INTERNATIONAL STANDARD

ISO 16084

First edition
2017-10

Balancing of rotating tools and tool systems

Équilibrage pour outils rotatifs et systèmes d'outillage

Reference number
ISO 16084:2017(E)

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Foreword

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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).

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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 29, *Small tools*.

Introduction

Increasing cutting speeds in combination with higher balancing requirements result in tighter balancing conditions for the tool spindle system (machine tool spindle, clamping device and tool system). Especially balancing tools and tool systems according to ISO 1940-1 are often being intensified by additionally choosing the next better balancing quality (e.g. G 2,5 instead of G 6,3). Not only that this is technically often not necessary and leading to high cost, it also cannot be achieved in many cases.

Unbalance acts as speed-harmonic excitation of the machine structure and the amount of the excited centrifugal force arises from the unbalance and the rotational speed. Another point of consideration in connection with this is the spindle load due to dynamic cutting forces (e.g. caused by the interrupted cut of a milling cutter) which are often remarkably higher than the centrifugal forces caused by demanded permissible residual unbalances.

The balancing quality requirements for rigid rotors stated in ISO 1940-1 (e.g. electromotor rotors, etc.) cannot be applied appropriately to these tool-spindle systems because machine tool spindles, clamping devices and tools show essentially different features:

— machine tool spindles, clamping devices and tools are varying systems (e.g. by tool changes in machining centres);

— due to radial and angular clamping inaccuracies, a repeated tool change within the spindle leads to varying balancing conditions for tool-spindle systems;

— fit tolerances of the individual components (spindle, clamping device and tool) set limits to the balancing process.

In particular, clamping inaccuracies between tool system and machine tool spindle set limits to the repeatability of the balancing conditions. This document, however, does not specify details for the balancing of tool-spindle systems that include the machine tool spindles.

In view of this, procedures have been developed to derive the balancing requirements of rotating tool systems taking all essential parameters into account. The main objective is the limitation of unbalance related machine vibrations and system loads, as well as process interferences.

The above circumstances were the reasons to develop a new approach to specify the requirements for the balancing of rotating tool systems. This document is based on research results gathered at the PTW "Institute of Production Management, Technology and Machine Tools of the Technical University Darmstadt", the GFE "Association for Manufacturing Technology and Development (Gesellschaft für Fertigungstechnologie und Entwicklung e. V.)" in Schmalkalden (Germany) and the discussions of the German standards working group "Requirements for Balancing of Rotating Tool Systems".

Research results and experiences in practice have shown that this document is suitable from both the technical and economical point of view.

Annex A shows several examples for static and dynamic balancing of differently shaped tools while modular tool systems are addressed by the examples of Annex B. Annex A also includes the derivations of the calculations of the dynamic permissible residual unbalances for the three different geometrical situations mentioned in this document.

An introduction to the subject "balancing" is also included in ISO 19499. This document includes useful information with regard to other standards dealing with the balancing of rotors.

EN 847 (all parts) contains additional specifications for the balancing tools for woodworking.

Balancing of rotating tools and tool systems

1 Scope

This document specifies requirements and provides calculations for the permissible static and dynamic residual unbalances of rotating single tools and tool systems. It is based on the guideline that unbalance related centrifugal forces induced by the rotational speed do not harm the spindle bearings, as well as prevent unbalance related impairments of machining processes, tool life and work piece quality.

NOTE 1 Tools and tool systems covered by this document are, for example, those with hollow taper interfaces (HSK) according to ISO 12164-1 and ISO 12164-2, modular taper interface with ball track system according to the ISO 26622 series polygonal taper interface according to the ISO 26623 series, taper 7/24 according to ISO 7388-1, ISO 7388-2, ISO 9270-1 and ISO 9270-2 related to their individual operating speed.

Modular tool systems are another important and complex issue of this document. Calculations and process descriptions for balancing these components and the assembled tool systems are included.

This document is putting an important focus on the possible clamping dislocations of tool shanks and their effects on the balancing procedure. These dislocations can occur between a tool or a tool system and the machine tool spindle (e.g. with every tool change), as well as within a modular tool system during its assembly.

NOTE 2 Unfavourable process or system conditions (e.g. partial resonances of the machine structure generated by particular rotational speeds) or design and machine-related technical conditions (e.g. the projecting length of the axes, narrow space conditions, vibration susceptible devices, clamping devices and tool design) may lead to increased vibration loads and balancing requirements. This is dependent on the individual interaction of the machine and the tool spindle system and cannot be covered by a standard. A deviation from the recommended limit values of this document can be required in individual cases.

NOTE 3 Wear of the shank interfaces may lead to possible variations of the clamping situation and thus to worse run-out and balancing conditions. These errors cannot be specifically addressed in a standard.

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*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925 and the following 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/

NOTE The specific field of balancing requires the introduction of terms and definitions which are not in accordance with ISO 13399.

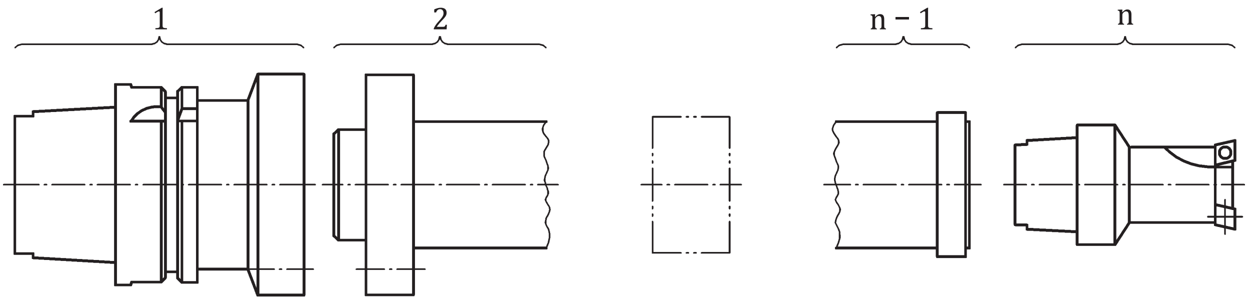
3.1.1
tool-spindle system
assembly of all components, i.e. machine tool spindle and *tool system* (3.1.2), which may cause unbalance due to design, shape, run-out, etc.

3.1.2
tool system
assembly of at least two components

EXAMPLE A shank adapter and a *single tool* (3.1.3).

Note 1 to entry: The term “modular tool system” is being synonymously used with “tool system” in this document.

Note 2 to entry: Component 1 (shank adapter) of Figure 1 could also be a tool that includes an interface to hold component 2.



Key
1 Component 1: Shank adapter
2 Component 2: Intermediate adapter
n − 1 Component n-1: Intermediate adapter
n Component n: (Single) cutting tool

Figure 1 — Example of possible components of a modular tool system

3.1.3
single tool
composition of the tool body, intermediate elements (e.g. cassettes, modular components) and the cutting edge(s) (e.g. cutting tip, bit) for removing material from a work piece through a shearing action at the defined cutting edge(s)

Note 1 to entry: The term “single tool” has the meaning “single cutting tool”.

3.1.4
basic adapter
adaptive item with different types and sizes of male or female connecting *interfaces* (3.1.7) on both the machine and workpiece side

3.1.5
intermediate adapter
adaptive item between a *basic adapter* (3.1.4) and a *single tool* (3.1.3) or another intermediate adapter

3.1.6
clamping device
device which constitutes the connection between machine tool spindle and *tool system* (3.1.2)

3.1.7
interface
contact point between the components of a *tool system* (3.1.2) and between a tool or a tool system and the machine tool spindle

3.1.8

unbalance moment

moment caused by an unbalance with an axial distance (i.e. a lever) to the front spindle bearing

3.1.9

couple unbalance

special kind of *unbalance moment* (3.1.8) caused by a pair of unbalance vectors of the same length, opposite direction and axial distance

Note 1 to entry: It mainly occurs due to quasi-static balancing (see Figure 5 and A.5.2).

3.2 Symbols and abbreviated terms

Symbols and abbreviated terms	Unit	Description
a	mm	Total lever arm — distance front bearing B1 to the tool centre of gravity CG
a_{M}	mm	Machine lever arm of generalized spindle model (i.e. distance from front bearing to spindle nose, e.g. HSK face)
B1	—	Spindle bearing 1
B2	—	Spindle bearing 2
b	mm	Distance between the balancing planes P1 and P2
b_{MIN}	mm	Minimal distance between the balancing planes P1 and P2
CG	—	Centre of gravity
CS	—	User (often also customer)
C_{DYN}	N	Dynamic load rating(s) of spindle bearing(s)
D	mm	Diameter
D_{REF}	mm	Reference diameter of a tool or a component for the G40 check
D_{S}	mm	Reference shank flange diameter (e.g. HSK-63 → D_{S} = 63 mm)
$e_{\mathrm{k,SYS,MAX}}$	mm	Maximum radial dislocation of component k within a tool system
e_{S}	mm	Pure radial dislocation of a tool shank of a tool or a tool component
$e_{\mathrm{S,i}}$	mm	Radial dislocation of the tool shank of component i
f_{BAL}	—	Weighting factor for the balancing quality
$f_{\mathrm{BAL,FINE}}$	—	Weighting factor for fine balancing
$f_{\mathrm{BAL,STND}}$	—	Weighting factor for standard balancing
$f_{\mathrm{P,MIN}}$	—	Factor to prevent falling below a minimal permissible unbalance per plane
$f_{\mathrm{SYS,k}}$	—	Factor to calculate the permissible component unbalances of special tool systems
$\vec{F}$	N	Force vector
F_{B}	N	Total force on a spindle bearing
F_{B1}	N	(Dynamic) Force on spindle bearing B1 due to an unbalance
F_{B2}	N	(Dynamic) Force on spindle bearing B2 due to an unbalance
$F_{\mathrm{B1,CPL}}$	N	Force at bearing B1 due to a couple unbalance
$F_{\mathrm{B1,RES}}$	N	Resultant force at bearing B1
$F_{\mathrm{B1,STAT}}$	N	Force at bearing B1 due to a static unbalance
G (x)	mm/s	Balancing quality G (x) according to ISO 1940-1, e.g. G 6,3
G40	mm/s	Safety limitation of the permissible unbalance according to ISO 15641
h_{P1}	mm	Distance from RP to plane P1
h_{P2}	mm	Distance from RP to plane P2
HSK-(x)	—	HSK of size (x) representing all different types (A, C, E, T, etc.), e.g. HSK-63

Symbols and abbreviated terms	Unit	Description
i	—	Index for serially numbered parameters or components (balancing planes, tool components, etc.)
k	—	Number of tool system components
k_{SYS}	—	Total number of tool system components
$k_{\mathrm{SYS,STND}}$	—	Total number of components of a standard tool system $k_{\mathrm{SYS,STND}} = 3$
L	mm	Length of a single tool or a tool system component
L_{B}	mm	Distance between the spindle bearings B1 and B2
L_{BL}	mm	Maximum length from RP to plane P2 that still enables mass compensation, i.e. $L_{\mathrm{BL}} < L$
L_{CG}	mm	Lever arm from RP to the tool centre of gravity CG
$L_{\mathrm{CG,i}}$	mm	Lever arm to the centre of gravity of component i
$L_{\mathrm{CG,i,SYS}}$	mm	Lever arm to the centre of gravity of component i within a tool system
$L_{\mathrm{CG,SYS}}$	mm	Lever arm to the centre of gravity of a tool system (distance from RP to CG)
$L_{\mathrm{CG,SYS,i}}$	mm	Lever arm to the centre of gravity of a tool system of (i) components
$L_{\mathrm{CG,SYS,k}}$	mm	Lever arm to the centre of gravity of a tool system of (k) components
$L_{\mathrm{CG,SYS,3}}$	mm	Lever arm to the centre of gravity of a standard tool system of (3) components
L_{CPL}	mm	Distance between the planes of the initial unbalance and the compensating unbalance (in case of a couple unbalance due to quasi-static balancing)
L_{P1}	mm	Distance from the spindle reference point RP to plane P1
L_{P2}	mm	Distance from the spindle reference point RP to plane P2
L_{SYS}	mm	Length of a tool system
$L_{\mathrm{STAT,MAX}}$	mm	Maximum length of a tool or a tool system for static balancing
m	g (kg)	Mass of a tool NOTE Input of masses in all formulae in gram (g).
m_{AVG}	g (kg)	Interface-relevant average reference mass of a tool or a tool system
m_{i}	g (kg)	Mass of tool system component i
m_{k}	g (kg)	Mass of tool system component k
m_{MAX}	g (kg)	Interface-relevant maximum reference mass of a tool or a tool system
m_{MIN}	g (kg)	Interface-relevant minimum reference mass of a tool or a tool system
m_{SYS}	g (kg)	Mass of a tool system
m_{U}	g	Unbalance mass
$m_{\mathrm{U,P1}}$	g	Unbalance mass at plane P1
$m_{\mathrm{U,P2}}$	g	Unbalance mass at plane P2
n	min^{-1}	Rotational speed
$n_{\mathrm{MAX,PER}}$	min^{-1}	Maximum permissible rotational speed
n_{SYS}	min^{-1}	Rotational speed of a tool system
P1	—	Balancing plane 1
P2	—	Balancing plane 2
RP	—	Reference point at the spindle nose (e.g. the HSK face)
r	mm	Radius
R_{DYN}	—	Ratio of utilization of the dynamic load rating C_{DYN}
$R_{\mathrm{L/D}}$	—	Ratio of tool length to diameter (to decide about static or dynamic balancing)
$R_{\mathrm{STAT,MAX}}$	—	Limit ratio for static balancing ($R_{\mathrm{STAT,MAX}} = 2{,}2$)
$R^{*}_{\mathrm{STAT,MAX}}$	—	Limit ratio for static balancing of tools with guidance

Symbols and abbreviated terms	Unit	Description
TM	—	Tool or component manufacturer
U	gmm	Unbalance (NOTE The unit “gmm” is equal to “g·mm”.)
$\vec{U}$	gmm	Unbalance vector
$U_{BM,MIN}$	gmm	Smallest measurable unbalance of a balancing machine
$U_{BM,ACC}$	gmm	Measuring accuracy of a balancing machine
U_{CPL}	gmm^2	Couple unbalance
U_{ECC}	gmm	Unbalance due to radial dislocation (eccentricity) relative to the spindle rotary axis
$U_{ECC,i}$	gmm	Unbalance of component *i* due to radial dislocation relative to the spindle rotary axis
$U_{ECC,MAX}$	gmm	Unbalance due to a maximum radial dislocation (i.e. eccentricity)
$U_{ECC,i,SYS}$	gmm	Unbalance due to radial dislocation of component *i* relative to component $i - 1$ within a tool system
$U_{ECC,k,MAX}$	gmm	Maximum unbalance of component *k* due to radial dislocation within a tool system
$U_{G\ (x),PER}$	gmm	Permissible residual static unbalance according to ISO 1940-1
U_{G40}	gmm	G40 safety unbalance according to ISO 15641
U_{MIN}	gmm	Achievable minimum residual unbalance
$U_{MIN,SYS,k}$	gmm	Achievable minimum unbalance of a tool system of *k* components
$U_{MOM,STAT}$	gmm	Moment of a static unbalance U_{STAT} (located in CG)
U_P	gmm	Unbalance per plane
$U_{P,MIN}$	gmm	Minimum unbalance per plane
$U_{P,PER}$	gmm	Permissible residual unbalance per plane
U_{P1}	gmm	Unbalance at balancing plane P1
U_{P2}	gmm	Unbalance at balancing plane P2
$U_{P1,PER}$	gmm	Permissible residual unbalance at balancing plane P1
$U^{*}_{P1,PER}$	gmm	$U_{P1,PER}$ but with the same angular orientation as $U_{P2,PER}$
$U_{P1,PER,LIM}$	gmm	Limited permissible residual unbalance at balancing plane P1 (case F)
$U_{P2,PER}$	gmm	Permissible residual unbalance at balancing plane P2
$U_{P2,PER,LIM}$	gmm	Limited permissible residual unbalance at balancing plane P2 (case F)
U_{QS}	gmm	Quasi-static unbalance (see Figure 5)
U_{STAT}	gmm	Static unbalance
$U_{STAT,ACT}$	gmm	Actual measured static unbalance
$U_{STAT,BAL}$	gmm	Static unbalance weighted by f_{BAL}
$U_{STAT,MAX}$	gmm	Maximum static unbalance
$U_{STAT,i,MAX}$	gmm	Maximum static unbalance of component *i* in a tool system of k_{SYS} components
$U_{STAT,i,SYS,PER}$	gmm	Permissible residual static unbalance of a universal component *i* that may be placed at any axial position within a tools system of k_{SYS} components
$U_{STAT,1\ \%}$	gmm	Static unbalance to ensure $F_{B1}/C_{DYN} \leq 1\ \%$ at spindle bearing B1
$U_{STAT,MAX,A}$	gmm	Maximum possible static unbalance of case A in Figure 7
$U_{STAT,MAX,B}$	gmm	Maximum possible static unbalance of case B in Figure 7
$U_{STAT,MAX,C}$	gmm	Maximum possible static unbalance of case C in Figure 7
$U_{STAT,PER}$	gmm	Permissible residual static unbalance
$U_{STAT,PER,CS}$	gmm	Permissible residual static unbalance for the user

Symbols and abbreviated terms	Unit	Description
$U_{STAT,PER,FINE}$	gmm	Permissible residual static unbalance for fine balancing
$U_{STAT,PER,FINE,RES}$	gmm	Resulting permissible residual static unbalance of a fine balanced tool or component taking U_{MIN} and G40 into account (see Figure 13)
$U_{STAT,PER,FINE,4}$	gmm	Permissible residual static unbalance of a component, fine balanced for a tool system of 4 components
$U_{STAT,PER,FINE,5}$	gmm	Permissible residual static unbalance of a component, fine balanced for a tool system of 5 components
$U_{STAT,PER,FINE,6}$	gmm	Permissible residual static unbalance of a component, fine balanced for a tool system of 6 components
$U_{STAT,PER,STND}$	gmm	Permissible residual static unbalance for standard balancing
$U_{STAT,PER,TM}$	gmm	Permissible residual static unbalance for the tool manufacturer
$U_{STAT,SYS,PER}$	gmm	Permissible residual static unbalance of a tool system
$U_{STAT,SYS,PER,FINE}$	gmm	Permissible residual static unbalance of an assembled (quasi monolithic) tool system for fine balancing
$U_{STAT,SYS,PER,STND}$	gmm	Permissible residual static unbalance of an assembled (quasi monolithic) tool system for standard balancing
$U_{STAT,P1,P2}$	gmm	Resulting static unbalance after a dynamic (two planes) balancing process
v_C	m/min	Peripheral speed at the cutting edge
v_{G40}	m/min	Peripheral speed limit of G40 according to ISO 15641→ v_{G40} = 1 000 m/min
v_{REF}	m/min	Peripheral speed of the reference tool diameter (i.e. biggest tool diameter)
x_{P1}	mm	Distance between plane P1 and tool centre of gravity CG
x_{P2}	mm	Distance between plane P2 and tool centre of gravity CG
α	°	Angle
α_{P1}	°	Angular orientation of the unbalance at plane P1
α_{P2}	°	Angular orientation of the unbalance at plane P2
α_U	°	Angle between static and couple unbalance
ρ_{ST}	mg/mm³	Density of steel (7,8 mg/mm³)
Ω	rad/s	Angular velocity of a component or a tool

4 Requirements

4.1 General

4.1.1 Clamping inaccuracies

Unbalances which are not related to the balancing quality of a tool may occur due to clamping inaccuracies caused by fit tolerances, e.g. when inserting a tool into the machine tool spindle. Even if a balancing result stands for a smaller eccentricity than the possible shank eccentricity, this balancing condition cannot be reproducibly achieved with every clamping action of this tool, either in the spindle of a machine tool or of a balancing machine. A radial joining inaccuracy of several micrometres may occur depending on shank type and size (see Table 2 for radial joining dislocations of different tool interfaces). Factors such as wear and run-out of the different interfaces may lead to a worse joining accuracy, thus generating a bigger residual unbalance of the tool-spindle system.

4.1.2 Influence of balancing machines

The achievable residual unbalance of a tool is limited by type and precision of the balancing machine (see 4.2.2 and 4.2.3). Table 2 shows the unbalance measuring limits of balancing machines built for different tool masses.

Systematic eccentricities like a run-out of the balancing spindle can be eliminated by index balancing. This procedure is described in ISO 21940-14.

NOTE ISO 21940-21 describes testing procedures for evaluating the limits and the performance of balancing machines.

4.1.3 Effects and frequent consequences of permissible residual unbalances according to ISO 1940-1

The following two examples show that common balancing qualities based on ISO 1940-1 are already exceeding possible limits.

The frequently required quality level G 2,5 at a rotational speed of 25 000 min^{-1} means a permissible residual unbalance of only 1 gmm/kg. The residual unbalance of 1 gmm for a tool mass of 1 000 g corresponds to a permissible eccentricity of just 1 µm for the tool centre of gravity. This value is lower than a new HSK can repeatedly provide (see Table 2).

In case of tools of even lower masses and higher rotational speeds, the requirements are increasing continuously. A HSK-40-tool of 350 g may only have a residual unbalance of 0,21 gmm (i.e. 0,6 gmm/kg) in order to comply with G 2,5 at a rotational speed of 40 000 min^{-1}. It also means a maximum eccentricity of the tool centre of gravity of only 0,6 µm.

Both examples show that neither the measurement of these residual unbalances nor their realization are reliably possible due to the clamping inaccuracies in a balancing machine itself and the measuring accuracy of commercially available balancing machines.

It also results from ISO 1940-1 that the same quality level permits different residual unbalances for different tool masses at the same rotational speed. Different unbalances as a consequence lead to varying centrifugal forces, i.e. spindle loads. The dynamic spindle load, however, is not dependent on the tool mass but on the unbalance of the tool system and its resulting forces.

4.1.4 Inherent properties of machine tools and components

The vibration amplitudes of a machine structure are related to the exciting force and frequency, as well as to the dynamic properties of the machine tool system. The same grade of excitation leads to higher vibration amplitudes if the frequency-dependent dynamic flexibility of a system is worse at certain frequencies of excitation.

Therefore, as far as the machine and in particular the tool-spindle system are concerned, the balancing requirements depend on the dynamic properties of the tool-spindle system. A universal description of the dynamic properties of machine tools is not possible. However, a limitation of unbalance-related machine vibrations may be achieved by balancing a tool to the limit of the reproducibly achievable residual unbalance, U_{MIN} (see 4.2.3).

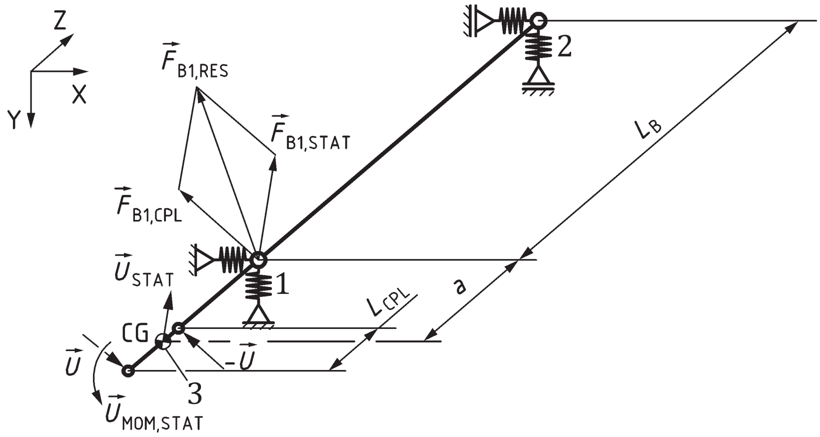
A reduction of machine vibrations can also be achieved by altering the cutting speed if the relevant machining process allows a modification of technological parameters within the relevant operating speed range. Thus, the excitation could take place in a more stable dynamic frequency range of the machine.

4.2 Balancing requirements based on the spindle load

4.2.1 General

In order to limit unbalance-related periodic loads on the spindle bearings, it is necessary to balance tool systems in dependence of the rotational speed and the properties of the spindle systems specified in this document (see Annex A for the theoretical approach). Figure 2 shows the structure and the geometric conditions of the general tool-spindle model with tool unbalances and their related forces for the bearing B1 taking the highest load.

NOTE This document indicates all permissible residual and other unbalances in "gmm". There are no specific quality levels like "G 6,3" according to ISO 1940-1.



Key

1 bearing B1

2 bearing B2

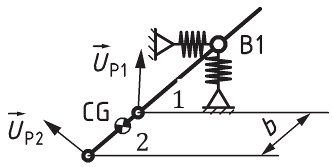
3 centre of gravity CG

Figure 2 — Tool-spindle model showing unbalance-related forces

The universal approach to determine the load $F_{B1,RES}$ at bearing B1 is calculating the vector sum of the forces $F_{B1,STAT}$ and $F_{B1,CPL}$. These forces are generated by a so-called "dynamic unbalance", the combination of a static unbalance, U_{STAT}, located in the tool centre of gravity and a couple unbalance, U_{CPL}. When static balancing, material should be removed or added at or next to the place of the material imbalance in order to minimize residual dynamic unbalances.

The force $F_{B1,RES}$ on the front spindle bearing B1 shall not exceed 1 % of the dynamic load rating C_{DYN} within the relevant rotational speed range. It is important to note that this dynamic load limit ratio $F_{B1,RES}/C_{DYN}$ = 1 % is independent of the tool mass.

A dynamic unbalance situation of a rigid rotor can be alternatively described by two independent unbalance vectors $\vec{U}_{P1}$ and $\vec{U}_{P2}$ located in two axial planes P1 and P2 with the distance b (see Figure 3). This "two-plane-balancing" procedure has prevailed in the industrial balancing practice of rigid tools and tool systems.



Key

1 plane 1

2 plane 2

Figure 3 — Model of a spindle and a tool with a two-plane dynamic unbalance

The permissible residual static unbalance, $U_{STAT,1\,\%}$ [see Formula (3)], however, has been calculated for a static unbalance located in the tool centre of gravity CG (see Figure 4). The decision whether static or dynamic balancing is required depends on a certain L/D-ratio of the tool (see 4.2.4 for details).

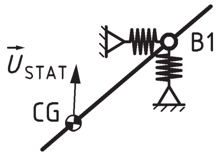
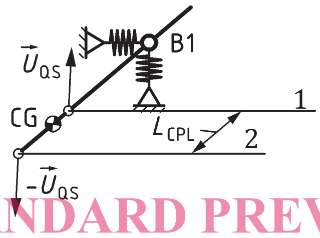


Figure 4 — Static unbalance in the tool centre of gravity CG

The permissible unbalances $U_{P1,PER}$ and $U_{P2,PER}$ for dynamic balancing have been derived from $U_{STAT,PER}$ located in the tool centre of gravity CG and based on the mandatory requirement that the load on spindle bearing B1 shall not exceed the load being generated by the permissible static unbalance, $U_{STAT,PER}$ (see 4.2.5).

A “short” tool according to 4.2.4 is being balanced statically. Due to functionally required tool designs, the centre of the related unbalance is usually not located in the tool centre of gravity CG. For single tools, this so-called quasi-static unbalance, U_{QS} (see Figure 5), is generated by cutting tips and chip flutes, thus often located near the tool front.



Key

1 correction plane

2 centre of quasi-static unbalance

Figure 5 — Couple unbalance due to quasi-static balancing

“At the balancing machine”, it is difficult for an operator to define the centre of gravity of the unbalance position. Even if the unbalance position was obvious, removing material directly on the opposite side of the tool body is often not possible either.

Therefore, static mass compensations often happen near the shank due to the bigger tool diameters. This means a distance L_{CPL} between the initial unbalance, U_{QS}, and the correction plane of the compensating unbalance, $-U_{QS}$.

The result is a statically balanced tool with a remaining couple unbalance, U_{CPL} [see Formula (1)] — an exceptional type of dynamic unbalance with the unit (gmm^2).

$$U_{CPL} = U_{QS} \times L_{CPL} \quad (1)$$

The distance L_{CPL} varies unpredictably depending on the tool design and the position(s) of the balancing measures. Therefore, the forces on the spindle bearings induced by a couple unbalance, U_{CPL}, are unknown and cannot be taken into account for static balancing. Nevertheless, it is possible to calculate the bearing forces F_{B1} and F_{B2} which are equal for both bearings because of the couple unbalance (see Formula (2)).

$$F_{B1} = F_{B2} = \frac{U_{CPL}}{L_B} \times \Omega^2 = U_{QS} \times \frac{L_{CPL}}{L_B} \times \left(\frac{2\pi \times n}{60}\right)^2 \quad (2)$$

Formula (2) also shows that the ratio of L_{CPL} and L_B has a significant influence on the bearing forces.