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THE VIBRATION INFLUENCE OVER CBN TOOL LIFE IN HARDENED BORING OPERATIONS USING TOOL OVERHANGS

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Abstract. *Turning operations, especially those performed in deep holes, are associated with significant problems related to chatter, which have considerable influence over some productivity factors, production costs, etc. In pre-roughing operations, the drill marks leave great irregularities on the part's surface. Those cause chatter during the internal turning process, especially during finishing operations, which are used to obtain internal diameters of better accuracy. The vibration is even more accentuated in the machining of hard materials, that requires more intense cutting forces and reach higher cutting temperatures. In such cases, the use of CBN tools is necessary to improve the performance during the machining operation. This work aims to verify the influence of vibration over tool life. To that end, the tests consisted in collecting acceleration signals determined from the Fast Fourier Transform (FFT) and monitoring the tool wear process using optical microscopy, so that the lifespan of the tool could be verified. The tool overhang was varied until it reached a limit (the deepest hole it could machine). The results show that, when the tool overhang is within its stability range, the tool vibration amplitude is greater in the beginning of tool life than in its end, and the surface roughness of the machined part is not affected. Also, the flank wear of the tool is accentuated when the tool overhang outreaches its stability limit.*

Keywords: *vibration, machining operation, tool wear.*

1. INTRODUCTION

Usually, the selection process of a cutting tool goes through a technical and economic analysis. In most situations, both analyses should be considered in order to make the final choice. In this context, it is important to be aware of the wear parameters and the lifespan of such tool, once the cutting edges of these inserts are generally vulnerable to wear and fretting, which significantly reduce their efficiency and affect the surface roughness of the final product (Meyer, et al., 2012).

1.1 Literature Review

Under ideal conditions, the surface roughness profile is formed by the replication of the tool tip profile at regular intervals of feed per revolution. However, many other factors like the dynamics of the metal cutting operation, elastic recovery of the cut region of the work material, ploughing, spindle rotational error and tool vibration, leading to the relative displacement of the tool and work material contribute to the modification of surface profile. In hard turning, theoretically tool vibration is likely to play a significant role in surface generation. Also, tool vibration is significantly influenced by tool wear (Bhaskaran, 2011).

It is convenient to calculate the material removal of the machining process, its important parameter that determinates the productivity of the process and quite fundamental for the calculation of the machine power. Therefore, the method of obtaining the volume values should be well calculated such as feed, cut depth, cutting speed and part diameter. The latter should be resized when the diameters of the part are very close to the depth of cut (small diameters), to avoid very large errors on the material removal rate with a variation of 4 to 25% (Isakov, 2009).

One of the initial assumptions of machining is that the insert must have a higher hardness than the material that is machined. However, in general, the greater its hardness, the more brittle the material turns to (Suyama, 2014).

In the turning of hardened materials operation, due to the high hardness of the cBN, the monitoring of the wear is a fundamental procedure to avoid chipping and breaking of the inserts (Suyama, 2014).

Previous work has already indicated the possibility of the use of cBN inserts in the machining of hardened materials and in facing operation, even during the occurrence of interrupted cutting. In the work of Diniz et al., (2005), the interrupted cutting caused the excitation of the cut around to 52 Hz; in the case of Oliveira et al., (2009) the interruptions generated by the geometry of the test specimens promoted excitations in the cut around 184 Hz and more recently, Godoy and Diniz (2011), again turning hardened steels with interruptions promoted excitations at the tip of the tool. The results of this work prove that the cBN insert also resists to higher frequency excitations, as is the case of boring bar operations (Suyama, 2014).

2. EXPERIMENTAL PROCEDURE

The main concern of this work consists in the comparative analysis of the tool vibration in the internal turning of hardened materials while using a conventional boring bar.

One 16 mm diameter boring bar of high hardenability ANSI 4140 steel (ISO code A16R SCLCR 09-R) were chosen – It was kindly supplied by Sandvik Coromant.

As for the tool insert, an adequate insert for finishing operations on smooth surfaces of hardened steels was chosen. It was composed of CBN (50 % wt) and a ceramic phase of TiCN and Al2O3; it is ISO code is CCGW09T308S01020F 7015 (class ISO H10). The advantage of the chosen tool insert, when compared to others with a greater CBN content, is its chemical stability in relation to iron. Besides, its toughness is enough to preserve its cutting edge, even though it is reduced when compared to other inserts with a greater CBN content.

The FRFs (Frequency Response Function) of the tool holders were obtained for different overhangs (length of the tool holder that protrudes from the turret) through impact tests (tap test). In each test, the boring bar was fixed to the turret of the machine tool used in the turning tests, as it is further described, with the desired L/D. A piezoelectric accelerometers (ccld accelerometer type 4507 - Brüel & Kjaer), model 4500 was installed on the boring bar, which was then hit with an instrumented impact hammer blend with a Photon model acquisition plate. Each impact was considered a measurement – 5 measurements were done for each L/D and each one of the boring bars used. In the data acquisition, a frequency range of 0 to 10000 HZ was used, with a resolution of 1 Hz, the smallest possible in data acquisition software used. For each test, the software calculated an average of the 5 measurements that were executed and made the results available.

The 4340 steel used in the fabrication of the test specimens is a widely employed material in the metal mechanical industry. It presents high hardenability, bad weldability and reasonable machinability, as well as a good resistance to torsion and fatigue –its hardness after quenching varies from 54 to 59 HRc.

The cutting conditions and the machine setup (tool overhang) were tested in two distinct machining tests. The first measured the tool lifespan, where a maximum flank wear (VBmax) of 0,2 mm according to ISO 3685 for operations without coolant was considered as the end of tool life criterion. The second measured the radial and tangential components of tool acceleration during the cutting process, in the beginning and in the end of tool life.

It is important to define some expressions employed in this work, which are:

- Stable cut: internal turning operation where the vibrations present acceleration signals inferior to 30 m/s2 because of the rigid tool holding; and which yields a surface whose roughness is less than 0.8 µm and that is free from chatter marks;
- Unstable cut: the surface roughness of the machined surface and the acceleration in turning exceed the values cited above as acceptable for a stable cut. A surface with chatter marks is formed;

For the tool life tests, we defined a complete experimental factorial matrix, composed of 2 factors in 2 levels of variation, resulting in 4 conditions. Each condition was replicated once and led to 8 tests. Thus, the 4 conditions were set below on Tab. 1.

Table 1. Cutting conditions for tool life test with an overhang of 70 mm

Condition	Overhang [mm]	Feed rate[mm/rev]	Cutting speed [m/min]
C1	70	0,08	360
C2	70	0,08	300
C3	70	0,06	300
C4	70	0,06	360

3. RESULTS AND DISCUSSION

The Table 2 reports the cutting conditions tested until the end of life, evidencing the results of metal removal rate, surface finish (Ra and Rz) and flank wear (VBmax). The results show that the tool at the end of life does not generate significant changes in the roughness of the part, but it generates transformations in the geometric profile of the tool, mainly in the rake plane of the insert, after the removal of a large volume of chips, limited by the flank wear values of the tool.

Figure 1 below shows the life of the tool in terms of material removal only for stable cutting, cut condition in which there is no chatter (vibration marks on the workpiece surface). It is known that the end of tool life was reached when tool flank wear reached 0.2 mm (ISO 3685). The parameter of material removal rate allows a better comparison of the tool life than the time of cutting, especially in cases where there are variations of the cutting speed.

Table 2. Machining parameters employed in the lifespan test of the CBN insert.

Condition	v_c [m/min]	f [mm/rev]	End of tool life			
			Material removal rate- Q [10^4x mm³]	Ra [µm]	Rz [µm]	$VB_{máx}$ [µm]
C1	360	0,08	6,05	0,58	2,9	201,6
C2	300	0,08	7,2	0,83	3,4	234,6
C3	300	0,06	7,56	0,5	2,72	220,8
C4	360	0,06	6,48	0,78	3,12	212,5

Figure 1 shows the average volume of material removed per minute during tool life (Q) in each one of the conditions described in Tab. 1. A tool overhang corresponding to a 4.4 length-to-diameter ratio (L/D) was used, as it is the longest overhang in which the cut is still stable.

If we compare the results of Tab. 1 and Fig. 1, it is possible to observe that the increase of the cutting speed causes a decrease in the tool life due to the higher cutting temperatures. The increase in feed rate permits an increase in life. This results carried out to check the significant contribution of each input factor (cutting speed and feed rate) showing the results for surface roughness. It can be observed that the feed rate has significant contribution whereas the cutting speed has less contribution and thus is of less importance.

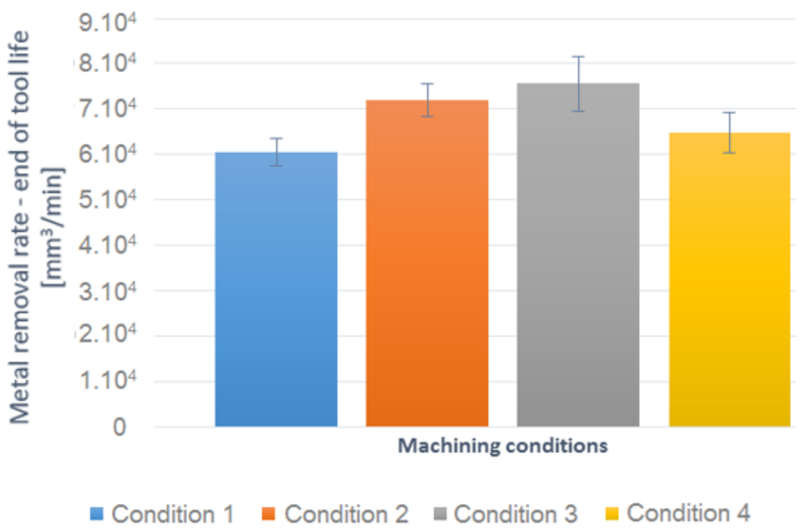


Figure 1. Average volume of material removed during tool life (L/D = 4.4)

Comparing Fig. 1 and Fig. 4, it can be seen that the lower level of vibration caused a slight increase in tool life, due to the stable cut, when seen in Fig. 3, the unstable cut is established when a certain balance is exceeded (L / D = 4.4) generating premature breakage of the tool since the vibration levels are large.

Vibrations are also related to the state of the tool tip profile. Figure 4 below shows the comparison between the acceleration RMS values for new and end-of-life (used) tool.

From the bar evaluated for the stable cut, it was observed that at the very beginning of the tool's life (non-wearable insert) the laboratory tests showed excessive vibration and could cause chip breakage among other problems such as noise and high acceleration amplitude, yielding a roughness of Ra = 1.96 µm and Rz = 8.21 µm, after 1min30s or 30 µm of flank wear, it was seen through a practical evaluation that the roughness reaches values lower than Ra = 0.8 µm.

It can be seen in Fig. 4, Fig. 5 and Fig. 6 that in all the cutting conditions the vibration amplitude in the end of tool life is lower when compared to the insert with low flank wear (slightly above 30µm) at the beginning of tool life. According to Babouri et al. (2017) and Bhaskaran (2011), this phenomenon could be explained by the three main phases of the cutting tool life: wear up period, wear stabilization period, and wear acceleration period where the rapid aging of the tool occurs. In the first phase, the frequency amplitude begins high and decrease with the evolution of flank wear. The wear stabilization period, characterized by lower frequency amplitude than the other phases where the signal remains stable until the flank wear (VB) reaches or exceeds the value of 0.2 mm, which is synonymous of the lifespan of the cutting insert. At this value, the insert is in the acceleration phase corresponding to a critical zone of the machining quality. Those authors also show that the frequency indicator's amplitude varies in a very similar way as the energy and the mean power variation.

This experimental study is also to analyze the impact of tool wear on the quality of surface generated in hard turning. Figure 2 show the roughness parameters Ra, as a function of the flank wear land. The bar graph indicates a gradual increase in the surface roughness as the flank wear land of the tool increases. It can also be observed that, even at the point when the flank wear land was about 0,2 mm, the Ra the value of the surface roughness is less than 0,8 μm for almost conditions. It is an example showing that the uniform flank wear up to 0.2 does not matter from the standpoint of surface finish (Nakayama, 1988). This shows that as a manufacturing process, hard turning can be employed for finish machining as an alternative to grinding. The deterioration in the surface roughness becomes very steep as the wear land crosses the critical value of 0,2 mm (Bhaskaran, 2011).

Nakayama (1988), Bhaskaran (2011) and Oleksandr et al. (2014) highlighted that the frequency amplitude is not the cause of influence in the surface roughness due to the lower acceleration amplitude and the stability of the cutting condition.

So we can state in this case that the amplitude of vibration at the end of life is strongly associated with the geometry of the tool and its wear, and then the overhang, since the cutting conditions do not interfere in the amplitude of beginning and end of life.

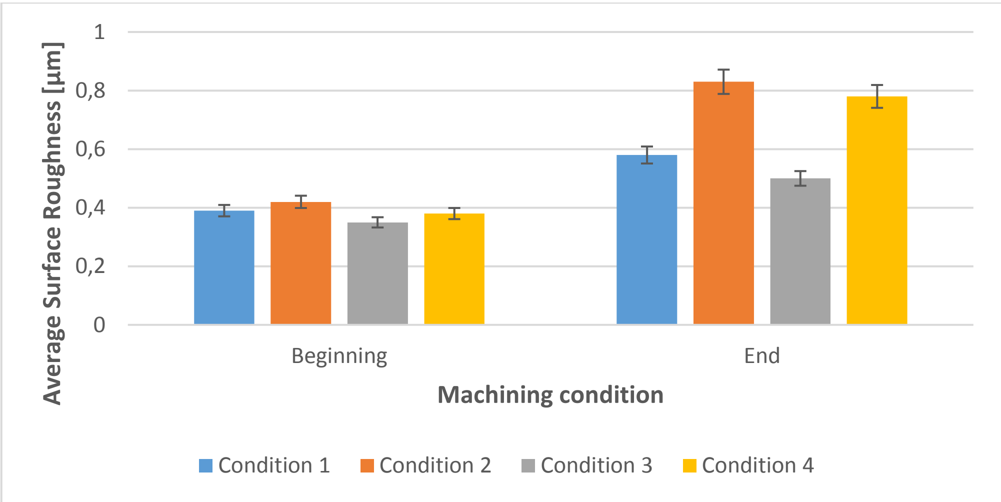


Figure 2. Comparative chart showing the average surface roughness (Ra) obtained in the beginning and end of tool life in the tested machining conditions.

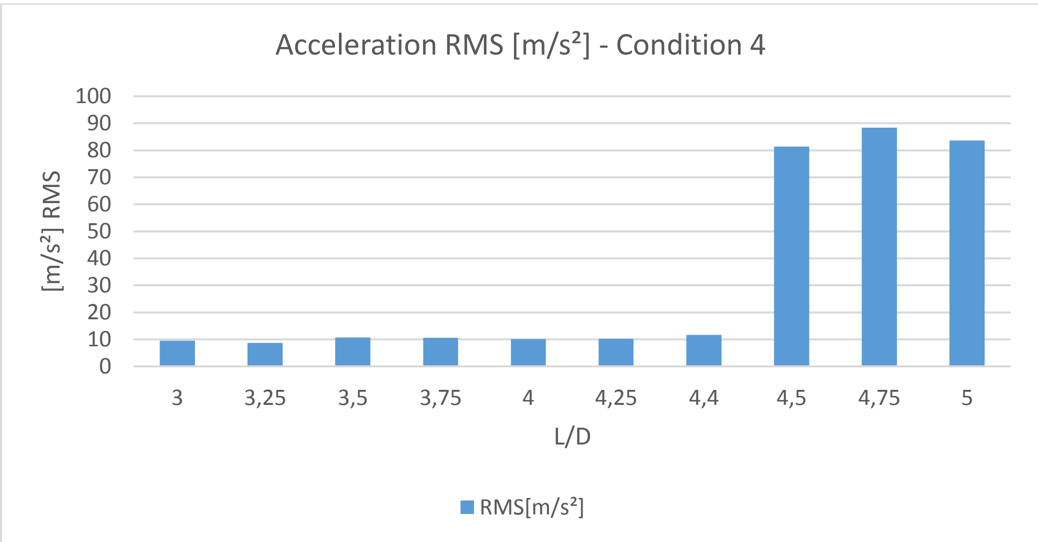


Figure 3. Amplitude of tool acceleration for various overhangs - Condition 4 (Table 1)

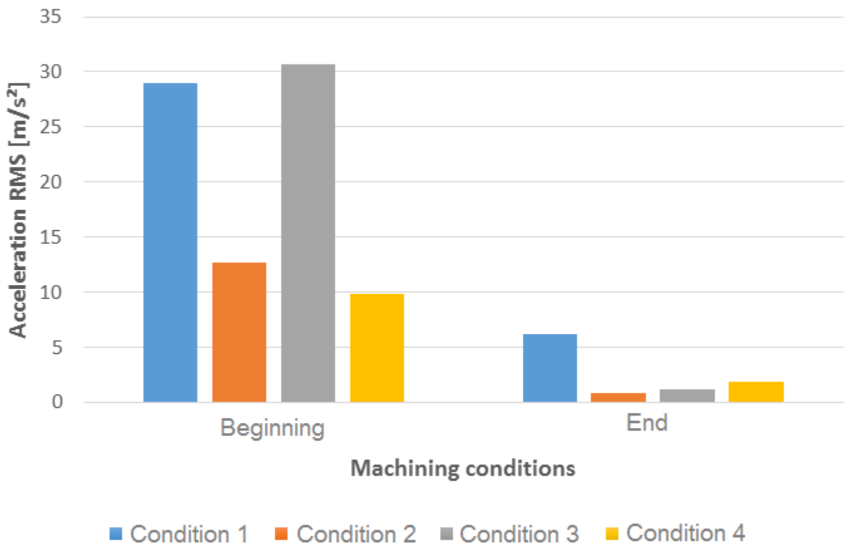
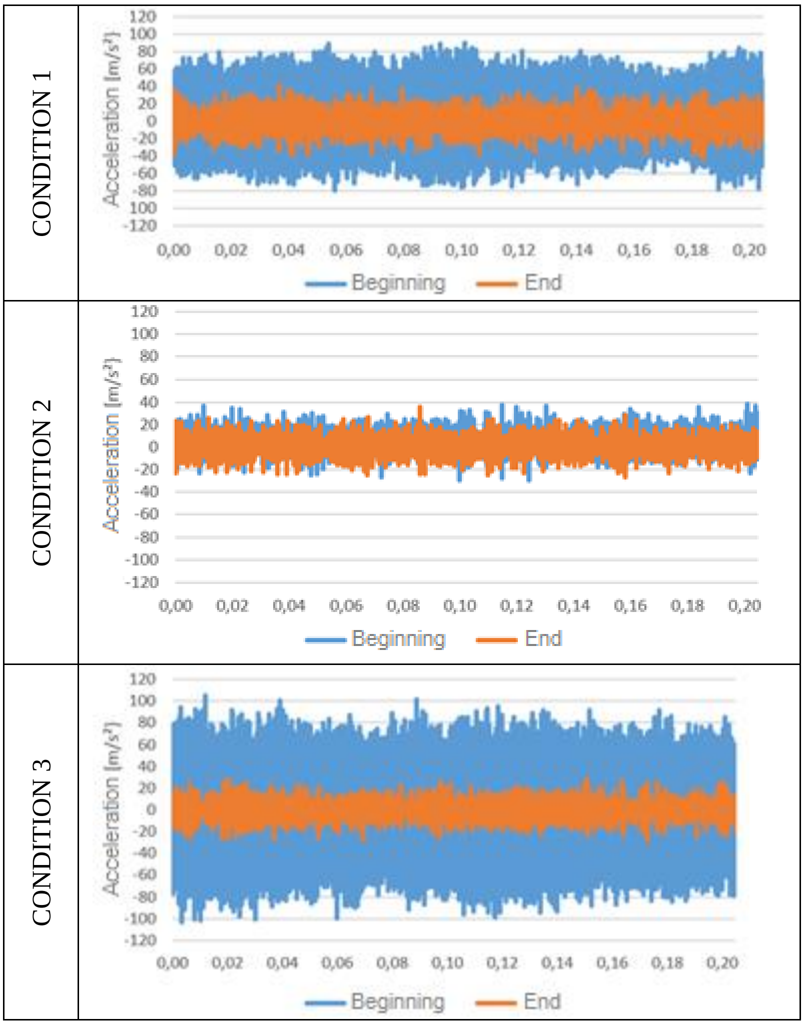


Figure 4. Acceleration amplitudes in the beginning and end of tool life in the tested machining conditions.



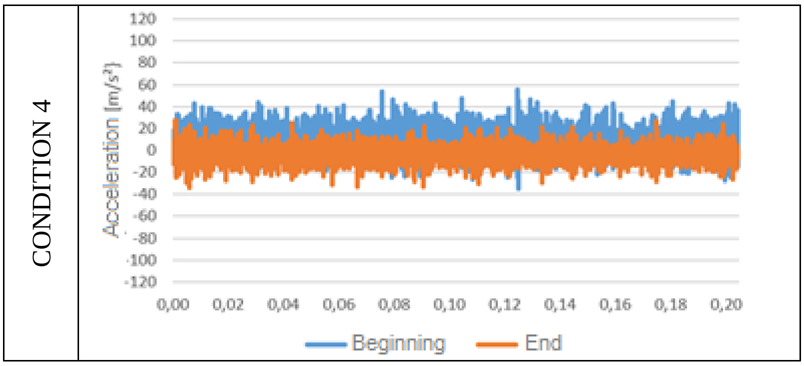


Figure 5. Tool acceleration signal in the time domain, as measured in the 4 machining conditions (Table 1), in the beginning and end of tool life.

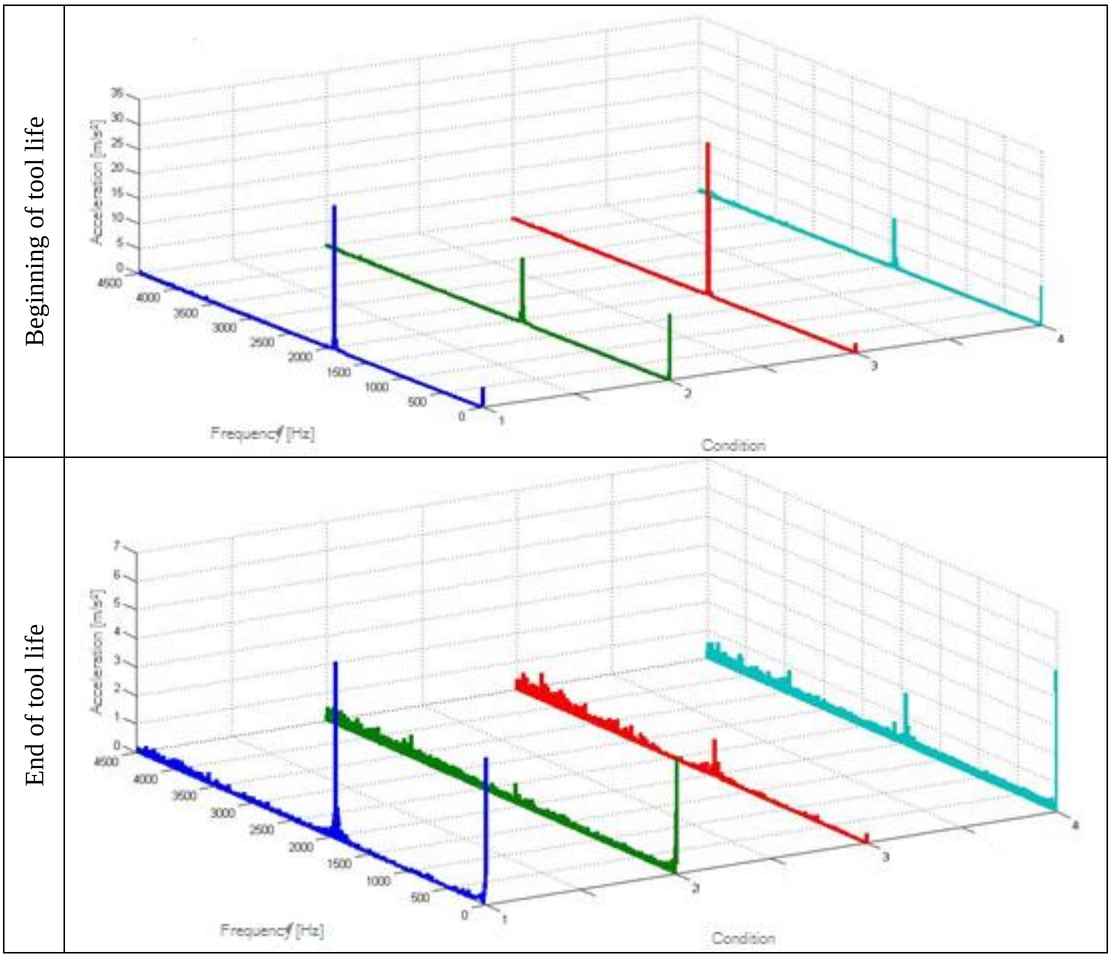


Figure 6. Tool acceleration signal in the frequency domain, as measured in as measured in the 4 machining conditions (Table 1), in the beginning and end of tool life.

Figure 7 shows the evolution of tool flank wear during the lifespan test for the 4 tested conditions and an of L/D = 4.4. Results prove that the cBN insert also resists to high frequency excitations, as it is the case in internal turning with continuous cutting.

The gradual evolution of the maximum flank wear (VBmax) indicates the absence of malfunctions leading to an abrupt change in the slope of the curve and to the sudden end of the life of the insert. Figure 7 shows that the cBN insert also suppress higher frequencies excitations, as is the case of continuous-cut internal turning in the stable cut. In the unstable cut when it reaches very high amplitudes, cause chipping and break into the tip of the tool, making the cutting impossible. This is due to the high brittleness of the cBN inserts which when in sudden shock deteriorates the tool.

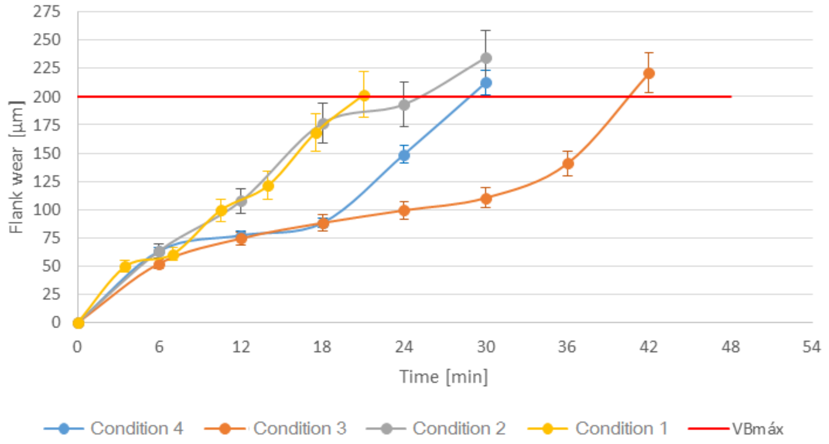


Figure 7. Evolution of tool wear in the 4 machining conditions (Table 1) for an end of tool life criterion of VB_{max}=200 µm.

4. CONCLUSION

- When the used tool overhang is within a stability range, the tool vibration amplitude is greater in the beginning of tool life than in its end, in all tested cutting conditions on the wear stabilization period.
- In boring bar operation in hardened materials with continuous cutting, the flank wear of the tool insert is mainly caused by the abrasion of CBN particles originated from it.
- Even at the point when the flank wear land was about 0,2 mm, the Ra the value of the surface roughness is less than 0,8 µm for almost conditions the frequency amplitude is not the cause of influence in the surface roughness due to the lower acceleration amplitude and the stability of the cutting condition.

5. ACKNOWLEDGEMENTS

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