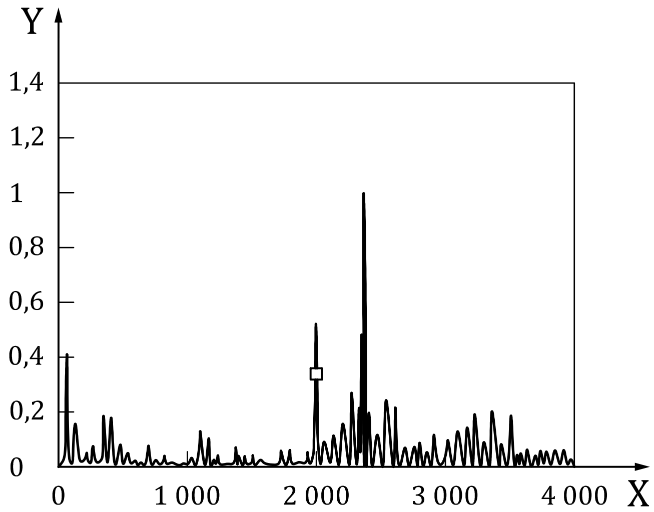
X frequency in Hz

Y axial vibration velocity in µm/s

1 high blower speed component

Figure C.1 — Motor drive end spectrum

Figure C.2 shows a typical spectrum from this blower gearbox. The gearbox showed a high gear mesh frequency of 1 966 Hz and a high twice gear mesh frequency. There is a pronounced series of peaks centred around 2 365 Hz, with sidebands. These have been interpreted as indicating some form of impact, triggering a natural frequency at 2 365 Hz. The highest vibration values were at the vertical and axial directions of the blower bearings with an RMS reading of 5,2 mm/s.



Key

X frequency in Hz

Y axial RMS vibration velocity in mm/s

Figure C.2 — Gearbox spectrum

The diagnosis of this sensitive machine was as follows: the blower is experiencing a couple unbalance producing an axial force that is creating an impact on the gearbox and deteriorating the gear meshing. This axial force is then transmitted to the electric motor causing the bearing failure. The recommendation was to inspect the gearbox, correct any problems and balance the blower.

The gearbox was dismantled; the drive end journal bearing on the gearbox was completely destroyed. The axial thrust collar on the gearbox and on the blower bearings showed clear signs of impact. The blower bearings showed excessive clearance and rubbing on the rotor and bearings.

The gearbox was replaced, the blower bearings and shaft were replaced, and the motor bearings were replaced. The machine showed reduced overall vibration, but balancing was still recommended. The vibration vectors showed the need for a couple correction weight. A trial mass of 10 g was used with this sensitive machine. The final trim balance weight was 3 g. The highest RMS vibration value was reduced to 1,2 mm/s. No motor bearing failures have been reported since.

This case study illustrates the need to clearly identify the cause of vibration from spectral analysis. These problems should be corrected before attempting to balance the machine. The diagnostic procedure in Figure B.1 was followed. No bearing frequencies were identified; however, spectral analysis indicated deterioration of the gearbox, and a clear 1x indicated unbalance in the blower. 1x axial vibration due to unbalance occurs only in overhung machines. This axial vibration was transmitted to the motor, and its presence at the blower speed on the motor drive end was key to the diagnosis of this machine train.

C.2 Example of balancing and ODS analysis

A cement factory had a kiln fan that was experiencing high vibration. The fan had been installed for 12 years, during which time it had experienced one catastrophic failure and a major design modification to overcome its problems. In recent years, the fan had been experiencing high vibration resulting in the need to reduce its speed to reduce the vibration. This adversely affected the production output.

On inspection of the machine, it was found to be a huge 10,5 t overhung fan on rolling element bearings with an impeller of a diameter over 5 m and driven by a 1 600 kW DC motor. The maximum fan speed was 490 r/min. Production required the machine to be operating at 95 % of its maximum speed, but, because of the high vibration, the machine was operating at 82 % of its maximum speed only. The 4 m high foundation showed visible cracks. Vibration measurements on the non-drive end bearing were 290 mm/s, mainly at 1x.

Applying the diagnostic procedure of Figure B.1, no bearing faults were found. Clearly the machine foundation required attention; however, due to production requirements, it was determined to balance the machine. This is unusual, and it was therefore recommended that other problems be resolved before balancing, but in this case the plant had requested a temporary solution, pending the resolution of the problem of the skid and foundation.

Before balancing, it was requested to clean the fan blades, by which the vibration values were reduced to 50 mm/s. A run-up test was performed to try to determine if any resonance conditions occurred and to mitigate any undesirable effects from the skid and foundation. Table C.1 illustrates the results of the run-up test.

Table C.1 — Run-up test on kiln fan

Speed	**Drive end bearing**		**Non-drive end bearing**	
r/min	RMS magnitude mm/s	Phase °	RMS magnitude mm/s	Phase °
284	6,74	–160	7,27	–159
309	3,36	–149	5,67	–144
355	3,52	173	2,72	172
380	3,74	162	5,2	155
415	3,73	140	10,9	135
425	5,8	126	16,5	125
440	10,6	112	31,8	111

From Table C.1, it is clear that the machine is approaching resonance as its speed increases. A computer model was developed and it was determined that resonance occurs at the maximum speed of the machine. The mode shape is shown in Figure C.3. Yet, it was decided to balance the machine. Inspection of the results of the run-up test showed that the machine exhibits vibration that is in phase at both bearings at nearly all speeds, even though it exhibits a conical mode at resonance.

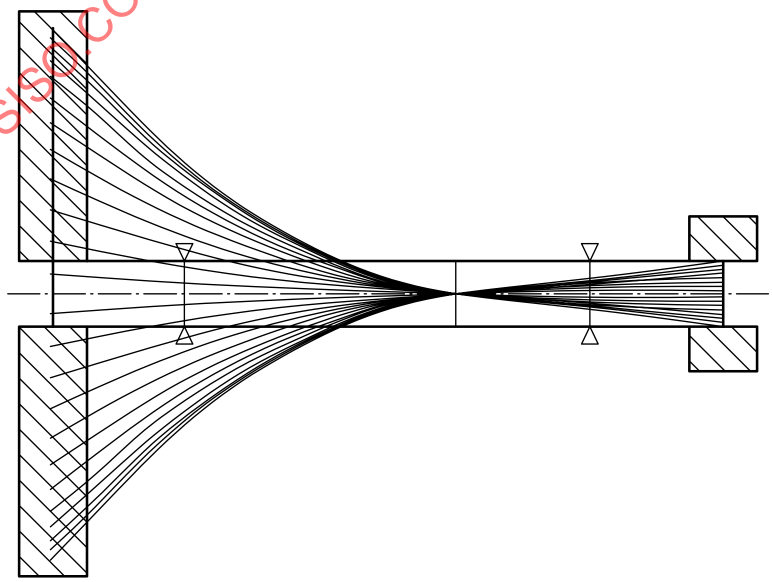
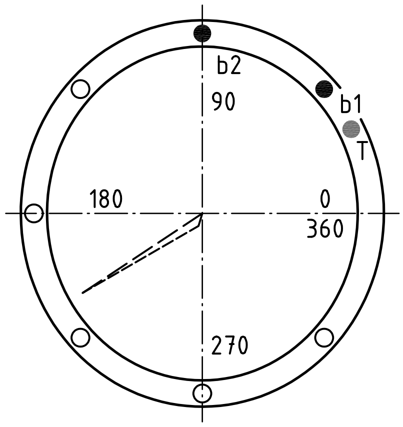


Figure C.3 — Mode shape of the fan

It was decided that the machine only needed static balancing because of the in-phase measurement. A trial mass of 2 kg barely made the machine respond but was used to obtain the balance sensitivity. The machine was finally balanced by a 6,1 kg correction mass, as shown in Figure C.4, after removal of the trial mass. The vibration was reduced to 2,7 mm/s and has been performing satisfactorily since then. With the balanced rotor, production can achieve maximum throughput with no excessive fan vibration. Figure C.5 shows the vibration spectra before and after balancing.



Key

b1, b2	correction masses
T	trial mass

Figure C.4 — Static balancing of the fan