UNIVERSITY OF MISKOLC
FACULTY OF MECHANICAL ENGINEERING AND INFORMATICS

NUMERICAL AND EXPERIMENTAL INVESTIGATION ON THE USE OF AN IMPACT DAMPER BORING BAR

BOOKLET OF PHD THESIS

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1. INTRODUCTION

Low amplitude vibration of the metal-cutting process is important to make sure the efficiency of the process with good quality and tight tolerances of the workpiece. In the opposite case, when the vibration amplitude increases, self-excited vibration takes place and the metal-cutting process starts to be unstable.

The stability goes around the cutting parameters, the material of the workpiece, the machine tool components, and the tool configuration. Among those parameters that affect the stability of the cutting process, the tool configuration is the weak link, it is because the chip formation that leads to the performance of the process needs a stable cutting tool and clamping system for the tool and the workpiece before setting up the other parameters.

In this way, to cover completely the main problems to avoid the chatter regime, this work suggests understanding the dynamic behaviour of a new type of impact damper (ID) boring bar which proved to be efficient for the three exposed scenarios, according to many authors [1]. The results are theoretically investigated and validated experimentally. For that reason, a mathematical model is proposed to let us understand the damping capacity of the ID bar compared to the standard tool. With that, it is possible to plot the limits of the stability lobe diagram (SLD) simulated numerically for the given tools to increase the depth of cut in the internal turning operation of hardened materials for long overhangs.

1.1 Objectives

The general objective of this PhD thesis is to contribute to the understanding of the use of an impact damper boring bar for turning the longest possible hole in hardened material. The focus is on the dynamic behaviour of the ID boring bar and its damping effect on the stability of the cutting process to avoid undesirable chatter regimes.

The specific objectives are:

1) To analyze the dynamical properties of standard and impact damper boring bars in different overhangs using impact test and numerical investigations. Additionally, to model and analyze the dynamic response of the boring bar as an Euler-Bernoulli beam partially on Winkler foundation.

2) To set up a mechanical model for the boring bar, perform numerical calculations for the ID tool with different numbers of balls, excitation forces, and clearance gaps, and determine the optimal configuration for achieving the highest damping capacity for different overhangs.

4) To test and investigate experimentally the stability of the impact damper tool in the internal turning operation of hardened material in long overhangs, and compare the roughness, roundness, and displacement parameters to a standard boring bar.

2. METHODOLOGY OF STUDY

The methodology and decisions used to solve the dynamic problem of the ID boring bar are formulated mathematically and investigated experimentally. Then the results of the dynamical behaviour of the ID boring bar compared to the standard tool are studied in free and forced vibrations. Finally, after a parametric study, many experiments are performed to validate the results in terms of stability, roughness, cylindricity and vibration measurements. In brief, the new scientific results will be stated to emphasize the novelty of the thesis by including the relevant references used in this work.

A new method is presented in this thesis to determine the foundation modulus under different clamping conditions with a boring bar, which is obtained through the Winkler theory. To check the convergence and accuracy of the present method, the results of the free vibration beam system partially resting on elastic foundation are presented. The damping effects and variations of the stiffness in the space domain are neglected.

The ID boring bar is modelled as a cantilever Euler–Bernoulli beam of two spans (segment L_1 and segment L_2), with one segment supported by a clamping mechanism that can be considered a Winkler foundation type, while the other is free, as illustrated in Figure 1. The stiffness of the clamping mechanism significantly impacts the natural frequencies of the boring bar and its mode shapes as well. When the clamping mechanism is very stiff (with large values of Winkler foundation's stiffness, k), it can become a fixed support [2],[3]. On the other hand, when the stiffness of the clamping mechanism decreases, the mode shapes become more extended into the turret of the CNC machine, and the natural frequencies decrease. This reduction in natural frequency can be beneficial in reducing the risk of resonance and chatter during internal turning operations. However, if the stiffness is too low, the boring bar may become too flexible, leading to excessive deflection and vibration [4],[5]. Therefore, the stiffness of the clamping mechanism needs to be carefully selected and optimized based on the operating conditions and requirements of the internal turning operation.

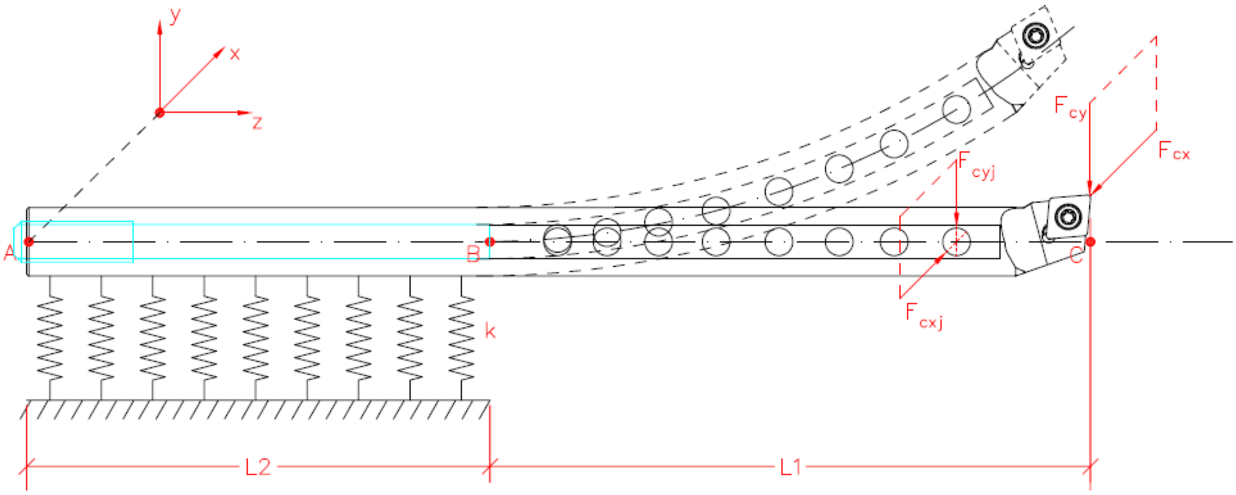


Figure 1. Mechanical model for an impact damper boring bar in Winkler foundation

The purpose of setting up a model for the ID boring bar is to better understand the behaviour of the impact damper mechanism and analyze the impact absorber in real machining operations. For that the radial force (F_{cx}), tangetial force (F_{cy}), the contact force in X direction (F_{cxj}) and contact in Y direction (F_{cyj}) were considerd in the forced vibration analyses. Thus, the numerical and experimental results can be qualitatively compared with the results obtained during the numerical simulations [6],[7].

It aims to investigate and compare the behaviour of internal turning processes when using a standard bar versus an impact-damped boring bar, using a boring bar with the largest possible length to diameter (*L/D*) ratio in a system with an *Easy Fix* bushing, as well as to improve absorption parameters of that impact-damped boring bar.

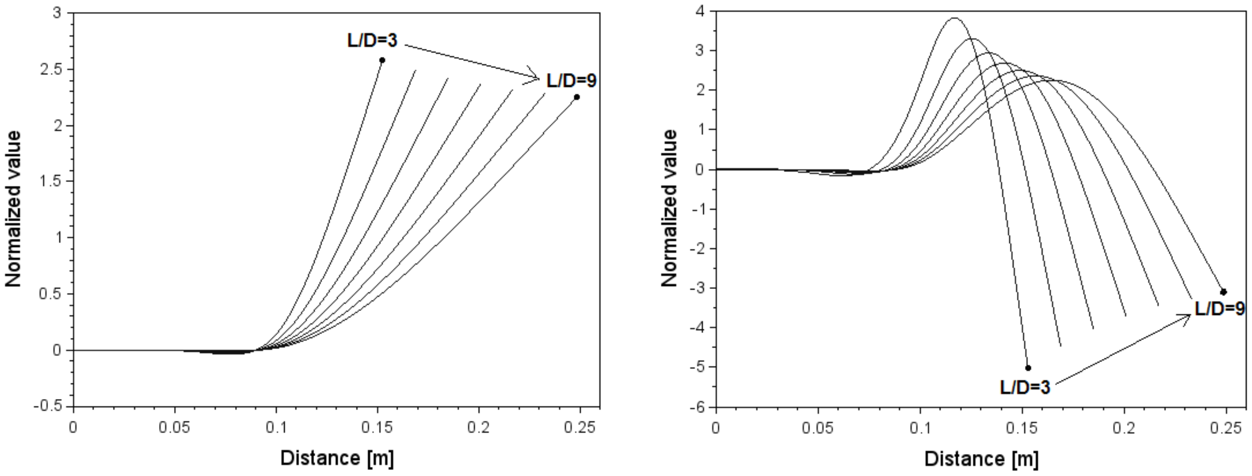
In this way, experiments are performed where the overhang is set to a given value, and internal turning is performed while measuring tool vibration. After cutting, surface roughness is measured on the turned surface. The procedure is repeated by increasing the tool overhang and following the same steps (turning, vibration measurement, and roughness measurement) until the cutting becomes unstable, which is determined by a sudden increase in vibration and roughness. Each experiment is performed twice, and cutting conditions are established beforehand.

2.1 Mathematical model of the standard bar in different overhangs

We present a complete and self-contained analysis of standard boring bar vibrational frequencies (Table 1) and mode shapes (Figure 2) based on the classic Euler–Bernoulli beam model. The analysis of the dependence of the bar's natural frequencies, damping ratio (Table 2), static stiffness (Table 3) and mode shapes on the overhang is also provided.

In this section, the eigenfrequencies and eigenfunctions of the boring bar are calculated in *SciLab*. We have avoided plotting the higher frequency modes in the interest of reducing clutter [8]. There is a clamped bushing (*Easy Fix*) fastening along the length L_2, which is modelled by Winkler-foundation.

The length of the elastic foundation, the cross-sectional area, the inertia of the cross-section, the density and the Young modulus are given, respectively: $L_2 = 0.105$ m, $A_x = 1.64 \times 10^{-4}$ m², $I_x = 2.84 \times 10^{-9}$ m^4, $\rho = 7860$ kg/m^3 and $E = 2.0 \times 10^{11}$ N/m². Besides, the value of L_1 changes for different overhangs when the length-to-diameter (*L/D*) ratio of the tool is between 3 and 9 for a tool with $D = 0.016$ m of cross-section diameter, it is because these *L/D* intervals are easily available commercially [9].



(a) (b)

Figure 2. Normalized mode shapes for the standard boring bar in (a) the first and (b) second mode for overhangs between L/D 3 and 9

The experimental measurements were compared with the Euler-Bernoulli proposed model. It is noted that, the Winkler foundation's stiffness obtained as $k = 1.0 \times 10^{11}$ N/m was adjusted to the highest overhang until the first mode theoretical natural frequency tuned to the measured natural frequency.

For long overhangs ($L/D \geq 5$) the identified maximum absolute error is *2.80%*. The analytical model proposed exhibits some slight differences with experimental results, particularly in short overhangs, but proved to be sufficiently accurate in long overhangs [10].

Table 1. Comparison of the lowest experimental (f_{exp}) and theoretical (f_m) natural frequencies for different overhangs for a standard boring bar

L/D	**5**	**6**	**7**	**8**	**9**
f_{exp} [Hz]	*1348.4*	*985.9*	*751.5*	*609.3*	*482.0*
f_m [Hz]	*1386.2*	*1006.4*	*763.6*	*599.1*	*482.6*
Error [%]	*2.80*	*2.08*	*1.61*	*1.67*	*0.12*

The damping of the tool is usually determined by a hammer test. The impact hammer induces transient vibration of the tool, which can be simulated by modal analysis assuming that the first two eigenmodes dominate the solution. It can obtain the logarithmic attenuation ratio, δ_i and the Lehr damping, ζ_i of Table 2 by applying the logarithmic decrement method in the acceleration signal captured by the hammer test. Table 2 summarizes the Lehr damping parameters for different overhangs. Interestingly, there is a trend, i.e., the greater the overhang the smaller the damping.

Table 2. Experimental Lehr damping of the standard tool in different overhangs for the first mode

L/D	**3**	**4**	**5**	**6**	**7**	**8**	**9**
δ_i	*0,1580*	*0.1260*	*0.0650*	*0.0347*	*0.02833*	*0.0210*	*0.0220*
ζ_i	*0.025*	*0.020*	*0.010*	*0.0055*	*0.0045*	*0.0033*	*0.0035*

According to [11], when replacing the natural frequency parameter (ordinate axis) with the tool deflection parameter, it was noticed that the lower the stiffness of the bar, represented by large *L/D* ratio values, the larger its deflection will be, and vice versa. Consequently, in Table 3, the values show that long overhangs decrease the dynamic stiffness of the tool, directly affect the acceleration amplitude of the tool and, consequently, influence the roughness of the workpiece and let the cutting process lose the necessary stability to avoid chatter. Table 3 demonstrates the possibility of estimating the experimental static stiffness, $(k_s)_i$ of the tool. As the *L/D* ratio increases, the static stiffness decreases, which makes the tool more vulnerable to deflections when long overhangs are compared to short ones. This low static stiffness can also make the tool more susceptible to vibration.

Table 3. Experimental static stiffness with different overhangs

L/D	**3**	**4**	**5**	**6**	**7**	**8**	**9**
$(k_s)_i \times 10^6$ [N/m]	*423.47*	*59.68*	*18.23*	*10.63*	*6.93*	*4.94*	*2.34*

2.2 Numerical computation of two-span Winkler-supported boring bars with overhang between 3 and 9 with and without impact damper

This section will analyse the forced vibrations of the standard and ID tools. The aim of the numerical computations is to understand the dynamics of the ID tool, and to find its best performances, i.e., highest damping for different overhangs.

In an internal turning tool operation, it is critical to determine the maximum overhang that the tool can handle without experiencing chatter. This is particularly important for long overhangs, defined as $L/D \geq 5$ [10],[12], which can limit the cutting operation. This section analyzes the behaviour and dynamic properties of the tool under different overhangs.

Table 4 contains the dynamic parameters calculated for the tool in order to obtain the damping ratio for different overhangs, such as the excitation amplitude (X_{RMS}), the ratio of the natural frequency and the excitation frequency (Ω) and the peak values of the FRFs spectrum (|G(iω)|). It is important to highlight that for long overhangs ($L/D \geq 5$), the ID boring bar presented at least *1.5* times better damping ratio than the standard tool. The best damping ratio was obtained for $L/D = 8$. In short overhangs the damping ratio is not relevant compared to long ones. It lets us conclude that the ID system is advantageous to use mainly for long overhangs but it is also not worse for short ones. In that way, higher depth of cut is possible during the internal turning operation, because the ID tool can absorb more vibration energy during cutting compared to the standard tool. Consequently, the productivity of the manufactured workpieces increases and the chatter can be avoided.

Table 4. Lehr Damping of the standard (ζ_{iS}) and ID (ζ_{iID}) boring bar for different overhangs when excitation force is $F_0 = 1.78$ N and $Gap_0 = 0.33$ mm

L/D	**Standard**				**ID**				**Ratio**
	X_{RMS}	**Ω**	**|G(iω)|**	ζ_{iS}	X_{RMS}	**Ω**	**|G(iω)|**	ζ_{iID}	ζ_{iID}/ζ_{iS}
3	0.00356	***1.0***	21.111	0.02368	0.00349	1.0	20,678	0.0241	1.021
4	0.00872		26.319	0.01899	0.00788	1.0	23.768	0.0210	1.107
5	0.02989		51.987	0.00961	0.02225	1.01	38.703	0.0129	1.343
6	0.08405		91.799	0.00544	0.02368	1.02	25.870	0.0193	3.548
7	***0.14897***		***109.02***	***0.00459***	***0.0251***	***0.95***	***16.875***	***0.02963***	***6.455***
8	0.27123		138.799	0.00360	0.0327	0.95	16.775	0.02980	8.274
9	0.34172		127.291	0.00392	0.18791	0.92	69.998	0.00714	1.818

2.3 Parametric studies

In this section, we will examine the best design of an impact damper boring bar with $L/D = 7$, as illustrated in Figure 3. To ensure that the dimensions of the cavity are within the stiffness and mass limits [1], we will use the clearance gap, $Gap_0 = 0.33$ mm multipliers of *0.25, 0.5, 0.75, 1.0, 1.25, 1.50, 1.75,* and *2*. Similarly, we will multiply the amplitude of the excitation force $F_0 = 1.78$ N with coefficients of *0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 3,* and *4*.

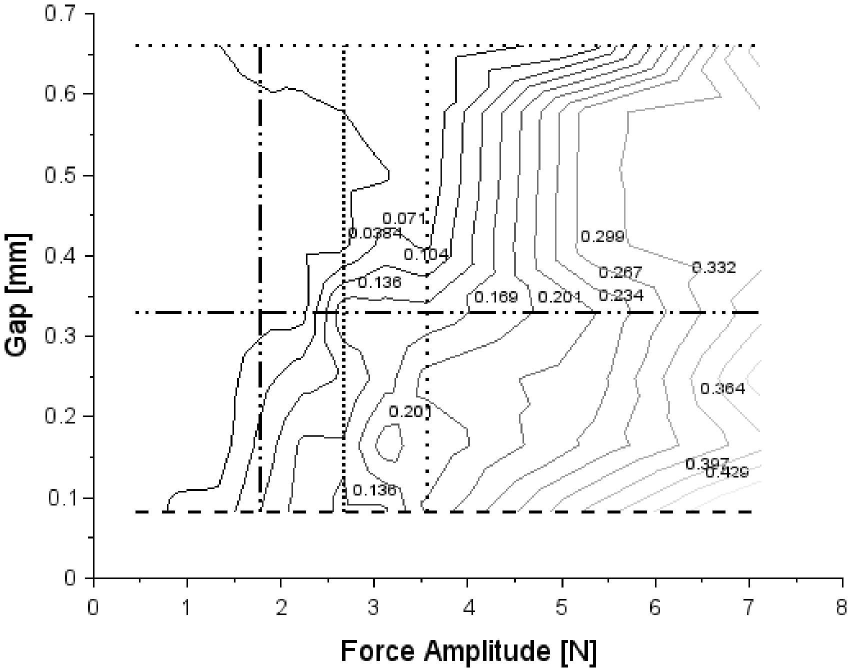


Figure 3. X_{rms} of the tool over different excitation forces and total clearance gaps when L/D = 7

Table 5 displays the best configuration for the ID tool with a clearance gap of *0.33* mm and excitation force of *1.78* N, which achieves the highest possible damping ratio. The analysis shows that an impact damper can be improved, where for *L/D = 7,* nine balls can achieve a Lehr damping of 0.*03303* after the parametric study (ζ_{ipID}), and *11* balls can achieve a Lehr damping of *0.02963* before the parametric study (ζ_{iID}).

Table 5. Comparison of the highest Lehr damping in an ID boring bar before (ζ_{iID}) and after (ζ_{ipID}) the parametric study for different overhangs when excitation force is $F_0 = 1.78$ N and $Gap_0 = 0.33$ mm

L/D	**N° of the ball**	ζ_{ipID}	**N° of the ball**	ζ_{iID}	ζ_{ipID}/ζ_{iID}
3	*1*	*0.24364*	*3*	*0.0241*	*1.01*
4	*4*	*0.024047*	*5*	*0.0210*	*1.15*
5	*3*	*0.015403*	*7*	*0.0129*	*1.20*
6	*3*	*0.023238*	*9*	*0.0193*	*1.20*
7	***9***	***0.03303***	***11***	***0.02963***	***1.12***
8	*11*	*0.03102*	*13*	*0.02980*	*1.04*
9	*11*	*0.008804*	*15*	*0.00714*	*1.23*

Similarly, the results of Table 4 demonstrate the highest damping ratio for different overhangs by considering various clearance gap and force multipliers. The advantage of using Table 6 is that it can help in the production of an appropriate ID tool for achieving the highest damping ratio.

Table 6. Comparison of the highest Lehr damping in an ID boring bar before (ζ_{iID}) and after (ζ_{ipID}) the parametric study for different overhangs, gaps multipliers and forces multipliers

L/D	**Gap Multiplier**	**Force Multiplier**	**N° of the ball**	ζ_{ipID}	**N° of the ball**	ζ_{iID}	ζ_{ipID} / ζ_{iID}
3	0.25	2.00	3	0.026696	3	0.0241	1.11
4	0.25	1.00	5	0.025049	5	0.0210	1.19
5	1.00	1.00	3	0.015403	7	0.0129	1.20
6	0.75	2.00	3	0.029043	9	0.0193	1.50
7	**1.00**	**1.00**	**9**	**0.03303**	**11**	**0.02963**	**1.12**
8	1.00	1.00	11	0.03102	13	0.02980	1.04
9	1.50	0.25	14	0.017214	15	0.00714	2.41

Once the appropriate number of balls, clearance gap multiplier, and force multiplier are selected to achieve the highest damping ratio, it is possible to plot Figure 4, which illustrates the stability lobe diagram (SLD) for *L/D = 7* [13],[14],[15],[16]. Based on this information, the cutting parameters can be reprogrammed to improve the performance of the tool and enhance the production process.

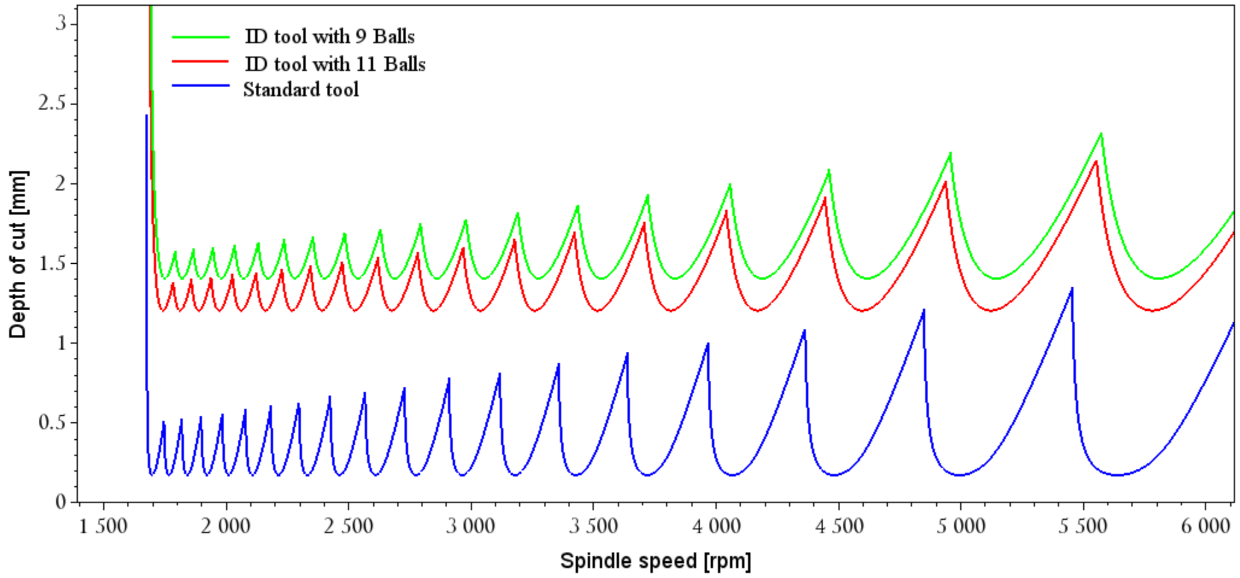


Figure 4. Stability Lobe Diagram for a standard boring bar, an ID boring bar with 9 balls, and an ID boring bar with 11 balls, with Gap_0 = 0.33mm, excitation force F_0 = 1.78 N, and L/D = 7

2.4 Experimental studies

In this section, the measurements of the standard and ID bar are performed. The impact of roughness profile and cylindricity profile on stable and unstable vibration conditions during internal turning operations in hardened materials is investigated. The aim is to determine the highest overhang possible in a stable condition and to validate the theoretical data for the previous sections. For that reason, an accelerometer was positioned to measure vibration in the radial direction in order to collect the vibration amplitudes. Thus, the stable and unstable limits were settled to different overhangs and tested at the same cutting conditions of cutting speed, $v_c = 360$ m/min, feed rate, $f = 0.14$ mm and depth of cut, $a_p = 0.1$ mm.

Table 7 is an important reference for guiding the selection of tools for an internal turning operation. It describes the exact overhang limits for tools with different structural configurations and dynamic properties. If we assume that short overhangs are up to 5 and over, this limit is a long overhang, and we can conclude that the best choice for operations with long holes comprises ID boring bars with a maximum L/D equal to 8. This proves the efficiency of the damper mechanisms of the multiple numbers of balls inside the cavity of the ID tool that can minimize the average arithmetic roughness (R_a), the total height of the profile (R_z) and the vibration amplitude of the tool and during internal turning operations with respect to hardened materials.

Another point to be mentioned is that, in forced vibration the damping mechanism can be explained by the dynamics of the bouncing balls as the excitation amplitude (X_{RMS}) increases and more balls are activated within the cavity to decrease the tool's vibration amplitude. When a ball is actively participating in the suppression of a tool's vibration, it performs an approximately circular motion in the cavity.

Table 7. Average values of roughness (deviation ± 0.02 mm) in longitudinal direction and acceleration amplitude (RMS) (deviation ± 0.1 m/s²) of the tip of the tool

Tool Type	***L/D***	**Stability**	**R_a [µm]**	**R_z [µm]**	**RMS [m/s^2]**
Standard	*< 4.5*	Stable	*0.360*	*1.860*	*16.189*
	≥ 4.5	Unstable	*1.507*	*7.002*	*347.795*
ID	*≤ 8*	Stable	*0.460*	*2.249*	*2.318*
	> 8	Unstable	*1.820*	*8.000*	*2.318*

3. THESES – NEW SCIENTIFIC RESULTS

T1. A) A novel multi-span boring bar model was proposed based on the Euler-Bernoulli beam theory. The bar is partially supported by a Winkler foundation of constant stiffness that represents the clamping of the tool. Numerical evaluation of the model was carried out, paying attention to the modal parameters for various overhangs, or length-to-diameter (*L/D*) ratios. The selected typical *L/D = 3...9* geometries are commercially used by the industry. Analysis results revealed how the mechanical properties, like mode shapes, Lehr damping, natural frequencies, dynamic and static stiffness depend on the overhang.

T1. B) The stiffness of the clamping mechanism has a significant impact on the natural frequencies of the boring bar and influences its mode shapes also. Using a trial-and-error method, the preferable Winkler foundation stiffness was determined to be $k = 1.0 \times 10^{11}$ N/m, which was found to operate the ID and standard boring bar for all studied overhangs. The analytical model shows excellent accuracy with experiments in long overhangs, with a maximum absolute error of less than 3%.

T2. A) A novel non-linear viscoelastic model was proposed to calculate the contact force of the impact damper (ID) bar by incorporating a damping coefficient and contact stiffness based on the Hertz theory. This model is also effective in calculating the contact force and is highly sensitive to variations in the clearance gap between the cavity wall of the tool and the balls within. The investigation presented uses a novel approach to model the damping mechanism of the ID bar. It is noted that not all balls within the cavity have the same efficiency as regard the damping. The trajectory of a ball depends on multiple factors such as clearance gap, excitation force and the location of the ball, i.e., distance from the tip. The balls near the tip of the tool have greater displacements compared to those close to the Winkler-type foundation.

T2. B) In forced vibration, the damping capacity of the balls is activated, leading to a significant decrease in the tool's vibration amplitude. For given clearance gap, excitation force, and first eigenfrequency of the tool, it can be observed that the ID boring bar reduces the frequency response peak by up to *85*% meaning a *6.4* times higher damping ratio than a standard tool.

T2. C) The damping ratio is improved depending on the number of balls within the tool cavity. For more than two balls, the damping ratio is consistently higher than for a single ball. Parametric studies proved that more balls do not necessarily mean better Lehr damping. With the technique developed, a map graph was drawn to select the highest damping ratio in terms of clearance gap multiplier and force multiplier. This makes it possible to plot of the stability lobe diagram (SLD) for different overhangs.

T3. A) There is a close correspondence between the numerical and experimental results regarding the obtained damping ratios. Both methods confirmed that the stability limit of the ID bar is $L/D = 8$. The ID boring bar can operate in a frequency range up to two times broader than a standard tool. Additionally, it can operate in a higher range of overhang in stable cutting ($L/D \leq 8$) than a standard tool ($L/D < 4.5$). When using both ID and standard bars at the limit of their stability, the ID bar exhibits a lower excitation amplitude than the standard bar, by approximately six times peak to peak.

T3 B) The irregular roughness and circularity profile in the experiments is attributed to the instability of the tool due to low static stiffness in long overhangs. It was observed that when the value of the arithmetic average roughness was greater than *0.8* μm, chatter marks started to appear in the workpiece. The unstable amplitudes of the standard boring bar (RMS acceleration amplitude > *300* m/s^2) were substantially higher compared to the stable ones (RMS acceleration amplitude < *50* m/s^2), except for the ID bar that did not show significant amplitudes relative to the long overhangs (RMS acceleration amplitude < *3* m/s^2).

4. LIST OF PUBLICATIONS RELATED TO THE TOPIC OF THE RESEARCH FIELD

(1) Wallyson Thomas Alves da Silva, Zsombor Fülöp, and Attila Szilágyi, Passive Damping Techniques for Vibration Suppression in Boring Operation with Long Overhangs, in Jármai K., Voith K. (eds) Vehicle and Automotive Engineering 3 (VAE 2020), 25. November, 2020, Miskolc, Lecture Notes in Mechanical Engineering. Springer, Singapore. DOI: 10.1007/978-981-15-9529-5_22.

(2) Wallyson Thomas Alves da Silva, Zsombor Fülöp, and Attila Szilágyi, Comparison between the performances of different boring bars in the internal turning of long overhangs, Nanomaterials Science & Engineering 2:3, pp. 124-134, 2020. DOI:10.34624/nmse.v2i3.19533.

(3) Wallyson Thomas Alves da Silva, Zsombor Fülöp, and Attila Szilágyi, Comparison Between a Conventional and an Antivibrating Boring Bar in the Internal Turning of Long Overhangs, Design of Machines and Structures, 10:2 pp. 145-149, 2020. DOI: 10.32972/dms.2020.026.

(4) Wallyson Thomas Alves da Silva, Zsombor Fülop, and Attila Szilágyi, Evaluating Cbn Tool Life in Hardened Boring Operations in Long Overhangs, Design of Machines and Structures, 10:2 pp. 150-154, 2020. DOI: 10.32972/dms.2020.026.

(5) Wallyson Thomas Alves da Silva, Zsombor Fülöp, and Attila Szilágyi, Köbös bórnitrid lapkás „hosszú” furat esztergakések élettartamának vizsgálata edzett acél megmunkálásának vonatkozásában, Multidiszciplináris Tudományok: A Miskolci Egyetem Közleménye, 10 : 4 pp. 31-35, 2020. DOI: 10.35925/j.multi.2020.4.5.

(6) Wallyson Thomas Alves da Silva, Zsombor Fülöp, and Attila Szilágyi, Hagyományos és rezgéscsillapított „hosszú” furat esztergakések viselkedéseinek összehasonlítása, Multidiszciplináris Tudományok: A Miskolci Egyetem Közleménye, 10:3 pp. 360-364, 2020. DOI: 10.35925/j.multi.2020.3.43.

(7) Wallyson Thomas Alves da Silva; Peterka, Jozef, Róbert Straka, Tomáš Vopát, Jakub Hrbál, and Michaela Kritikos. "Analysis of form Error and Roughness of Hardened Steel Workpieces Internally Turned with Different Tools in Long Overhangs." Research Papers Faculty of Materials Science and Technology Slovak University of Technology 30: 50 pp. 21-29. DOI: 10.2478/rput-2022-0003.

(8) Wallyson Thomas Alves da Silva; Lucas Alexandre de Carvalho; Nobre; Filipe Ribeiro, and Silva Lima Matheus, Analysis of form errors and roughness of hardened steel workpieces internally turned with tool in long overhangs, Conference: Curitiba, Brazil 24.05. Conference proceedings Scientific. 2021. DOI: 10.26678/ABCM.COBEF2021.COB21-0123.

(9) Wallyson Thomas Alves da Silva, Anselmo Eduardo Diniz, and Attila Szilágyi, Performance of CBN Insert Over Internal Turning Operation, Proceedings of the World Congress on Engineering 2021.

(10) Wallyson Thomas Alves da Silva, Rouben Rostamian, Attila Szilágyi, Dynamic Analysis of an Internal Turning Tool with Elastic Foundation (Winkler Model), Proceedings of the 10th ECCOMAS Thematic Conference on MULTIBODY DYNAMICS. 2021.

(11) Wallyson Thomas Alves da Silva, Dynamic Modeling of Internal Turning Tool Considering Different Spans and Boundary Conditions, Proceedings of the 24th Spring Wild Conference 2021.

(12) Glazyrin, Vladimir, Juraj Ruzbarsky, Yury Nikitin, Pavol Bozek, and Wallyson Thomas de Silva, Study of Dynamic Processes During the Finishing of Spherical Parts Made of Difficult-to-Machine Materials, MM Science Journal. 2022. DOI: 10.17973/MMSJ.2022_10_2022013.

(13) Wallyson Thomas Alves da Silva, Jozef Peterka, Tomas Vopat, Experimental Research on the Dynamic Stability of Internal Turning Tools for Long Overhangs, Journal of Manufacturing and Materials. Processing. 2023. DOI:10.3390/jmmp7020061.

(14) Wallyson Thomas Alves da Silva, Jozef Peterka, Tamas Szabo, Marcos Vieira Albuquerque, Robson Pederiva, Laszlo Peter Kiss. Analytical and Experimental Investigation of the Dynamic Stability in Passive Damper Boring Bars. Procedia CIRP. 2023. (status: accepted).

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