CHATTER MITIGATION IN REAMING: EXPLORING EFFECTIVE TOOL HOLDER DESIGN

KRYSTOF LANC[1], ZDENEK FIALA[1]

[1]Department of Manufacturing Technology, Faculty of Mechanical Engineering, Brno University of Technology, Technicka 2, Brno, 616 69, Czech Republic

DOI: 10.17973/MMSJ.2024_06_2024017

Krystof.Lanc@vutbr.cz

Reaming is a crucial technology in finishing operations, demanding high stability in the machining process for optimal results. The clamping system significantly influences the dynamic properties of the system tool – clamping - machine and is key in mitigating chatter. The introduction of new designs in clamping exchangeable reaming heads presents several challenges, particularly in terms of vibration suppression. This study explores various constructions of clamping bars, examining their dynamic properties in both static conditions and during machining. Through these evaluations, the research aims to understand how different designs impact the stability and effectiveness of reaming operations. The measured data from these experiments reveal how the construction of the holder influences machining process stability, providing insights into optimizing clamping system designs for improved reaming performance. the outcomes of this study contribute to the development of more effective and efficient clamping systems for finishing operations.

KEYWORDS

Chatter, dynamic properties, reaming, clamping, precision machining

1 INTRODUCTION

In the pursuit of excellence in finishing machining operations, particularly in the reaming process, the stability of tool bars is of paramount importance. This study examines the dynamic characteristics of various tool bar designs, aiming to understand their influence on the quality and efficiency of reaming operations. The primary focus is on how the design and material of the tool bars impact their ability to suppress chatter, a prevalent issue affecting surface finish and hole quality.

The development of new options for clamping reaming heads was necessitated by the need for more economical and sustainable solutions in larger dimensions, where the use of solid material becomes prohibitively expensive, and transportation and coating processes are less affordable. Mechanical clamping of reaming head emerges as a primary consideration in making the product more convenient and sustainable, addressing the economic and transportation challenges. Inspiration for the creation of this research was needed to explore different designs and find a chatter-free combination.

The current article explores the development of a commercial tool bar, employing specific cutting edges geometries while also considering the applicability of traditional reaming head designs. There is a growing focus on passive damping techniques in operations such as boring, turning, and milling. Recent publications have introduced various passive damping solutions for boring bars, including Constrained Layer Damping (CLD) and the use of composite structures [Nanda 2021 and Song 2016], which absorb vibration energy more effectively than traditional steel constructions. The incorporation of particles within these structures offers additional resistance to chatter, leveraging the loss mechanisms of momentum and friction between particles [Ftiend 2000 and Chockalingam 2017].

Another approach to chatter suppression involves friction, where a direct application of additional mass to the boring bar. This mass, which slides along the bar, serves to absorb vibrational energy [Edhi 2001]. A particularly effective method for mitigating chatter involves the use of tuned dampers. These are specifically designed for a certain frequency range, adding mass at frequencies most susceptible to chatter occurrence [Yadav 2020].

Other researchers have concentrated on the numerical analysis of hole quality post-reaming, to cutting parameters [Epureanu 2003, Dilley 2005 and Towfighian 2007]. A commonality among these studies is the application of low cutting speeds, aligning with the quasi-static formulation of the reaming process.

[Epureanu 2003] employed linear stability analysis and nonlinear dynamic analysis to evaluate conditions and their effects, comparing these with practical outcomes. Another study [Dilley 2005] observed the impact of additional damping on numerical results, highlighting its significance and confirming through modeling that non-even pitch contributes to enhanced stability conditions. [Dilley 2005] introduced a numerical model for chatter analysis using a frequency domain approach, examining how damping influences the stability lobe diagram.

This body of research aims to categorize the reaming process, pinpointing main influences and emerging trends. Studies [Bezerra 2001, De Chiffre 2008 and Fulemova 2017] have focused on how cutting parameters affect hole quality, while articles [Fulemova 2017 and Bhattacharyya 2006] consider the misalignment between the hole and reamer. Findings suggest that hole quality and dimensions are influenced by factors beyond mere tool-workpiece misalignment

Compared to other machining processes, reaming receives less attention, particularly regarding vibration mitigation through practical experiments and the exploration of passive solutions. The use of a reamer with specific geometry introduces additional complexities to the process.

2 EXPERIMENTAL SETUP

2.1 Used machine methodology and tool design

Presented experiment was designed to cover needs for deeper understanding of dynamic behaviour of toolbar, which is in current development and chatter was present in all previous attempts. Investigation of dynamic properties of specific toolbar designs, including the determination of resonance frequencies and damping ratios, and to compare these characteristics across different designs from FRF measurement. The study also aimed to estimate the behavior of the tool under conditions of vibration and stability. For this purpose, Fast Fourier Transform (FFT) analysis was employed on two selected cutting speeds, which ensure fundamentals data for further experiments.

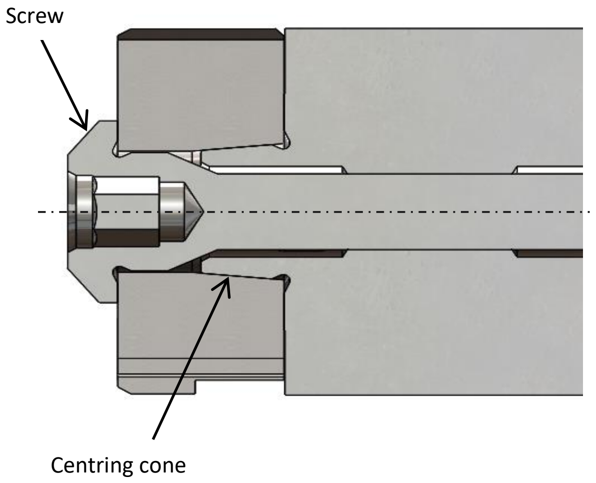

Figure 1. Clamping system

All tests were executed using a CNC milling machine, specifically a Deckel Maho DMU 60 T equipped with HSK63-A interface. the toolbar was firmly clamped within the hydraulic tool holder, also featuring the HSK63-A interface. Three distinct designs of the toolbar incorporating a conical clamping mechanism were explored, each designed to securely centre the reaming head position. The reaming head was securely fastened against the cone using a screw. The clamping cone's interface is depicted in Fig. 1. to prevent any undesirable rotation, an anti-rotation driving key was employed, as illustrated in Fig. 2.

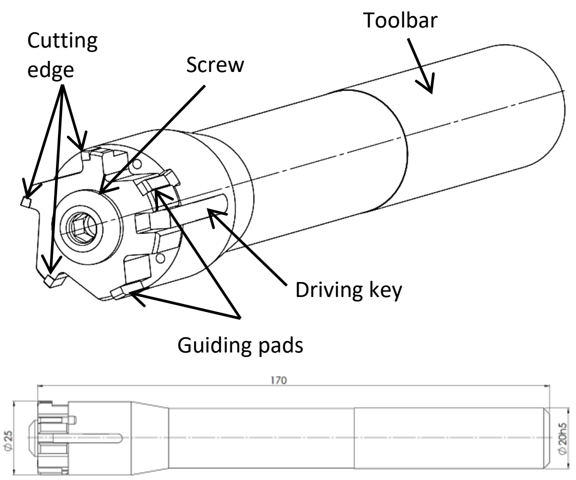

Figure 2. Steel toolbar

A specialized reamer design was used, featuring three cutting edges and two guide pads. The design of the reamer is named MT3 and it is patented by company Finaltools (patent nb. CZ308960). On one side of the remaer is placed 3 cutting edges from CBN, on opposite side is brazed the guiding pads made from PCD. The placement and sharpening of cutting edges are governed by specific guidelines in axial and angular position to ensure functional operating conditions because cutting edges are just on half of the tool. Cutting edges are manufacture on bigger diameter than guiding pads. The principle of this reaming process is similar to that used with single-edge reamers, although in the current situation there are three cutting edges on one side instead of just one. That means the feed rate is fixed due to specific adjustment of the cutting edges. During machining, a slight deviation (in the range of micrometres) is necessary to ensure contact with the guide pads. However, during the initial rotations, only the cutting edges are in contact with the workpiece, causing deviation without any support from the guides. This phenomenon excites vibrations, which are then challenging to mitigate. This situation could be reduced by increasing the stiffness of the system and reducing deviation, which prevents a crash of guide pads into the material. Or increase a damping properties and mitigate an already attending chatter.

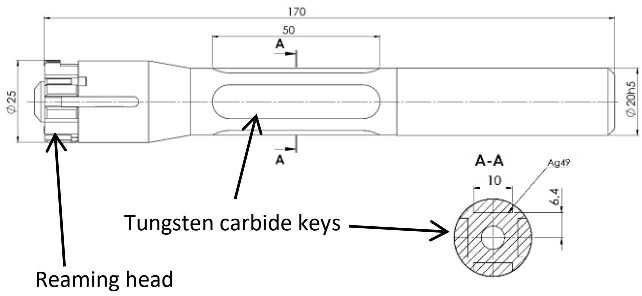

Figure 3. Modified steel toolbar

Steel 1.2343 (X37CrMoV5-1), quenched and tempered to 45±2 HRC was used to construct these toolbars. The first design was a straightforward implementation of this material displayed on Fig. 2. The second modified: four cemented carbide elements in the shape of a parallel key was brazed to the surface of the steel bar to enhance its performance (Fig. 3). This design presents attempt for changing properties, which has direct influence on dynamic behaviour, such as mass and its centre and adding extra connection which can dissipate vibration energy. Connection was ensured by the soldering with solder Ag49 on the bottom of the key hole. Lastly, the third design was manufactured from a solid carbide body with a shrink-fitted clamping interface, made from the same material as the previous design, representing the most rigid option for evaluating dynamic properties (Fig. 4). The interface part was heated and clamped onto the solid carbide body with an overlapping diameter. This overlap ensures a secure connection between the two parts. All designs were made compatible with the conical clamping interface, ensuring a consistent platform for evaluation.

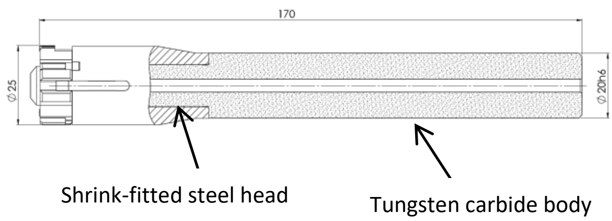

Figure 4. Solid carbide design

The micrometry of the reaming head was made by silicon brush with grit 600. All the tools were prepared with uniform edge. For evaluation of micro geometry was used Helicheck PRO optical measuring machine, which is equipped with a camera capable of magnifying images up to 1 000 times. Radius variations in repeated measurements was 0,003 mm.

The highest value of used tool was 16 µm and the radius is uniform with κ equal close to one (Fig. 5).

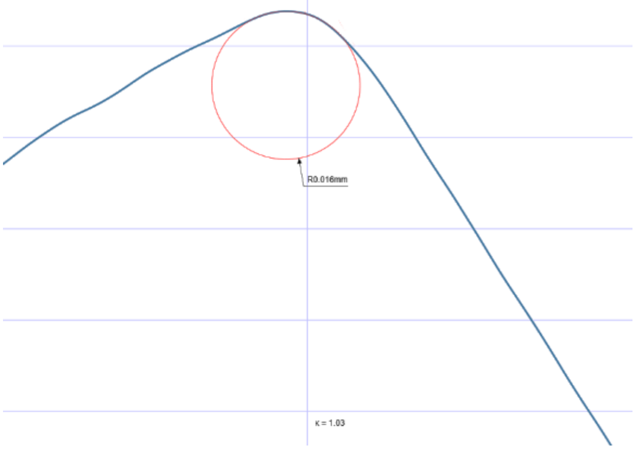

Figure 5. Tool micro geometry

2.2 Data collection - FRF

In the examination of the tool bars dynamic behaviour, data were gathered through static modal testing. An accelerometer (Bruel & Kjaer, type 4513-B with sensitivity 1,001mV/ms-2) was affixed at position 100 mm from the tool holder along the tool bar by magnet and vax (Fig. 6). Consistent excitation was induced at 100 mm from the tool holder using an impact hammer (Bruel & Kjaer type 8206-003) with plastic tip, which can cover frequency range up to 1 000 Hz. This setup aimed to accurately capture the natural frequencies and displacements of the tool bars under static conditions.

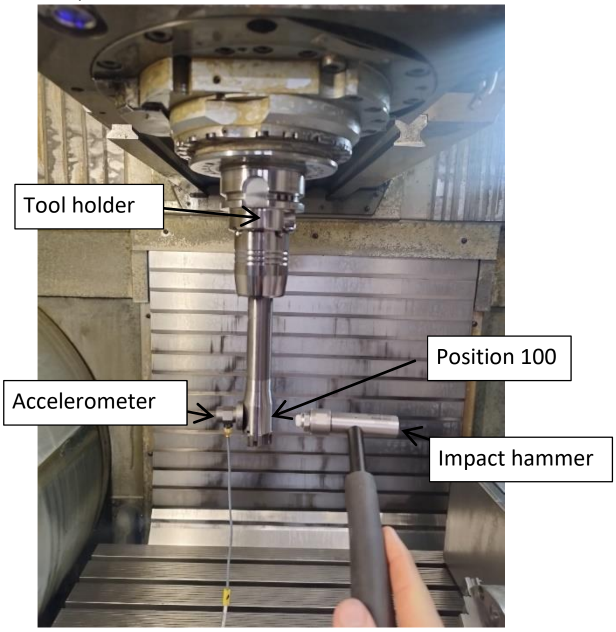

Figure 6. FRF setup

Frequency Response Functions (FRF) and acceleration data were meticulously gathered. The Bruel & Kjaer Photon+ switch and amplifier were utilized to ensure the transfer of data to the PC. Additionally, the RT Pro Photon+ software was employed for the processing of the data.

A frequency span was set up to 1600 Hz was targeted, and a total of 6400 samples were recorded. The gathered data were then used to identify the resonance frequencies at two directions to establish the damping ratio of each toolbar. These data were subsequently utilized for the comparison of the dynamic behavior of all designs.

2.3 Data collection - FFT

The material selected for the reaming experiment was compacted cast iron (GGG40 equivalent EN-GJS-400-15). The specimen comprised a solid cylindrical bar, measuring 160 mm in diameter and 40 mm in length. The hardness of the material was established using a Brinell hardness test, conducted with a 5 mm diameter tungsten carbide ball on an R-187.5 machine by Proinex. The hardness was measured as HBW/5, with ten repetitions at various points on the sample to ensure accuracy and reliability. The average value derived from these measurements was 165 HBW.

Data was collected using a three-axis accelerometer (Bruel & Kjaer, type 4525-B), which has sensitivities of 1.039, 1.042, and 1.032 mV/ms-2 in the X, Y, and Z directions, respectively, which was positioned next to the machined hole and replaced to the same position (in reference to new hole) with every repetition. The experiment was conducted with two different cutting speeds as the minimum for getting fundamentals information about toolbar designs. Each test was repeated three times under each cutting condition and across all designs. FFT analysis was performed, and the octave spectrum were determined, contributing to design optimization. The three-dimensional accelerometer data helped to estimate the dominant vibration direction. For each set of cutting condition was used new reaming head. Run out of the tool was adjust to 5 µm to avoid misalignment with workpiece.

3 RESULT

3.1 FRF analysis

The dynamic behavior of the three toolbar designs was assessed by analyzing the amplitude of their Frequency Response Functions (FRF). These amplitudes reveal the vibrational characteristics of each design, essential for their capability to suppress chatter during machining.

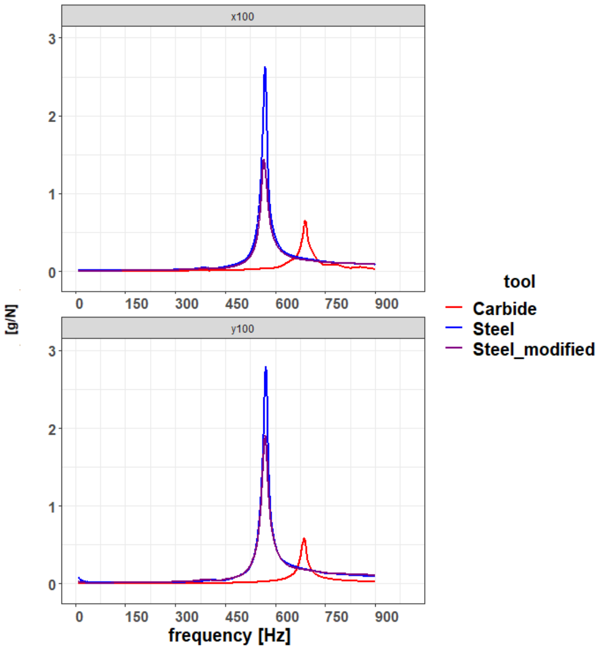

Figure 7. FRF Amplitude X and Y axis

The FRF amplitude comparison revealed that each toolbar design responded differently at various critical frequencies, where peak amplitudes were noted. Such variations highlight the role of toolbar design in achieving optimal dynamic performance and the potential for chatter reduction.

FRF functions were taken in two perpendicular directions. Fig. 7 illustrates the amplitude progression of all three designs in position 100 m from the tool holder. Natural frequencies were consistently 570 Hz, 568 Hz and 688 Hz respectively for all designs.

The 3 dB Bandwidth method was applied to determine the damping ratio for each design. A summary of measured, respective calculated data is in Tab. 1. All three designs showed comparable behavior in their FRF profiles, with the graphs appearing similar regardless of the design, and natural frequencies of steel toolbar and modified are close to one another. However, the damping ratio and maximum amplitude varied, with the modified steel holder exhibiting the highest damping ratio and the cemented carbide holder showing the lowest amplitude.

Comparing these three designs, it is notable that design number 2 with the lowest resonant frequency, medium amplitude and highest damping should theoretically absorb vibration more effectively and potentially lead to less vibration during operation. Conversely, the cemented carbide design with the highest resonance frequency - often associated with higher stiffness – a moderate damping ratio and significantly the lowest amplitude, indicates a less pronounced response at resonance.

Design	f_N X [Hz]	f_N Y [Hz]	Damping ratio [-]	Amplitude X [g/N]	Amplitude Y [g/N]
1. Steel	569	571	0,021	2,77	2,61
2. Mod. steel	566	569	0,030	1,9	1,44
3. Cem. carbide	689	687	0,023	0,58	0,63

Table 1. Dynamic properties summary

3.2 Wilcoxon test - symmetry

To evaluate the consistency of vibrational behavior in the perpendicular directions of the toolbar, the Wilcoxon signed-rank test was employed. This non-parametric test is particularly suited for the analysis due to the non-normal distribution of the Frequency Response Function (FRF) amplitude data. The test compares the median of the paired differences to assess whether there is a statistically significant shift away from zero. An overview of the p-values and T-values from the Wilcoxon test is displayed in Tab. 2. The R software was utilized to perform the calculations. The ranks of the differences between paired measurements (T-values) and the p-value are used as criteria for hypothesis testing.

Upon applying the Wilcoxon test to the FRF amplitude data in the X and Y directions along the toolbar, a statistically significant difference was detected. The p-value is nearly zero, indicating a rejection of the null hypothesis and confirming a true difference in the median amplitudes across all measurements. This result indicates an asymmetry in the whole system response depending on the direction of the applied force. The toolbar itself is a rotation part and the reaming head is asymmetric, but asymmetry in FRF response is mostly caused by clamping and machine components which typically have a directional behavior.

This anisotropic behavior is likely influenced by the design of the reaming head, which features three cutting edges on one side and two guide pads on the other. Consequently, the general construction of the toolbar has been adapted to accommodate this design.

Design	p-value	T- value	Hypothesis
1. Steel	1.779e-07	5 839	H0 rejected
2. modified steel holder	2,2e-16	3 039	H0 rejected
3. Cemented carbide	2,2e-16	1 746	H0 rejected

Table 2. Wilcoxon test results

3.3 FFT analysis

In the study, Fast Fourier Transform (FFT) analysis played a proving role in evaluating the effectiveness of the toolbar designs under various cutting conditions. The analysis was conducted using a three-axis accelerometer, consistently positioned next to the hole for each test (Fig. 8), ensuring uniformity in data collection. Three holes for each cutting condition (Tab. 3) were reamed and average values were calculated. For each experiment set (toolbar/cutting condition) was used new reaming head. FFT was evaluated in a midle of the reaming with duration 0,5 s.

Spindle rotation [rev/min]	Rotation frequency [Hz]	Feed rate [mm/rev]	Feed rate [mm/min]	Reaming time [s]
2 802	46,7	0,42	1 177	2
4 459	74	0,42	1 872	1,3

Table 3. Cutting condition

The FFT analysis covered a frequency range of up to 1600 Hz, with a line resolution of 800, providing insight into the vibrational characteristics of the toolbars during a reaming process. 1/3 octave spectrum with linear filter from FFT analysis was utilized as a major evaluation, which revealed that dominant frequency bands in the vibration data were closely aligned with the rotation frequencies of the spindle. the visualized data is plotted in Fig. 9. The octave spectrum provides overall information about vibration energy during the process.

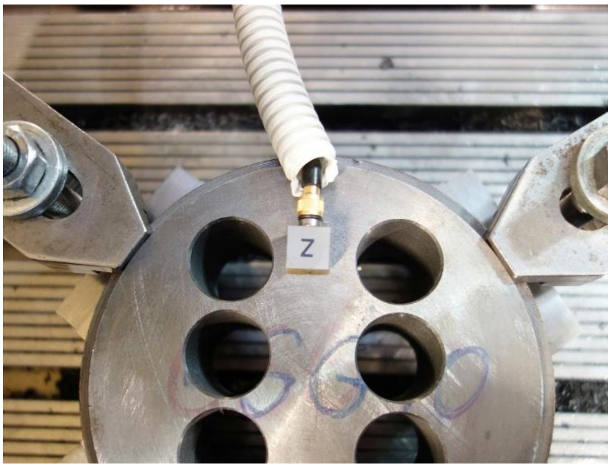

Figure 8. Dynamic experiment- accelerometer position

A significant observation from the FFT analysis was the distinct performance of all three toolbar designs at a cutting speed of 220 m/min, with the modified steel and carbide toolbars

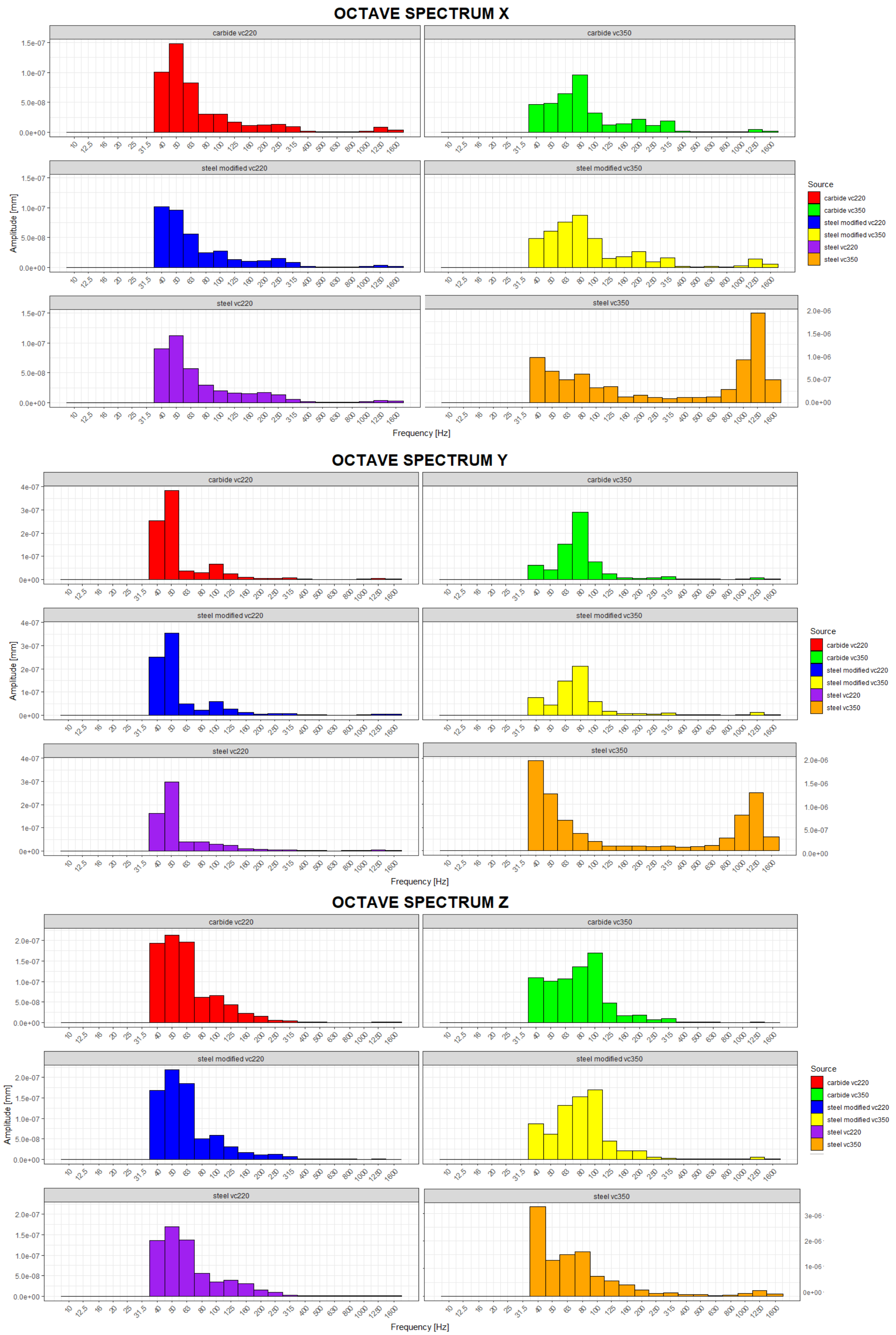

Figure 9 Octave spectrum (FFT analysis)

demonstrating stability even at both cutting speeds. This consistency suggests that both the modification provide better chatter resistance. All three designs showed a major concentration of amplitude near the rotation frequencies, indicating that the machining process does not excite frequencies close to or at multiples of the system's natural frequency. However, the standard steel toolbar exhibited different behaviour. At a cutting speed of 350 m/min, the FFT analysis revealed vibration issues and cutting edge breakage. the main octave spectrum bins for the steel bar were at 40 Hz and 1250 Hz, suggesting resonance frequencies different from the toolbar's natural frequency. The 40 Hz peak, differing from the rotation frequency, indicates sub-harmonic vibration due to some non-linearity in the system comprising the machine, tool, and workpiece. The 1250 Hz frequency, higher than the natural frequency or close multiples of the rotation frequency, suggests a critical frequency where the system's dynamics become unstable.

The presence of a slight increase in the bin with 1250 Hz band in the other designs indicates that it might be related to the interaction between the tool and workpiece. The fact that the tool bar's resonance frequency is 569 Hz and the spindle frequency is 74 Hz, coupled with the occurrence of chatter, indicates that the chatter mechanism is more complex than simple resonance with the tool's natural frequency. The alternative scenario is that torsion vibration occurred.

Despite the observation of a significant peak in octave spectrum in the 1 250 Hz band, a closer examination reveals a lack of correlation with the tool's natural frequency of 570 Hz. Dominant peaks are observed at 1 330 Hz and 1 175 Hz from 1 250 band, that do not align with any simple multiples of the natural frequency as is presented in Fig. 10. This discrepancy indicates that the 1 250 Hz peak is not a result of harmonic multiplication of the tool's natural frequency suggests that other dynamic phenomena within the machining system are contributing to these vibrations. The amplitude of the steel bar at higher cutting conditions was significantly higher than in other experiments, highlighting a potential limitation in its design when operating at these speeds and underscoring the need for further optimization. In terms of tool dynamics, it was observed that the Z direction plays a minority role when the main cutting forces are presented in the X and Y directions, due to ground deflection of the tool on one side during the process. A comparison of the same axis under different cutting conditions revealed a decrease in maximum amplitude, suggesting that a cutting speed of 350 m/min might be more suitable for the cutting geometry and the material being machined. The pattern of the octave spectrum was similar across all axes, but amplitudes varied in different directions, which correspond with Wilcoxon hypothesis about asymmetry response. The vibration responses were similar in all three measured directions within the same frequency bin.

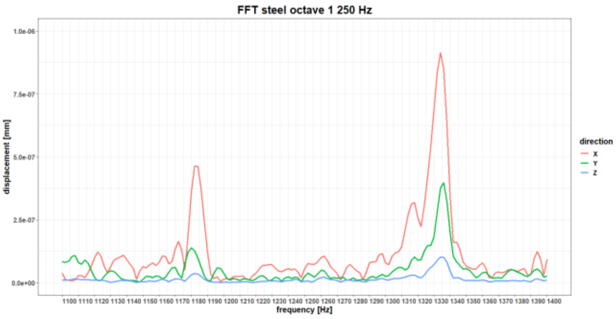

Figure 10. Steel tool bar FFT detail 20th band

The FFT shows no differences at the middle and end of the hole because throughout the process, the reamer maintained continuous contact with the cut along the entire length of the cutting edge, ensuring that both the cutting edges and guiding pads remained engaged. When no chatter occurred, the start of the hole demonstrated similar results from the perspective of frequency peaks in amplitudes, comparable to those in the middle of the cut. For instance, an experiment with modified steel at a cutting speed of 350 m/min is shown in Fig. 11. The analysis at the start covers the first 0.04 seconds, which corresponds to the first three rotations—from the initial contact of the cutting edges until the guiding pads engage with the machined hole. Peaks are visible in the X and Y axes at the rotational frequency of 74 Hz in both charts, although the displacement values differ; peaks in the middle of the cut are more pronounced and reach higher values. The Z direction shows a major peak at 108 Hz, which is also dominant in the octave spectrum for a cutting speed of 350 m/min. Higher cutting speeds result in greater vibration response along the tool axis out of the rotation frequency. This greater displacement is evident at the start until the guiding pads are fully engaged. The vibration case (steel tool body) exhibits the same pattern but with significantly increased amplitudes at certain frequencies compared to stable conditions.

3.4 *Surface quality*

Surface quality is a critical parameter, that is very sensitive to chatter. In this study, the occurrence of chatter had a direct and observable impact on surface quality. Notably, when chatter occurred, it severely compromised the integrity of the machined surface, making it impossible to measure accurately. The occurrence of chatter in v_c=350 m/min was particularly destructive, creating a pattern resembling

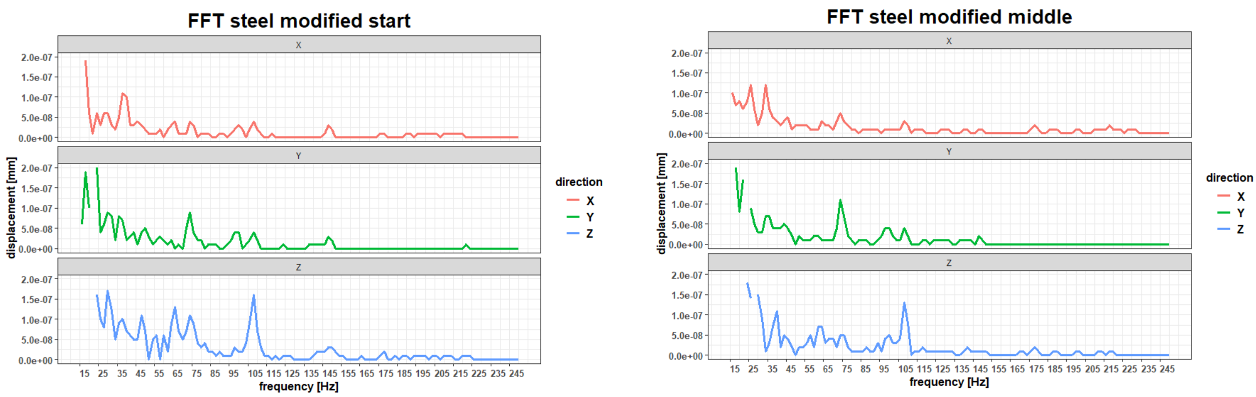

Figure 11. FFT comparison modified steel tool bar

a “1 000 edge shape” on the surface, characterized by cuts in the material and damage to the hole represented by fig. 12.

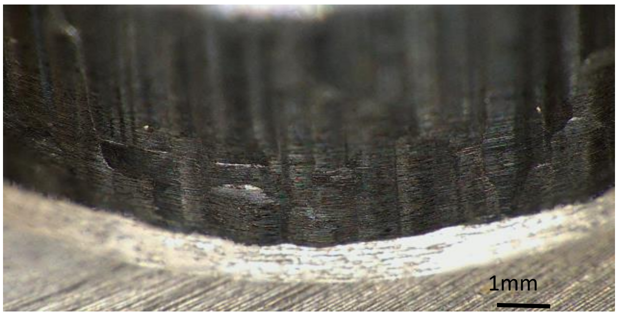

Figure 12. Steel holder v_c=350m/min

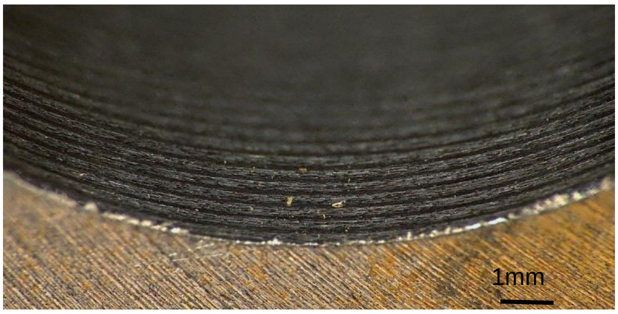

Figure 13. Carbide holder v_c=350 m/min

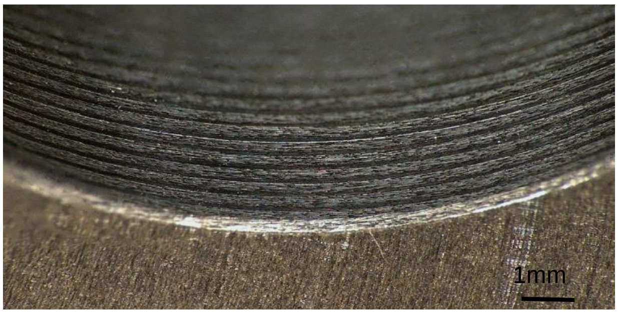

Figure 14. Carbide holder v_c=220m/min

Measuring device mahrsurf PS 10 was utilized for surface roughness measurement. Evaluation were repeated 10 times, when highest and lowest values were excluded and from residue box plots were created. To evaluate surface quality, the Rz parameter, which measures the highest peak-to-valley height of the surface profile, was employed. The length 4,2 mm was measured 5 mm from the starting edge in hole axis direction.

The results indicated a correlation between cutting speed and surface quality. At lower cutting speeds, the surface quality was found to be worse than for higher speed. This deterioration in surface finish at lower speeds is likely attributable to unsuitable rotation speeds for the given machining operation. In contrast, at higher cutting speeds, there was a marked improvement in surface quality. This improvement suggests that the machining process becomes more efficient and effective at higher speeds Fig. 13, 14 represent machined surfaces on both cutting speeds, the visual look has a pattern of concentering rings, which is typical for guided reamers.

Material GGG40 is often used in hydraulic distributors, where on/off piston slide in reamed hole. For these components is often required Rz 6 µm and better to avoid leakage. Both cutting speeds are not found to as suitable for sufficient surface finish. In all cases surface has visible scratches and Rz values are high. The additional increase in cutting speed would be challenging in the scenario of current problems with chatter elimination.

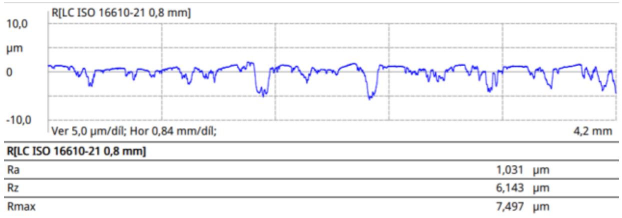

Figure 15. Roughness profile v_c=350m/min cemented carbide toolbar

Fig. 15 presents results from surface profile measurements, indicating that high Rz values are predominantly caused by valleys rather than peaks. This is a typical scenario for guided reamers, where guiding pads either rip off or compress the material's peaks. The presence of valleys suggests a low cutting speed and material adhesion during the cutting process, which subsequently leads to material being torn from the surface.

This relationship between cutting speed and surface quality underscores the importance of optimizing machining parameters to achieve the desired surface characteristics. Additionally, it highlights the detrimental effect of chatter on surface quality. Given the current cutting geometry and the principle of machining, where deviation during reaming occurred during first few cuts, it becomes evident that chatter is not only destructive for the surface quality but also for the hole dimensions and the reamer itself. When chatter occurs, it compromises the integrity of the entire machining process, leading to significant issues in both the finished product and the tool's performance. The summarized data from roughness measurement are visualized as a box plots in Fig. 16.

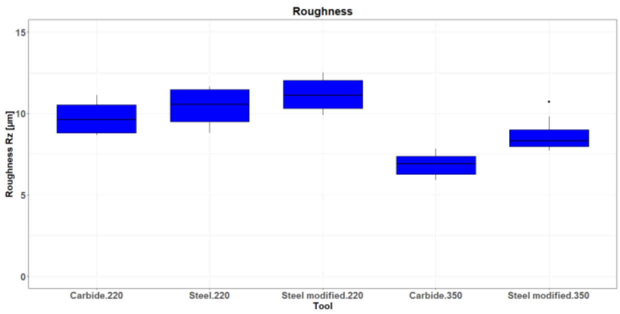

Figure 16. Boxplot roughness all designs

3.5 Hole roundness

The inherent design of the reamer construction allows to achieve the highest possible quality of the machined holes, as the principle is very similar to single edge reamer. This aspect of tool design is crucial, as it directly influences the precision and accuracy of the machining process. To evaluate the roundness throughout the height of the holes, a 3D CMM Mitutoyo Crysta Apex V machine was used. Roundness measurements were taken perpendicular to the hole axis using a scanning method at a speed of 3 mm/s. An iridium probe with a 3 mm diameter was employed. For each height, measurements were taken at 900 points, and a 50 UPR filter was applied.

The results obtained were exceptionally positive for both cutting speeds (v_c), indicating the effectiveness of the reamer design in maintaining hole quality under varying operational conditions. Entrance of the hole exhibits worse roundness in all cases. This effect is caused by a deflection, followed by stabilizing by a guide pads. Notably, the best roundness was achieved with the tungsten carbide toolbar (Fig 17). This outcome is significant as it highlights the superiority of tungsten carbide in terms of enhancing the geometric accuracy of the holes. The precision in roundness achieved with the tungsten carbide toolbar underscore its potential as a preferred material in toolbar construction.

The results are affected by errors associated with the unknown surface texture in the direction of probe movement. Additionally, even with knowledge of the surface texture, the spherical shape of the scanning probe would likely overcome valleys in the material. More accurate results could be obtained using a roundness measurement instrument with sharper probe design or an optical scanning machine. Despite these potential inaccuracies, the commonly used CMM was employed as the standard evaluation tool in many manufacturing environments.

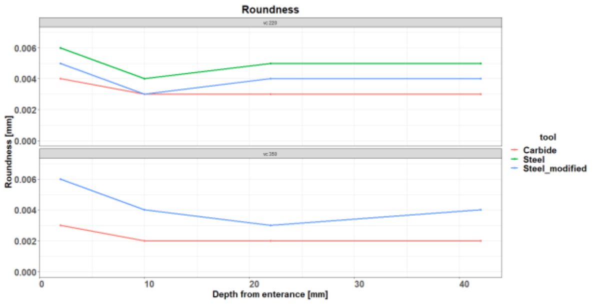

Figure 17. Geometry quality of hole- all designs

4 DISCUSSION

This article, grounded in practical application, provides a data that will be instrumental in guiding future work with tool design.

Key findings have been identified from the study, particularly regarding the effectiveness of modifications in enhancing performance at higher cutting speeds (v_c). These modifications, especially those involving passive solutions, have been shown to significantly improve the handling of complex challenges associated with excitation at the start of the reaming process. A comprehensive understanding of this excitation is deemed necessary for future development. It is suggested that any design development should be based on a deeper investigation into the causes of chatter and the initial phenomena leading to it. The inclusion of a numerical model, in conjunction with the current experimental data, is anticipated to facilitate the development of a new design with enhanced resistance chatter.

The current experiment faces limitations in identifying mode shapes, particularly torsional vibrations. Another limitation is found in the frequency coverage during FRF analysis; an impact hammer with a plastic tip, limited to a maximum frequency range of 1 000 Hz, was used. This constraint could lead to misinterpretation, as only one natural frequency was identified.

Future research is expected to focus on validating the current results with a numerical model, grounded in the data obtained from the experiments. A full understanding of the current machining process is considered crucial for future development. The primary goal is to identify the source of the higher frequency that becomes dominant during chatter. This investigation might involve FRF measurements focusing on the modal shapes of the toolbar to correlate these measurements with a FEA model.

In commercial applications, the tungsten carbide toolbar has been identified as a sufficient choice. Its effectiveness in fulfilling functional requirements along with its ease of integration, makes it a practical option for immediate industrial use, eliminating the need for additional development. However, caution is advised in scenarios where higher cutting speeds are necessary, as this could lead to chatter.

Future consideration could lead to the combination of advances of stiffness cemented carbide body with passive tune damper or other solution increasing a chatter resistance.

5 CONCLUSION

- The dynamic behavior of the three toolbar designs was assessed by analyzing the amplitude of their Frequency Response Functions (FRF). the comparison of FRF amplitudes indicated that each toolbar design exhibited distinct responses at various critical frequencies, with notable peak amplitudes observed. Among these, the tungsten carbide toolbar demonstrated the highest resistance to deviation, and its resonance frequency was the highest compared to the other designs. This suggests that achieving resonance frequency through rotation frequency is more challenging with the tungsten carbide toolbar, highlighting its stiffness in the context of machining stability. Modified steel bar with tungsten carbide represents a solution with the highest tendency to dissipate vibration energy due to the highest damping ratio.

- After measuring FRF the notable differences in X and Y direction were observed. The Wilcoxon signed-rank test was employed to evaluate the consistency of vibrational behavior across the perpendicular directions of the toolbar. A statistically significant difference was detected, indicating an asymmetry in the system response depending on the direction of the applied force, which is caused by asymmetry in the tool but mostly by the construction of the machine.

- The FFT analysis played a proving role in evaluating the effectiveness of the toolbar designs under various cutting conditions. The analysis indicated that the modified steel and carbide toolbars behave more stable in tested cutting speeds, while the standard steel toolbar showed limitations at higher cutting speed, which is necessary for achieving sufficient surface finish.

- Surface quality, measured using the Rz parameter, showed a direct correlation between cutting speed and surface finish. Higher speeds resulted in better surface quality, highlighting the importance of optimizing machining parameters. This result fails to meet the necessary standards required for components made with this material, which are standardly hydraulic components with Rz 6 micrometers and lower requirements.

- The hole quality assessment revealed that the tungsten carbide toolbar achieved the best roundness, indicating its superiority in enhancing the geometric accuracy of the holes.

- Despite the scarcity of articles focusing directly on the application of reamers, a few researchers have explored the fundamentals of multi-edge reaming without guidance. It has been observed that some parameters, such as the misalignment between the workpiece and reamer, significantly affect hole quality, while cutting speed impacts the achieved surface quality, as presented in studies by [Bezerra 2001, De Chiffre 2008, Fulemova 2017, and Bhattacharyya 2006]. Currently, there is a notable gap in research regarding the development and testing evaluation of clamping systems for reaming applications.

ACKNOWLEDGMENTS

This article was conducted in cooperation with Brno University of Technology and did not receive any external funding. We extend our deepest gratitude to the university community for their support and the provision of resources that facilitated the successful completion of this study.

REFERENCES

[Nanda 2021] Nanda, B., & Srinivas, J. (2021). Investigation of Stability in Internal Turning Using a Boring Bar with a Passive Constrained Layer Damping. Facta Universitatis, Series: Mechanical Engineering, 19(2), 384-399. https://doi.org/10.5937/FME2102384Y

[Song 2016] SONG, Qinghua; SHI, Jiahao; LIU, Zhanqiang; WAN, Yi a XIA, Feng. Boring bar with constrained layer damper for improving process stability. Online. the International Journal of Advanced Manufacturing Technology. 2016, roč. 83, č. 9-12, s. 1951-1966. ISSN 0268-3768. Available fro: https://doi.org/10.1007/s00170-015-7670-5. [cit. 2024-02-21].

[Friend 2000] FRIEND, R. & KINRA, V.. (2000). Particle impact damping. Journal of Sound and Vibration - J SOUND VIB. 233. 93-118. 10.1006/jsvi.1999.2795.

[Chockalingam 2017] Chockalingam S, Natarajan U, George Cyril A. Damping investigation in boring bar using hybrid copper-zinc particles. Journal of Vibration and Control. 2017;23(13):2128-2134. doi:10.1177/1077546315610946

[Edhi 2001] Edhi, Evita & Hoshi, Tetsutaro. (2001). Stabilization of high frequency chatter vibration in fine boring by friction damper. Precision Engineering. 25. 224-234. 10.1016/S0141-6359(01)00074-5.

[Yadav 2020] YADAV, Ajay; TALAVIYA, Devangkumar; BANSAL, Ankit; LAW, Mohit a XIA, Feng. Design of Chatter-Resistant Damped Boring Bars Using a Receptance Coupling Approach. Online. Journal of Manufacturing and Materials Processing. 2020, roc. 4, č. 2, s. 1951-1966. ISSN 2504-4494. Available from: https://doi.org/10.3390/jmmp4020053.

[Epureanu 2003] Epureanu BI. an investigation of stability and pattern formation in reaming. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 2003;217(2):269-281. doi:10.1243/095440503321148894

[Dilley 2005] Dilley, David & Bayly, P.V. & Whitehead, Brian & Calvert, Sean. (2005). an analytical study of the effect of process damping on reamer vibrations. Journal of Sound and Vibration. 280. 997-1015. 10.1016/j.jsv.2004.01.054.

[Towfighian 2007] Towfighian, Shahrzad & Behdinan, Kamran & Papini, M. & Saghir, Ziad & Zalzal, Paul & Beer, J.. (2007). Finite element modeling of low speed reaming vibrations with reamer geometry modifications. Journal of Intelligent Manufacturing. 18. 647-661. 10.1007/s10845-007-0038-4.

[Bezerra 2001] Bezerra, A.A & Machado, Alisson & Jr, A.M & Ezugwu, E.. (2001). Effects of machining parameters when reaming aluminium–silicon (SAE 322) alloy. Journal of Materials Processing Technology. 112. 185-198. 10.1016/S0924-0136(01)00561-1.

[De Chiffre 2008] De Chiffre, L., Tosello, G., Piska, M., & Müller, P. (2008). Investigation on Capability of Reaming Process using Minimal Quantity Lubrication. in B. Lindberg, & J. Stahreand (Eds.), Proceedings of the Swedish Production Symposium: SPS08 (pp. 85-92). Royal Institute of Technology (KTH) (Stockholm, Sweden). http://www.sps08.se

[Fulemova 2017] FULEMOVA, Jaroslava; KUTLWASER, Jan; GOMBAR, Miroslav a REHOR, Jan. Influence of Selected Technological Factors on the Hole Quality During Reaming. Online. Proceedings of the 28th International DAAAM Symposium 2017. DAAAM Proceedings. 2017, s. 0334-0340. ISBN 9783902734112. Available from: https://doi.org/10.2507/28th.daaam.proceedings.046. [cit. 2024-02-20].

[Bhattacharyya 2006] BHATTACHARYYA, Onik; JUN, Martin B.; KAPOOR, Shiv G. a DEVOR, Richard E. the effects of process faults and misalignments on the cutting force system and hole quality in reaming. Online. International Journal of Machine Tools and Manufacture. DAAAM Proceedings. 2006, roc. 46, č. 12-13, s. 1281-1290. ISBN 9783902734112. ISSN 08906955. Available from: https://doi.org/10.1016/j.ijmachtools.2005.11.002. [cit. 2024-02-20].

CONTACTS:

Ing. Krystof Lanc
Brno University of Technology
Faculty of Mechanical Engineering
Departure of manufacturing technology
Technicka 2, Brno, 616 69, Czech Republic
+420 605 369 774, Krystof.Lanc@vutbr.cz