TECHNICAL REPORT

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Machine tool spindles — Evaluation of spindle vibrations by measurements on non-rotating parts —

Part 2: Direct-driven spindles and belt-driven spindles with rolling element bearings operating at speeds between 600 r/min and 30 000 r/min

Broches pour machines-outils — Évaluation des vibrations des broches par mesurage sur les parties non tournantes —

Partie 2: Broches à entraînement direct et broches à entraînement par courroie à roulements à billes opérant à des vitesses entre 600 r/min et 30 000 r/min

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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 on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

A list of all parts in the ISO 17243 series, published under the general title, *Machine tool spindles — Evaluation of spindle vibrations by measurements on spindle housing*, can be found on the ISO website.

Machine tool spindles — Evaluation of spindle vibrations by measurements on non-rotating parts —

Part 2: Direct-driven spindles and belt-driven spindles with rolling element bearings operating at speeds between 600 r/min and 30 000 r/min

1 Scope

This document provides information on how to assess the severity of machine tool spindle vibrations measured on the spindle housing. It gives specific guidance for assessing the severity of vibration measured on the spindle housing at customer sites or at the machine tool manufacturer's test facilities.

Its vibration criteria apply to direct-driven spindles and belt-driven spindles intended for stationary machine tools with nominal operating speeds between 600 r/min and 30 000 r/min.

It is applicable to those spindles of the rolling element bearing types only, to spindles assembled on metal cutting machine tools, and for testing, periodic verification, and continuous monitoring.

It does not address

— geometrical accuracy of axes of rotation (see ISO 230-7),

— unacceptable cutting performance with regards to surface finish and accuracy,

— vibration severity issues of machine tool spindles operating at speeds below 600 r/min or exceeding 30 000 r/min (due to lack of supporting vibration data and limitations in many vibration measurement instruments), or

— frequency domain analyses such as fast Fourier transform (FFT) analyses, envelope analyses or other similar techniques.

Annex A presents an introduction to alternative bearing condition assessment techniques.

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 1925, *Mechanical vibration — Balancing — Vocabulary*

ISO 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925, ISO 2041, ISO 13372, ISO 2954 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

NOTE A concept limited to a special meaning of a term in a particular context is indicated at the beginning of its definition by a subject field between angular brackets (< ... >), e.g. “<spindle condition monitoring>” for the definition of *alert* (3.11).

3.1
belt-driven spindle
spindle where the power transmission is achieved by a belt between the drive motor and the spindle

3.2
direct-driven spindle
machine tool spindle in a motor-coupling-spindle configuration with no belts, gears, or other power transmitting elements in the power train

3.3
gear-driven spindle
machine tool spindle with one or more power transmitting gear units in the power train

Note 1 to entry: Gear-driven spindles may also incorporate coupling and/or belts in the power train.

3.4
spindle with integral drive
spindle unit where the rotor of the drive motor is the rotor of the spindle

3.5
short term
<spindle condition monitoring> time period of six months or shorter

Note 1 to entry: Time periods may differ for specific spindle types and/or operational conditions.

3.6
long term
<spindle condition monitoring> time period of longer than six months

Note 1 to entry: Time period may differ for specific spindle types and/or operational conditions.

3.7
machine condition monitoring
detection, collection, and interpretation of information and data that indicate the *spindle condition* (3.8) of a machine tool spindle

3.8
spindle condition
root-mean-square (r.m.s) values for vibration velocity and acceleration of machine tool spindles as defined by specifications

3.9
short-term spindle condition
STSC
parameter indicating the condition of a machine tool spindle in the *short term* (3.5)

3.10
long-term spindle condition
LTSC
parameter indicating the condition of a machine tool spindle in the *long term* (3.6)

3.11
alert
<spindle condition monitoring> condition where a significant change in spindle vibration magnitude, with respect to normal values, has been detected

3.12
alarm
<spindle condition monitoring> condition where the vibration velocity magnitude [*LTSC* (3.10)] induces increased dynamic load on spindle bearings, thus often reducing bearing lifetime and/or the vibration acceleration [*STSC* (3.9)] magnitude indicates moderate spindle bearing deterioration

3.13
threshold for shutdown
<spindle condition monitoring> condition where the vibration velocity magnitude [*LTSC* (3.10)] induces increased dynamic load on spindle bearings, often with substantial loss of bearing lifetime and/or the vibration acceleration [*STSC* (3.9)] magnitude indicates severe spindle bearing deterioration

3.14
steady-state spindle operating temperature
<spindle condition monitoring> condition where machine tool spindle has been running for a sufficient time to reach a stable operating temperature

4 Preliminary operations

4.1 General

When measuring vibration, the operational condition of the machine tool is of great importance. This document is applicable to all normal operational conditions of the machine tool when machining.

For any spindle vibration measurement intended to characterize the spindle condition according to this document, important operational conditions should be recorded. Such operational conditions include, but are not limited to, the characteristics listed in 4.2 to 4.11.

When using vibration measurement results for evaluation of spindle condition, other factors contributing to or interfering with the measured signals should be taken into consideration. Such factors include spindle motor current control signals with their associated frequencies, influences of machine foundation and the position of the other moving components affecting the dynamic response of the overall system, and possible high level of scatter due to low energy content in the frequency range of interest. If such interfering signals or conditions are suspected, frequency analysis techniques can be used to differentiate bearing signals from other contributing factors.

4.2 Process load

All vibration measurements should be made under no-load conditions (no cutting, milling, or grinding).

4.3 Spindle speed

This document is applicable for every speed within the nominal speed range of the machine tool/spindle. The manufacturer may specify non-continuous speed ranges such as 600 r/min to 17 000 r/min or 19 000 r/min to 24 000 r/min in order to avoid unreasonable limits at resonance speeds. Two such resonance speed intervals are allowed, together occupying a maximum of 10 % of the nominal operating speed range of the spindle. The possibility of excluding certain speed ranges only applies to the vibration velocity parameter as defined in 6.1, i.e. indicators for long term spindle condition (LTSC).

The vibration acceleration parameter as defined in 6.2, i.e. indicators for short-term spindle condition (STSC), applies to any speed within the nominal speed range of the spindle.

When measuring vibration magnitude as a function of spindle speed, it is important to execute the spindle speed changes in such a way that a steady-state vibration of the spindle is reached before recording the measurements. The following are typical methods.

— **Step**: Increase or decrease the spindle speed in steps not greater than 3 % of spindle maximum speed with 10 s of constant speed at each such selected speed.

— **Acceleration**: Increase or decrease the spindle speed with a rate of not more than 20 % of maximum spindle speed per minute.

Both the above methods will result in approximately 5 min measurement time.

4.4 Thermal conditions

Thermal conditions will need to be agreed upon between manufacturer/supplier and user. If no conditions are specified, the tests should be made under conditions as near as possible to those of normal operation with regards to lubrication and warm-up. Therefore, the machine should have an idle running performance in accordance with the conditions of use and the instructions of the manufacturer until the machine/spindle has reached steady-state operating temperature. Refer to ISO 230-1 for the installation of the machine before testing and warming up of the spindle and other moving components.

4.5 Spindle position and orientation

Spindle position: This document is applicable for all possible linear axis positions.

Spindle orientation: This document is applicable for all possible spindle orientations.

Spindle direction of rotation: For spindles that can be operated in either direction, this document applies to both clockwise and counter clockwise spindle rotation.

Spindle position, orientation, and direction of rotation for vibration measurements will need to be agreed upon between manufacturer/supplier and user.

4.6 Tool or workpiece balancing

4.6.1 General

A tool or workpiece mounted in the spindle might influence the vibration measurements due to the unbalance of the tool or workpiece itself. It should be recorded whether or not a tool/workpiece is used during the measurements. If used, the mass, balancing grade according to ISO 21940-11 and angular orientation (if applicable) of tool/workpiece used during vibration measurements should be recorded.

4.6.2 Spindle vibration measurements with a tool/workpiece mounted in the spindle

Care should be taken to avoid errors introduced by the unbalance of the tool/workpiece. For most machine tools/spindles this implies that a balance quality grade of G2.5 or better according to ISO 21940-11:2016 is required. If possible the same tool/workpiece should be used for each measurement of the same machine tool/spindle. If available, refer to the spindle manufacturer's recommendations.

4.6.3 Spindle vibration measurements without tool/workpiece

Spindles that can be operated throughout their entire operating speed range without any tool/workpiece mounted and which do not require tool/workpiece for balance can be measured without a tool/workpiece mounted in the spindle.

4.7 Spindle chuck

Spindle chuck mechanical settings — such as chuck front-end position with respect to spindle gauge line for clamped and unclamped positions — as well as jaw positions, should be recorded.

4.8 Spindle cooling

The spindle cooling system settings should be set appropriately and the performance confirmed. All settings should be recorded.

4.9 Drawbar

The drawbar status should be recorded as tool clamped, tool unclamped, or tool improperly clamped. It is recommended that all spindle vibration measurements be performed with tool clamped or without tool. Refer to 4.6.

4.10 Background vibration

If the measured vibration magnitude is greater than an acceptance criterion established by mutual agreement between the manufacturer/supplier and user, and background vibration is suspected, measurements should be made with the machine shut down to determine the degree of external influence. If the vibration magnitude with the machine shut down exceeds 10 % of the value measured when the machine is running, corrective action might be necessary to reduce the effect of background vibration.

NOTE In some cases, the effect of background vibration can be nullified by spectrum analysis or by eliminating the offending external source.

4.11 Idle operation

It can be beneficial to conduct vibration measurements with the spindle idle but other machine tool systems, such as pumps, fans, and hydraulic systems, active. Vibration data acquired this way can be useful when comparing spindle vibration changes over time.

Idle spindle vibration measurements should be taken at the same measurement locations/directions as running spindle vibration measurements. Refer to 5.2.

5 Measurement and operational procedures

5.1 Measuring instruments

The measuring instrument should comply with the requirements of ISO 2954 for a specified frequency range of 10 Hz to 10 kHz.

Various methods exist for computing the r.m.s value of a specified frequency band. Refer to ISO 2954:2012, Annex A for further information on how to test the r.m.s indicator of any measuring instrument.

Care should be taken to ensure that the measurements are not influenced by environmental factors or other external factors including, but not limited to, the following:

— temperature variations;

— magnetic fields;

— sound pressure fields;

— sensor cable length;

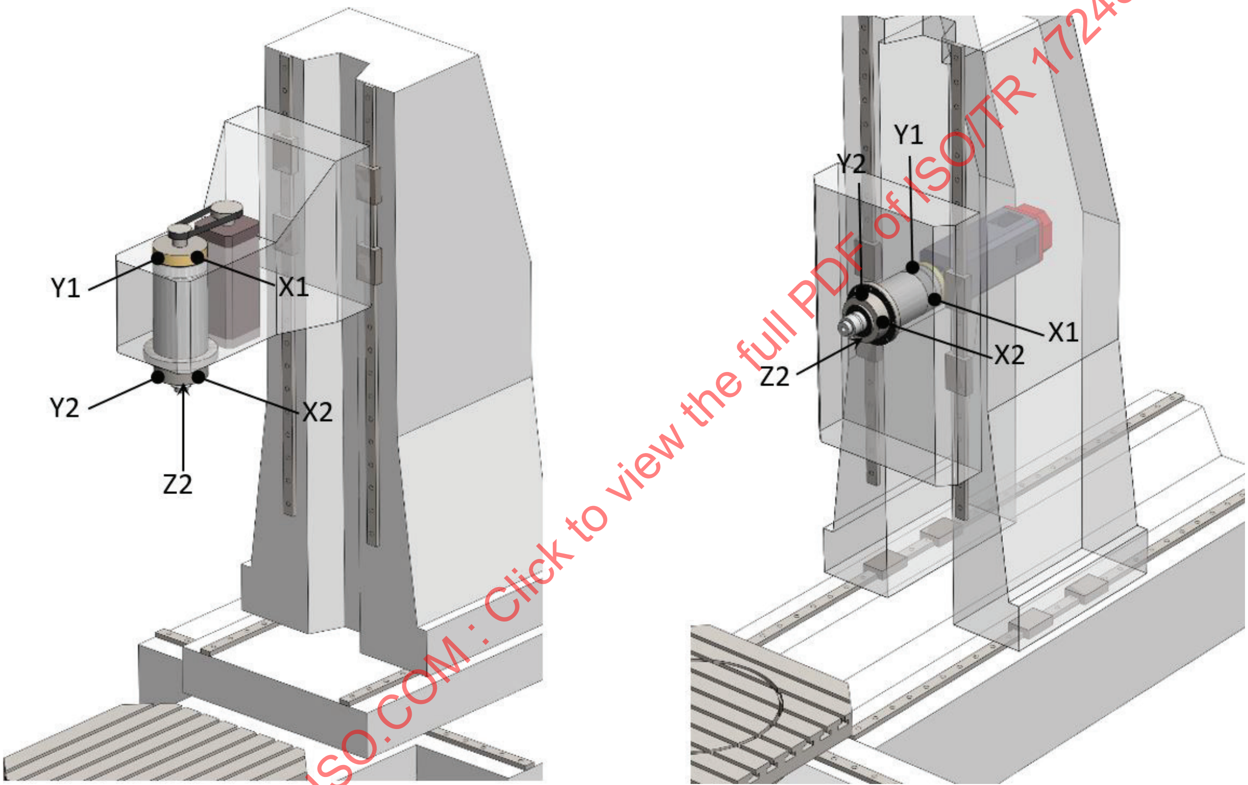
— power supply noise.

Refer to 5.3 for further information on sensor mounting procedures.

5.2 Measurement locations/directions

5.2.1 General

For vibration criteria presented in this document, measurements should be taken on the spindle housing at the front end of the spindle, as well as at the back end. Preferably, sensor longitudinal locations should coincide with spindle bearing longitudinal locations as close as possible. Measurements should be taken in a minimum of two radial directions at both ends of the spindle and in axial direction in at least one end of the spindle (see Figure 1). It is recognized that the back end of the spindle in many cases can be hard to access, requiring dismantling of covers, etc.



Key

X1, X2 preferred radial measurement locations in x-axis direction of the machine

Y1, Y2 preferred radial measurement locations in y-axis direction of the machine

Z2 preferred axial measurement locations in Z-axis direction of the machine

Figure 1 — Examples of preferred measurement locations and possible naming conventions of common machine/spindle configurations

The preferred sensor locations/directions ensure good transmission with low distortion of the vibration signal from the mechanical interface (the bearings) between rotating and non-rotating parts of the machine and hence, ensure low damping with good signal quality.

If, for practical reasons, some of the preferred sensor locations are not deemed possible to access, these sensor locations may be omitted or alternative sensor positions be established by mutual agreement between manufacturer/supplier and user. If alternative sensor locations are selected, the measurement results might be affected.

The two radial measurement directions should be perpendicular to each other and coincide with the movement axes of the machine tool, such as X and Y or any other axes defined by ISO 841. Refer to Figure 1 for examples on common machine types.

For some machine tool designs, other measurement directions might be preferred.

It is recommended that the vibration sensor be placed at the preferred measurement locations of Figure 1. For periodic measurements where the main interest is in observing changes in the vibration related parameters over time, a single tri-axial sensor is a valid solution. In this last case, a fixed threaded installation of the vibration sensor (see 5.3) is suggested to ensure measurement repeatability.

All sensor locations/directions used for vibration measurements should be recorded.

Alternatively, permanently mounted vibration sensors on the spindle housing could be used.

5.2.2 Naming convention for measurement locations

Direct-driven spindles and belt-driven spindles covered by this document are used in many different machine tool types and applications. Therefore, no obvious naming convention exists for assigning names to the measurement locations/directions.

The nomenclature is according to ISO 841 when referring to directions coinciding with movement axes of machine types covered by that International Standard. Possible measurement location names are

— “Spindle front end X”, and

— “Spindle back end Y”

In any case where measurement location/direction names could be misinterpreted, additional data should be supplied (i.e. a simple drawing).

5.3 Sensor mounting procedures

The sensor mounting should be as rigid as possible, ensuring that the mounting procedure does not influence the measured value in any significant way. Proper care should be taken to minimize any sensor mounting resonances and signal saturation.

For acceptance testing of new or overhauled machine tools or spindles, chemical bonding or threaded sensor mounting is recommended since these mounting procedures will ensure best possible measurement results for all parameters defined in this document.

For periodic measurements, sensors mounted on wax or a magnetic base may be considered as a practical alternative procedure.

Table 1 provides an overview of sensor mounting procedures and precautions.

Table 1 — Sensor mounting procedures

Type of mounting	Suitability	Precautions
Threaded	Preferred	Ensure clean, flat mounting surface
Chemical bonding	Preferred	Ensure clean, flat mounting surface
Wax	Possible	Be careful not to use wax on hot surfaces since this will significantly reduce the upper frequency limit of the mounting. Wax mounting might influence the upper frequency limit of the measurements even when used on normal temperature surfaces.
Magnetic base	Possible	Always be careful when assessing parameters involving high frequency data when measured with magnetic base mounting. Be careful to use suitable magnetic base type depending on mounting surface type. For curved surfaces, use magnetic base if surface is single-curved and never use magnetic base for double-curved surfaces. Make sure mounting surface is clean. Also, note that magnetic base performance can vary with vibration magnitude.
Hand-held sensor	Not applicable	

Refer to ISO 5348 for further information regarding the mounting of accelerometers.

6 Evaluation parameters

6.1 Vibration velocity parameter

6.1.1 General

The vibration velocity parameter is measured as the broadband vibration magnitude in mm/s r.m.s, typically within the frequency range of 10 Hz to 5 kHz.

The vibration velocity parameter can be used as an indication of long term spindle condition (LTSC).

The vibration velocity is selected because it has been found to reflect long term machine condition in a very consistent manner. It is also the preferred parameter in other machine condition related International Standards such as ISO 10816-3[10] and References [18], [19] and [20].

Even if the LTSC parameter is very low, spindle lifetime can be shortened dramatically by inappropriate working conditions.

The typical frequency range of 10 Hz to 5 kHz ensures that low frequency vibrations from building movements, etc. are removed from the signal but still any unbalance vibration (1 × running speed) from a 600 r/min spindle would be within the selected frequency band. On the high end, the 5 kHz upper frequency limit allows for multiple speed harmonics (as would be produced by, for example, a loosely mounted spindle) on a 30 000 r/min spindle to be reflected in the evaluation parameter. Other frequency ranges can be used and the used frequency range should be recorded.

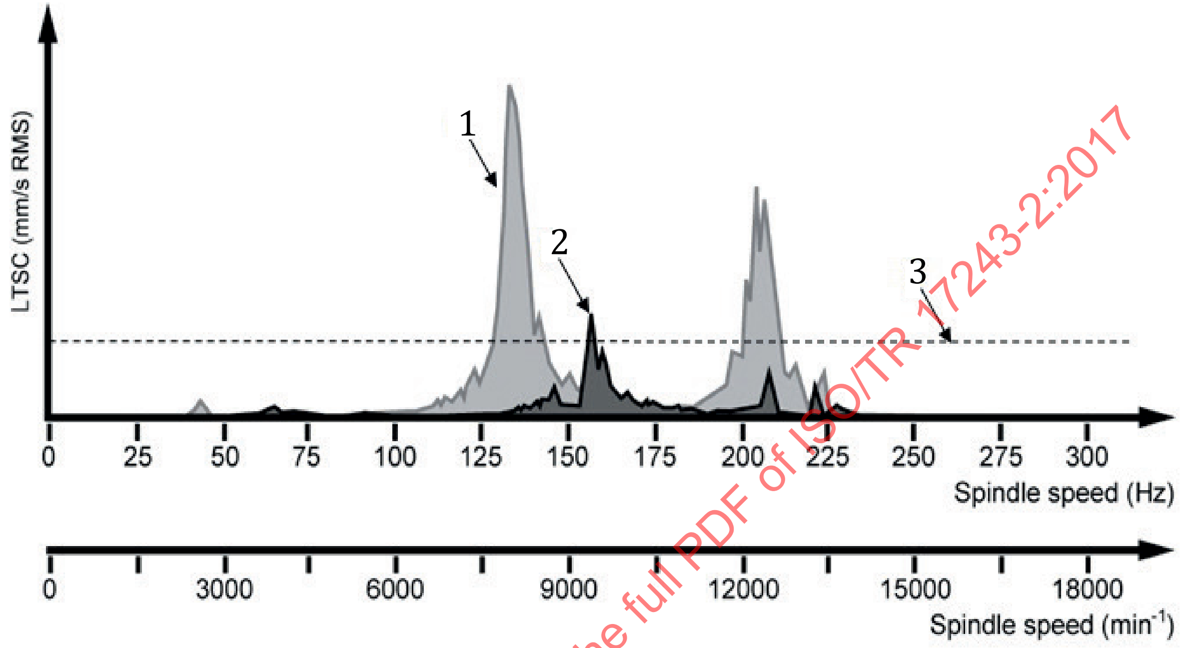
6.1.2 Spindles with maximum speed between 6 000 r/min and 30 000 r/min

For spindles operating at speeds between 6 000 r/min and 30 000 r/min, typically, one or two speed ranges may be excluded with respect to the LTSC parameter. This is due to the fact that most such spindle designs exhibit at least one resonance speed within the nominal operating speed range of the spindle (see Figure 2). Applying the LTSC parameter at the resonance speeds of a spindle might be considered an unrealistic demand leading to costly design changes for new machine tools.

Together, the excluded speed ranges can occupy a maximum of 10 % of the nominal speed range of the spindle. For a spindle with a maximum speed range of 20 000 r/min, the total excluded speed range is therefore, 2 000 r/min distributed on the excluded ranges.

It should be noted that any speed range that the machine tool manufacturer would like to exclude from the LTSC evaluation parameter should be stated beforehand. The user needs this information to evaluate any machine tool involving such a spindle.

If such excluded speed ranges are not specified by the machine tool manufacturer, the spindle should be tested with the assumption that the LTSC parameter applies without exclusions of certain speed ranges.



Key

1 vibration signal (LTSC) which does not comply with the typical 2 × resonance speed range exclusion criteria because the total width of the speed ranges where the vibration magnitude exceeds the evaluation zone limit (above line 3) occupies more than 10 % of the nominal speed range of the spindle

2 vibration signal (LTSC) which do comply with 2 × resonance speed range exclusion criteria

3 evaluation zone limit

Figure 2 — Example of low frequency broad band vibration velocity (LTSC) of 18 000 r/min (300 Hz) spindle

6.1.3 Spindles with maximum operating speed below 6 000 r/min

For spindles with a maximum speed below 6 000 r/min, the LTSC parameter criteria applies without any exclusion of speed ranges.

6.2 Vibration acceleration parameter

The short-term vibration acceleration parameter is intended to reflect problems that might lead to a catastrophic failure of the spindle within a reasonable short time period, in most cases, ranging from days to six months. For spindles covered by this document, the major concern is the spindle bearings. Since rather severe bearing problems are not safely detected by low frequency broadband vibration measurements, the vibration acceleration parameter is measured as broadband vibration magnitude in m/s2 r.m.s; typically within the frequency range of 2 kHz to 10 kHz.

The vibration acceleration quantity is selected because of its sensitivity to very short vibration impulses resulting from damaged rolling element bearings. The stipulated frequency range will suppress low frequency speed harmonics below 2 kHz and is easily measured with most modern instrumentation since the upper frequency limit is 10 kHz. Other frequency ranges may be used and should be recorded.

The vibration acceleration parameter can be used as an indication of short-term spindle condition (STSC).

The vibration acceleration evaluation parameter (STSC) does not offer the possibility of excluding certain speed ranges, whereas the vibration velocity evaluation parameter (LTSC) does offer this possibility.

7 Spindle classification

7.1 General

Spindles covered by this document are divided with respect to the following:

— rated power;

— maximum speed of spindle;

— bearing type.

7.2 Classification according to rated power

Direct-driven spindles and belt-driven spindles are divided into

— spindles with rated power ≤ 5 kW, and

— spindles with rated power > 5 kW.

7.3 Classification according to maximum spindle speed

Four speed ranges are defined, with respect to spindle maximum speed, expressed in r/min:

Speed range 1, sr_1 — $600 < sr_1 \leq 6\,000$;

Speed range 2, sr_2 — $6\,000 < sr_2 \leq 12\,000$;

Speed range 3, sr_3 — $12\,000 < sr_3 \leq 18\,000$;

Speed range 4, sr_4 — $18\,000 < sr_4 \leq 30\,000$.

Spindle speed only affects the vibration evaluation zone boundaries for STSC (vibration acceleration) and does not affect the zone boundaries for the LTSC (vibration velocity).

Classification according to spindle maximum speed is reflected by four speed range classes in the general vibration evaluation zone boundaries, as defined in Figure 3.

7.4 Classification according to bearing type

This document divides direct-driven spindles and belt-driven spindles according to the following bearing types:

— ball bearings (point contact);

— roller bearings (line contact).

Refer to ISO 5593 for further information on different bearing types.

8 Evaluation

8.1 General

8.1.1 Overview

Both LTSC (vibration velocity) and STSC (vibration acceleration) are addressed.

The criteria apply to measurements at the customer's, as well as tests at the manufacturer's, test facilities, with the spindle mounted in the machine tool. They apply to broadband measurements taken on the spindle housing during steady-state operating conditions with no load (no cutting) and within the nominal speed range. Testing, periodic measurements, as well as continuous monitoring when measurements are taken without load are covered.

If measurement results are suspected to be influenced by signals not coming from the spindle itself, an analysis in the frequency domain, e.g. fast Fourier transform (FFT) analysis, envelope analysis, or other similar techniques, is useful. However, these analyses are outside the scope of this document.

The evaluation zones have been established by the extensive experience of several large multinational companies over a period of more than 15 years, covering a significant number of machines.

Numerical values assigned to the zone boundaries defined in Figure 3 are not intended to serve as acceptance specifications, which should be subject to agreement between the machine/spindle manufacturer/supplier and user. However, these values provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided. In certain cases, there might be specific features associated with a particular machine/spindle design which would require different zone boundaries. For example, on low rigidity machine tools or on a long spindle with flange at the rear, higher vibration magnitudes can be measured; considering a given spindle condition. Consequently, the monitoring thresholds could be increased in that case. It is recommended that the manufacturer explain the reasons for different zone boundaries, especially if the zone boundaries are to be set at greater values than those recommended by this document.

8.1.2 Measurement uncertainty

Measurement uncertainty is a combination of the uncertainty of the measuring instruments, the sensor mounting procedure, and electrical and environmental influences. Refer to 5.1 for recommendations regarding measuring instruments, 5.3 for sensor mounting procedures, and Clause 4 for preliminary operations. If such recommendations are considered according to ISO 2954:2012, 5.6, acceptable measurement uncertainty can be obtained with typical uncertainties for the LTSC and STSC not exceeding 10 % of the indicated values.

The stated typical measurement uncertainty is obtainable under the assumption that electrical and environmental factors do not influence the measurements significantly. Refer to 4.1 for information on the influencing factors.

For further information, see ISO/IEC Guide 98-3:2008[14] [15] [16] [17].

8.2 Criterion I: vibration magnitude

8.2.1 General

This criterion defines limits for acceptable vibration magnitudes measured on the spindle bearings. The maximum vibration magnitude observed at each measuring location/direction is assessed against the evaluation zone boundaries for the relevant machine class. When determining vibration magnitudes, extraneous factors influencing the measurements mentioned in 4.1 should be taken into consideration.

8.2.2 Evaluation zones

The evaluation zones are defined to permit a qualitative assessment of the vibration of a given spindle and provide guidelines on possible actions:

Zone A	newly commissioned machine tools/spindles;
Zone B	normal operating conditions, unrestricted long term operation;
Zone C	increased vibration magnitudes, not suitable for long term operation;
Zone D	unacceptable vibration magnitudes, critical condition.

8.2.3 Exemplary evaluation zone boundaries

The values for the zone boundaries which are given in 8.5 are based on the maximum broadband vibration values of velocity and acceleration, respectively, when measured in directions as specified in 5.2. Therefore, the higher of each of the values measured, in each measurement plane, should be used.

8.3 Criterion II: change in vibration magnitude

This criterion provides an assessment of a change in vibration magnitude from a previously established reference value. A significant change in broadband vibration magnitude might occur which requires some actions even though zone C of criterion I has not been reached. Such changes can be instantaneous or progressive with time and can indicate incipient damage or some other irregularity. Criterion II is specified on the basis of the change in the broadband vibration magnitude occurring under steady-state operating conditions.

When criterion II is applied, the vibration measurements being compared should be taken at the same sensor location and orientation and under approximately the same machine/spindle operating conditions. Obvious changes in the normal vibration magnitudes, regardless of their total amount, should be investigated so that a dangerous situation can be avoided. When an increase or decrease in vibration magnitude exceeds 25 % of the upper value of zone B as defined in 8.5, such changes should be considered significant, particularly if they are sudden. Diagnostic investigation should then be initiated to ascertain the reason for the change and to determine what further actions are appropriate. Such diagnostic investigation can include vibration signal spectrum analysis (FFT), specific bearing condition analysis methods (Hilbert transformation of vibration signal) or geometric tests according to ISO 230-7.

8.4 General zone boundaries

Zone boundaries are subject to agreement between the machine manufacturer/supplier and user. The numerical values assigned to the zone boundaries (see Figure 3) in 8.5 are examples only and can serve as guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided.

Normally, the upper value assigned to zone A would be a reasonable acceptance value for a new or overhauled machine/spindle.

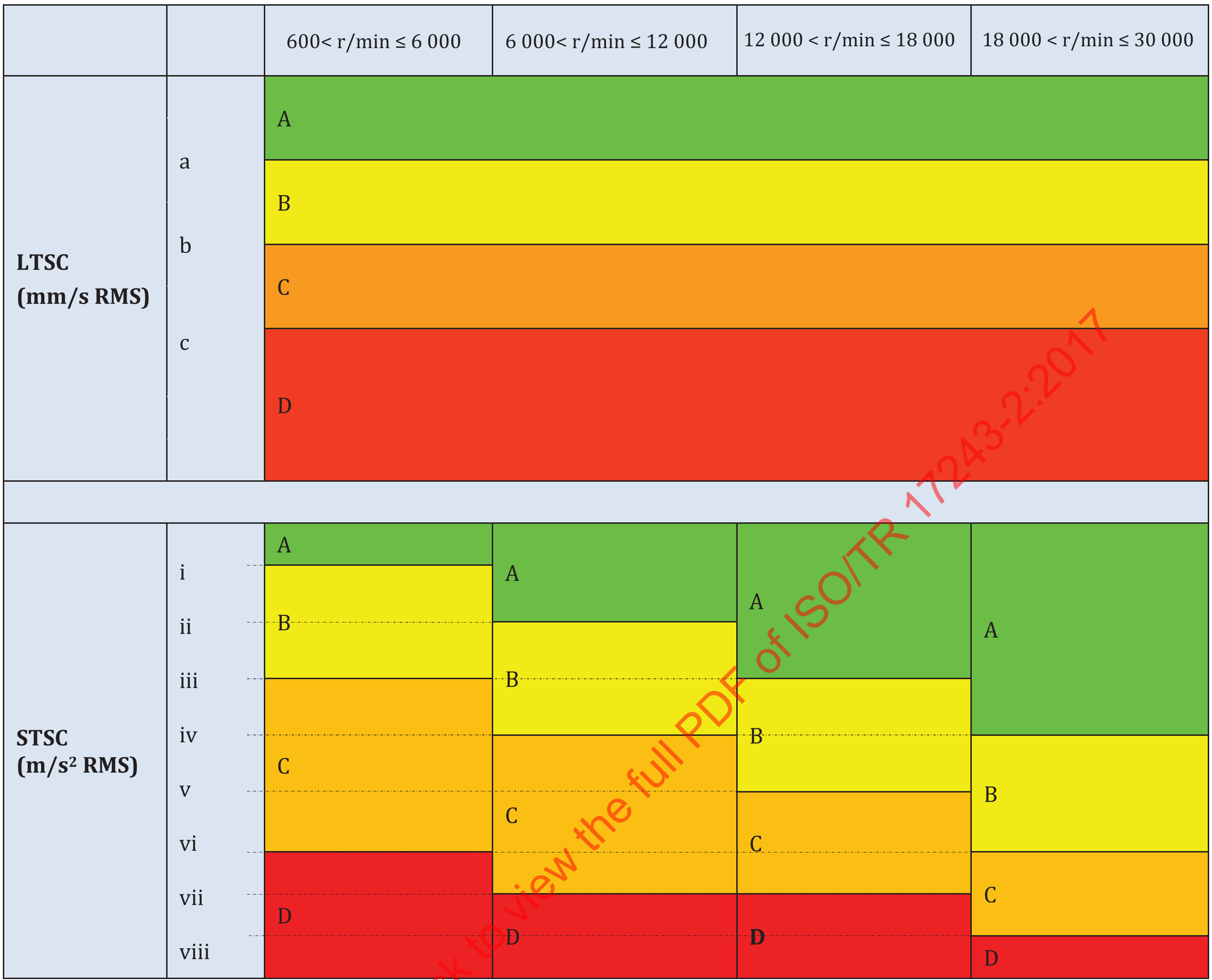


Figure 3 — General zone boundaries

8.5 Examples of evaluation zone boundary values

Table 2 shows examples of zone boundary values for typical spindle classes.

Numerical values assigned to the zone boundaries defined in Figure 3 are not intended to serve as acceptance specifications, which should be subject to agreement between the machine/spindle manufacturer/supplier and user (customer). However, these values provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided. In certain cases, there can be specific features associated with a particular machine/spindle design which would require different zone boundaries. Normally, it is necessary for the machine/spindle manufacturer to explain the reasons for different zone boundaries, especially if the zone boundaries are to be set at greater values than recommended by this document.

Table 2 — Examples of evaluation zone boundary values

Zone boundary	Unit	Spindle classification			
		Rated power ≤ 5 kW ball bearing (point contact)	Rated power > 5 kW ball bearing (point contact)	Rated power ≤ 5 kW roller bearing (line contact)	Rated power > 5 kW roller bearing (line contact)
a	mm/s r.m.s	0,9	0,9	0,9	0,9
b	mm/s r.m.s	1,4	1,8	1,4	1,8
c	mm/s r.m.s	2,3	3,6	2,3	3,6
i	m/s^2 r.m.s	6	6	8	8
ii	m/s^2 r.m.s	10	10	13	13
iii	m/s^2 r.m.s	15	15	20	20
iv	m/s^2 r.m.s	20	20	26	26
v	m/s^2 r.m.s	25	25	32	32
vi	m/s^2 r.m.s	30	30	39	39
vii	m/s^2 r.m.s	40	40	52	52
viii	m/s^2 r.m.s	50	50	65	65

8.6 Operational limits

8.6.1 General

Operational limits for the vibration magnitudes given here refer solely to the condition of the machine tool spindle. Refer to ISO 230-7 for information on vibration issues related to work piece quality and spindle error motion.

8.6.2 Setting of alerts

The *alert* values aim to indicate a change of broadband vibration magnitude irrespective of spindle classification. For specific spindles it is true that they might exhibit extremely low broadband vibration magnitudes. In these cases, the general recommendation for setting the *alarm* values could generate values exceeding three times the spindle baseline values. In such cases, the broadband vibration magnitudes could change very significantly without violating the alarm values.

For these reasons, the alert value is introduced. Typically, the alert value can be set to 1,4 to 2,0 times established baseline value depending on baseline fluctuation over time.

Although not covered in this document, it should be noted that for certain machine/spindle types, vibration magnitudes exceeding the alert value might induce detrimental effects on work piece quality. This is especially true for grinding machines.

8.6.3 Setting of alarms

The alarm values may vary considerably, up or down, for specific spindles. The values will normally be set relative to a baseline value determined from experience for the measurement position and direction for that particular machine type.

It is recommended that the alarm value be set higher than the baseline by an amount equal to 25 % of the upper limit for zone B. If the baseline is low, the alarm value may be below zone C. See ISO 20816-1 and ISO 10816-3.

If there is no established baseline (e.g. with a new machine), the initial alarm setting should be based either on experience with similar machines or relative to agreed acceptance values. After a period of time, the steady-state baseline will be established and the alarm setting should be adjusted accordingly.

