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Milling cutters for high speed machining — Safety requirements

Fraises pour usinage à grande vitesse — Prescriptions de sécurité

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15641 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 29, *Small tools*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this standard, read "...this European Standard..." to mean "...this International Standard...".

Annexes A and B of this International Standard are for information only.

Contents

Foreword

The text of EN ISO 15641:2001 has been prepared by Technical Committee CEN/TC 143 "Machine tools – Safety", the secretariat of which is held by SNV, in collaboration with Technical Committee ISO/TC 29 "Small tools".

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2002, and conflicting national standards shall be withdrawn at the latest by March 2002.

The annexes A and B are informative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

This standard is intended to assist designers, manufacturers and suppliers of milling cutters to satisfy their obligations in respect of high speed machining applications. It defines requirements for design, confirmation testing and information for use that manufacturers and suppliers are to provide.

The prime objective is to ensure that milling cutters, employed for high speed machining, will be able to safely withstand the quadratic increase in centrifugal force resulting from their application at increased rotational speed.

It is based upon a collaborative German research project established to investigate the suitability of milling cutters for use in high speed machining operations.

This standard deals only with the tool and is not sufficient alone to ensure the safety. The safety of machinery is dealt with by other specific safety standards.

This standard takes account of cutting conditions only by requiring the manufacturer to provide application information.

Informative annex A provides guidance for reduction of hazards by design and informative annex B explains the scope limits.

1 Scope

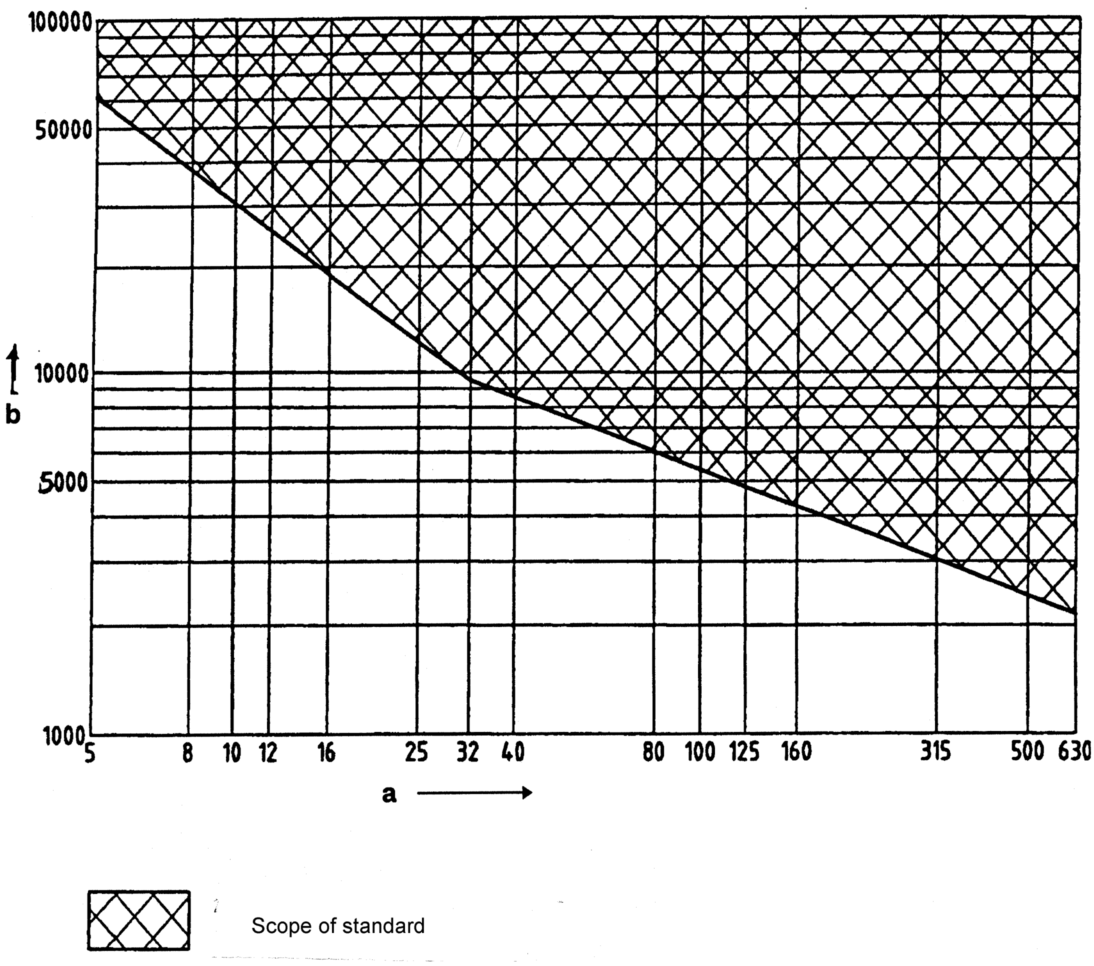
This standard deals with the principle hazards arising from use of milling cutters, e.g. milling cutters according to ISO 3855, used for high speed machining (chip removal machining at increased peripheral speeds) on metal working machine tools and prescribes safety requirements.

It specifies design methods, centrifugal force test procedures, operational limits and the provision of information that will lead to minimisation or elimination of these hazards.

The standard is applicable to milling cutters which are intended for operation at speeds in accordance with figures 1 and 2.

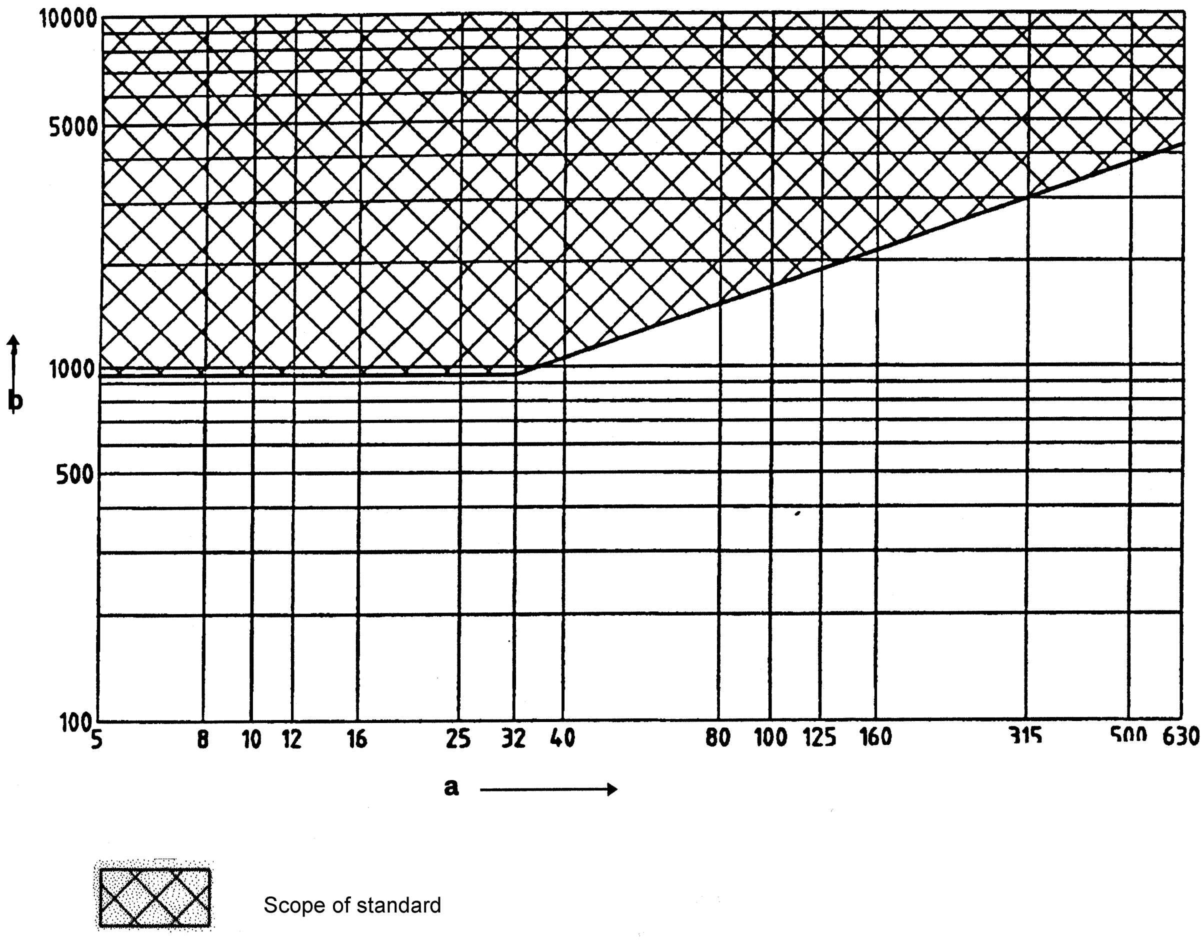
These figures respectively define the rotational speed limits and peripheral speed limits for specific cutter diameters.

NOTE A detailed explanation is provided in annex B.



a Maximum diameter of tool *D* in mm
b Rotational speed *n* in min^{-1}

Figure 1 - Rotational speed *n* vs maximum diameter of tool *D*



a Maximum diameter of tool *D* in mm

b Velocity at *D* (speed v_D at maximum diameter of tool D) in $\frac{m}{min}$

Figure 2 - Velocity at *D* (speed v_D) vs maximum diameter of tool *D*

2 Normative references

This European Standard incorporates by dated or undated reference provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 1070
Safety of machinery – Terminology

ISO 1940-1:1986
Mechanical vibration – Balance quality requirements of rigid rotors – Part 1: Determination of permissible residual unbalance

ISO 3002-1
Basic quantities in cutting and grinding – Part 1: Geometry of the active part of cutting tools – General terms, reference systems, tool and working angles, chip breakers

ISO 3855
Milling cutters – Nomenclature

3 Terms and definitions

For the purposes of this standard the terms and definitions given in EN 1070, ISO 3002-1 and the following apply:

3.1 Tool classification terms

3.1.1
solid or one-piece cutter
milling cutter which has no detachable parts. Its body and cutting part or parts are one piece.

3.1.2
composite cutter
milling cutter in which the cutting part or parts (e.g. tips) are attached to the body by material bonding (e.g. by brazing).

3.1.3
complex cutter
milling cutter in which one or more parts (e.g. indexable inserts, cartridges, clamping elements) are attached to the body by mechanical fastening (e.g. key bolt, screw bolt or clamp bolt fixing which operate by friction lock or form lock principles).

3.2 Types of fixing

3.2.1
bonding
securing of cutter parts with material bonding such as brazing, welding or gluing.

3.2.2
separable
securing of cutter parts by detachable fastening(s). Examples are friction lock and form lock fixings, or a combination of these, which can be mounted and detached repeatedly.

3.2.3
friction lock
means of securing cutter parts where friction force prevents the movement of parts in use.

3.2.4
form lock
means of securing cutter parts where the shape and arrangement of parts prevents their movement in use.

3.3 Terms for the designation of geometric parameters

3.3.1
maximum diameter of tool *D*
maximum diameter of the circle created by cutter rotation. See *D* in figures 3, 4 and 5.

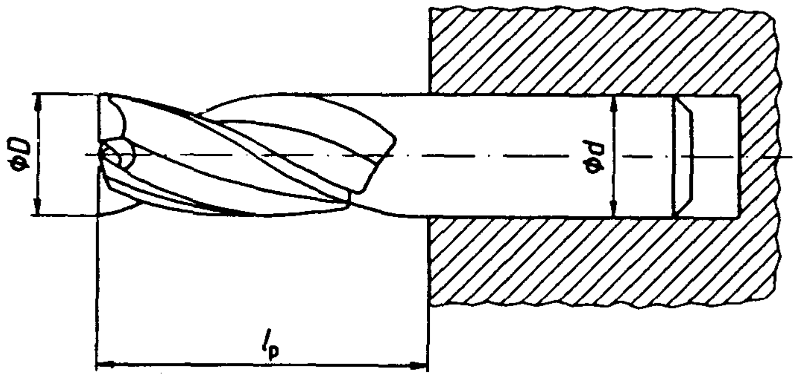


Figure 3 - Example for solid, one-piece or composite cutter

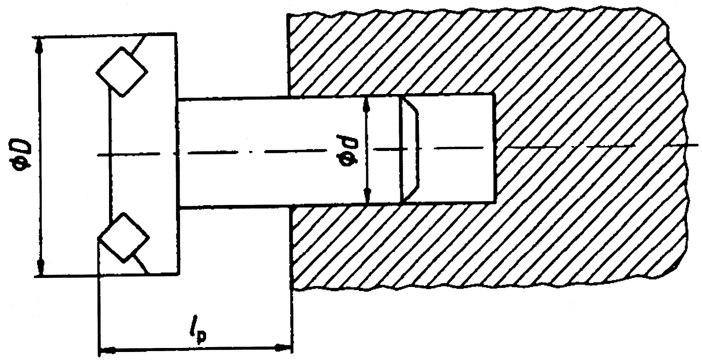


Figure 4 - Example for complex cutter

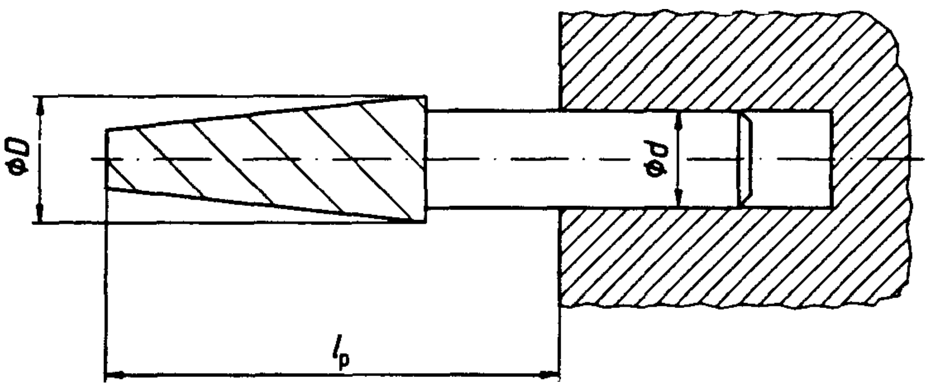


Figure 5 - Example for tapered solid, one-piece or composite cutter

3.3.2
critical diameter *d* for bending
diameter exposed to greatest stress of bending due to centrifugal and cutting forces. See *d* in figures 3, 4 and 5.

3.3.3
protruding tool length l_p
free accessible length of a mounted cutter measured along its axis of rotation. See l_p in figures 3, 4 and 5.

3.4 Terms for the designation of mechanical parameters

3.4.1
mass of milling cutter m_w
mass of a completely mounted and ready-to-use milling cutter.

3.4.2
component masses m_t
masses of component parts of a complex milling cutter.

3.5 Terms for the designation of load parameters

3.5.1
maximum rotational speed n_{max}
maximum rotational speed indicated by the manufacturer for a specific milling cutter.

3.5.2
rotational speed for test
speed determined by multiplying n_{max} by the rotational speed safety factor used for speed testing.

4 Hazards

4.1 Effects which generate hazards

4.1.1 Primary hazards

When milling cutters are applied at high peripheral speeds, the forces associated with normal machining are exceeded by the squared increase in centrifugal force due to the high rotational speeds employed. Other forces, for example: through the acceleration of the cutter to working speed, clamping at the drive end, prestressing forces in complex cutters and fluid forces from air or cooling liquids have also to be considered. The centrifugal force will usually be the primary load and the high levels of energy applied leads to high structural loads which can, in the extreme, burst the cutter.

High levels of rotational energy are contained within milling cutters when they are applied at high peripheral cutting speed. In the event of cutter failure, this energy is likely to be released. The released component masses will move, in the rotational or translatory directions, away from their original axis of rotation at high velocities and with unpredictable trajectories. Their energies can only be dissipated through single or multiple collisions or deformation of machine parts in their motion paths.

Dependant upon the mode of cutter failure, the released energy can be sufficient to destroy and penetrate machine parts. This may lead to serious injury of persons at or near the machine. It is inconceivable that operating personnel will be able to stop the machine or to leave the danger zone, in time to avoid such injury, because of the dynamics of these high speed machining operations.

4.1.2 Handling hazards

Hazards for operating personnel also arise from the handling of milling cutters as may be necessary both before and after their use in machining operations (e.g. transport, assembly, mounting/dismounting, clamping at the machine spindle) (see clause 7).

4.2 Modes of cutter failure

Failure of milling cutters, used at high peripheral speeds, can be attributed to the following fundamental causes:

4.2.1 Body failure

Deformation or bursting of the milling cutter body as a result of structural overload. This can result from:

– Long protruding cutters which fail due to cutting forces, centrifugal forces or by unbalance. The mounting of such long protruding cutters is critical since the introduction of eccentricity can lead to failure at substantially reduced rotational speed due to out-of-balance forces.

– Short protruding cutters which fail when stresses due to the centrifugal force exceed the ultimate strength of the cutter body material.

4.2.2 Failure of cutting element fixing

In complex cutters the connection between the body and the cutting element (e.g. indexable insert or cartridge) fails due to centrifugal and/or cutting forces causing structural overload (e. g. by deformation or fracture).

4.2.3 Failure of cutting element

Structural overload of the cutting element due to centrifugal and/or cutting forces.

5 Safety requirements and/or measures

5.1 Providing safety by design

Milling cutters, intended for application at high peripheral speeds, shall be designed such that they can withstand the centrifugal forces generated in use. The rotational speed safety factor shall be two (2) which provides a four to one (4 : 1) centrifugal force safety factor or 1,6 in accordance with the requirements of 5.4.3.

As far as tools with geometrical similarity within product lines are concerned, calculation is permissible if the results are sufficiently assured by centrifugal force type testing of at least one tool from that product line.

Verification: By calculation and/or centrifugal force type testing.

5.2 Importance of balance

Out-of-balance forces due to eccentricity increase quadratically with increase in rotational speed.

For safety reasons a milling cutter shall have a balance quality grade equal or better than G 40 in accordance with ISO 1940-1 : 1986 at the maximum rotational speed n_{max} (see 3.5.1).

If, for performance (e.g. improved tool life or machined finish), a lower value (e.g. G 6.3, G 2.5) is needed, this is also acceptable for safety.

The graph in figure 6 for the permissible specific residual unbalance U_G* is based on the following formula and has been extended for higher speed level:

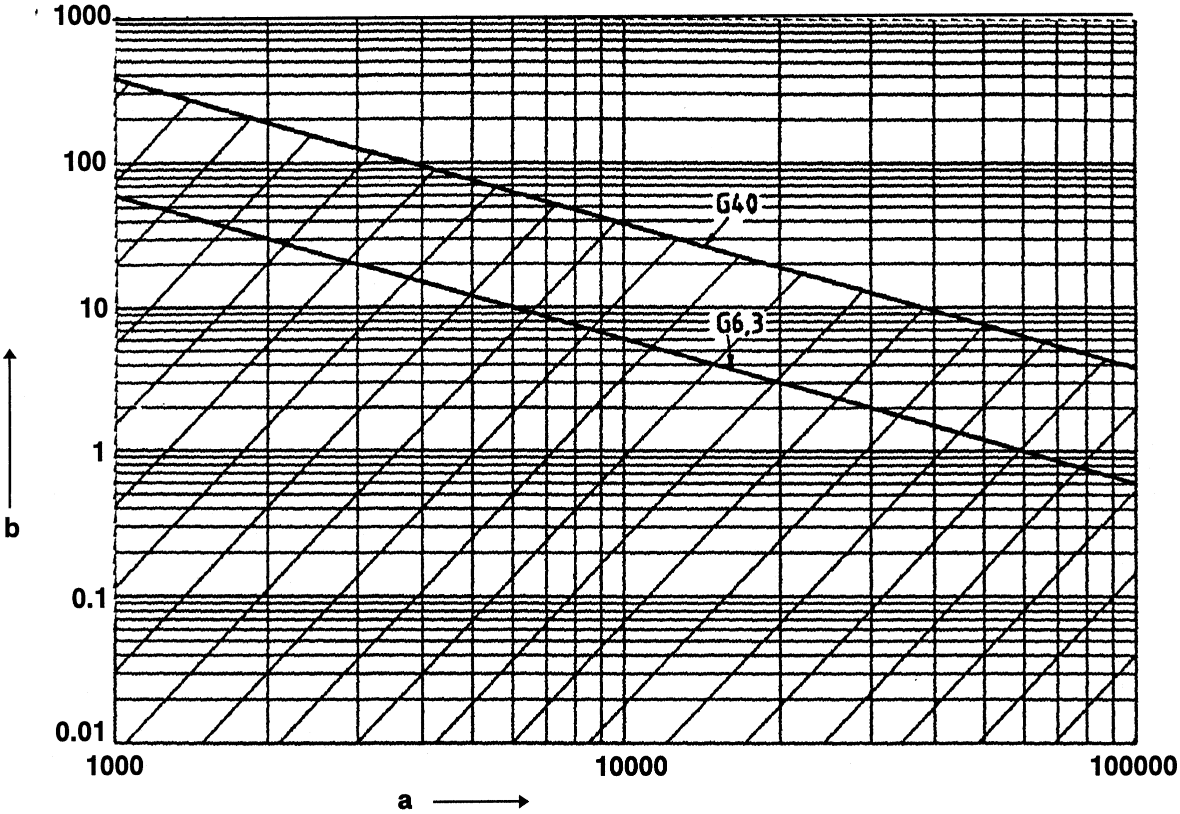
$$U_G^* = 3{,}8197 \bullet 10^5 \bullet \frac{1}{n_{max}}$$ (see annex of ISO 1940-1 : 1986)

where

– n_{max} is the maximum rotational speed in $\min^{-1}$

– U_G* is the permissible specific residual unbalance for milling cutters in $\frac{g \bullet mm}{kg}$ = permissible residual mass centre displacement in µm

Verification: Measuring of milling cutter unbalance.



a n_{max} in min^{-1}

b U_G* in $\frac{mm \bullet g}{kg}$ or µm

Figure 6 - Permissible specific residual unbalance for balance quality grades G 6.3 and G 40

5.3 Integrity of manufacturing

To ensure that milling cutters intended for use at high peripheral speeds can be safety applied their manufacturing shall be of consistent quality and free from physical defects caused by heat treatment or other cracks.

Verification: Manufacturer's quality procedures.

5.4 Centrifugal force type testing

5.4.1 General requirements

To ensure that milling cutters intended for high speed machining can be safely applied, centrifugal force type testing shall be performed for each cutter design type.

This type testing also includes:

a) Verification of conformance with design drawings and, if necessary design calculations and

b) Visual inspection, measurement and checking of the assembled condition of the milling cutter.

5.4.2 Testing of solid, one-piece or composite cutters

Solid, one-piece or composite cutters shall be subjected to centrifugal type testing at twice their declared maximum rotational speed without bursting or fracture occurring.

5.4.3 Testing of complex cutters

Complex cutters may be tested in accordance with 5.4.2 but sufficient assurance of resistance to centrifugal force is also demonstrated when a rotational speed for test of 1,6 times the declared maximum rotational speed is reached without bursting or fracture and any permanent deformation or displacement does not exceed 0,05 mm.

5.4.4 Duration of rotational speed for test

The rotational speed for test applied in accordance with 5.4.2 or 5.4.3 shall be sustained for a minimum duration of one minute.

6 Marking of milling cutters

Milling cutters intended for high speed machining shall be clearly, visibly and permanently marked with the following minimum data:

– the maximum rotational speed

and, if possible, with the following minimum data:

– name or trademark of the manufacturer or supplier

– specific code which, in conjunction with the manufacturer's accompanying documentation, enables cutter characteristics to be determined

Verification: Visual inspection of the cutter and examination of the relevant drawings and documentation.

7 Documentation and information for use

The manufacturer shall provide documentation to accompany the cutter. This shall contain or give reference to information for the safe application of the cutter. This information shall include, as a minimum:

– specification of the maximum rotational speed for the cutter n_{max}

– confirmation of the type-test

– specific instructions for correct assembly and dismantling of all component parts

– decoding of the marking on the cutter in clear text

– information for repair and maintenance of the cutter with particular reference to spare parts and parts subject to wear

– information to determine the maximum permitted protruding length for the cutter l_p (see 3.3.3)

– information as to the condition of balance of the cutter

– information as to the correct manner of milling cutter application (is particularly important for safety in high speed machining)

– information for applicable cutting and other exchangeable parts

– information for correct clamping of the tool.

The manufacturer or supplier shall declare in the information for use or sales literature whether the milling cutters have been manufactured in accordance with this standard.

Annex A
(informative)
Indications for design relative to hazards

A.1 Indications for design relative to hazards

In tools for machining by chip removal at increased peripheral speeds the high centrifugal loads, which increase quadratically with the speed, will significantly exceed cutting forces. The design is based upon the maximum rotational speed n_{max} not only with respect to the loads specific to the process but particularly with respect to the structural loads due to centrifugal forces. At any rate, these loads are reached independent of the cutting process when the tools are brought to the rotational speed required for machining.

Based on the forces stated in clause 5, the hazard potentials and modes of failure described, the following essential recommendations should be considered for the design:

A.2 Total tool mass or tool component masses

The mass is entered directly into the calculation of the centrifugal force and thus into the stress load due to centrifugal force of the tools. Therefore:

a) the masses of tools or the component masses of all individual parts should be reduced to the necessary minimum, in particular

b) mass accumulations on large radii should be avoided. This relates in particular to the dimensioning of component masses such as indexable inserts and cartridges as well as to their mounting mechanisms.

A.3 Unbalance

Rotors operated at increased peripheral speeds are highly critical to unbalance. Design measures should therefore be provided to prevent or eliminate unbalances.

a) To prevent unbalances

1) by rotationally symmetrical construction of tools
2) by adopting connecting elements or adjusting and clamping mechanisms which are free from play and repeatedly mountable

b) Design characteristics to eliminate unbalances

1) by specifying suitable planes for unbalance equalization (correction)
2) by devices for unbalance equalization (e. g. surfaces for application and removal of masses, mechanical balancing elements such as peripherally arranged set screws and similar).

A.4 Tool design

a) Choice of material

Tools for machining by chip removal at increased peripheral speeds are primarily loaded by the high stresses due to centrifugal forces. Therefore materials of adequate ductility and crack resistance should be used.

To determine the stress load of the tool, for first approximations analytical models should serve for calculation of the two principal tool types, i.e. shank mounted tool and milling cutter. As the real component geometries are in part widely different from the ideal model due to constructional changes required for functional performance, materials in each individual case should be chosen relative to the diameter with strength parameters which by far exceed the given limiting values.

b) Minimizing excessive stresses

When designing milling tools for high speed machining constructional notches should be avoided, if possible, on account of the excessive stresses generating under load. As this is in many cases incompatible with the required functionality of such tools (e.g. chip space groove, cutting edge area and similar) the minimization of excessive concentration stresses should be taken into account by the appropriate design of notches with generous internal radii.

c) Selection and arrangement of elements of design in consideration of the load

For complex tools design elements should be selected and arranged so that clamping forces are not reduced by centrifugal forces. Form lock fixing should be preferred to friction lock fixing. For non-exchangeable cutting parts material bond fixing has proven successful.

d) Separation points and connecting elements

Connecting elements, adjusting and clamping mechanisms as well as separation points should be reduced to the necessary minimum as they may lead to impairment of the tool.

Annex B
(informative)
Explanatory notes to the scope

The scope of this standard defined in clause 1 follows the mathematical conditions:

$$v_D/A \geq 1 \tag{B.1}$$

A = 958 in m/min

and

$$\frac{n^2 \bullet D}{B} \geq 1 \tag{B.2}$$

$B = 2{,}9 \times 10^9$ in mm/min^2

To be within the scope of this standard both conditions have to be satisfied.

The scope of this standard defined in clause 1 is based on the demand to have a uniform and universal specification for the tools to be considered. To determine the limit curves (see figure 1 and figure 2) an imaginary complex tool with the following design characteristics was taken as a basis:

a) radial mass clamped by friction lock at the maximum diameter of tool

b) clamping with screw M3, property class 8.8, by a central bore in the mass

c) clamped mass m = 0,015 kg

d) coefficient of friction in the parting line μ = 0,1

To calculate the limit curve, those limit speeds were determined from the maximum diameter of tool D at which failure of the friction lock and consequently slipping of the clamped masses will occur. With the specifications laid down above the limit speed is calculated as a function of the diameter as follows:

$$\mu \bullet F_V \geq F_F = m \bullet \frac{D \bullet 10^{-3}}{2} \bullet (2 \bullet \pi \bullet n)^2 \tag{B.3}$$

$$n \leq \sqrt{\frac{\mu \bullet F_V}{2 \bullet m \bullet \pi^2 \bullet D \bullet 10^{-3}}} \tag{B.4}$$

$$n \leq \sqrt{\frac{0{,}1 \bullet 2390}{2 \bullet 0{,}015 \bullet \pi^2 \bullet D \bullet 10^{-3}}} \bullet 60 \tag{B.5}$$

Symbols:

μ = coefficient of friction,

F_V = screw prestressing force in N,

F_F = centrifugal force in N,

m = mass of cutting part in kg,

D = maximum diameter of tool in mm,

n = rotational speed in min^{-1},

v_D = velocity at D in m/min.

With the specifications laid down above the limit speeds are on the safe side. This is confirmed by experimental findings.

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