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VIBRATION ANALYSIS OF THE 6351-T6 ALUMINUM BORING PROCESS

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Abstract. *This paper aims to analyze the vibration of the boring process using a tool holder with a high length / diameter ratio. Tools with great overhang length are likely to occur regenerative vibrations during machining, damaging the process and generating an undesired surface roughness. Tests performed to obtain data were performed using measurement equipment such as microphones and loading platforms. The proposal was to analyze the influences of machining parameters such as speed, depth of cut and advance in the vibrations of the boring process through the use of data generated for the determination of process stability chart, data that aid in simulations in Matlab software completing the analysis. It was observed that the pre-tests during the unstable process, vibration occurs in the natural frequency of the system. For the analysis of data collected by the microphone is used a signal acquisition board, a microcomputer and a program for analysis, ITA-Toolbox. The material used for the experiments was aluminum 6351-T6, and was used a type of tool holder with L/D=6, allowing the analysis of the vibrations in the experiments.*

Keywords: *chatter , regenerative vibrations, boring process*

1. INTRODUCTION

In a boring process, three different types of mechanical vibrations are present due to the lack of dynamic stiffness of the machine tool system comprising the tool, the tool holder, the part and the machine tool. These vibrations can be free, forced and regenerative. Free vibrations are induced by shocks and forced vibrations are due to an imbalance effect in the machine tool, in the sets of gears, bearings and spindles. Free and forced vibrations can be easily identified and eliminated. But regenerative vibrations are not yet fully understood because of the complexity of their nature. They are more harmful to some machining processes including turning (Siddhpura and Paurobally, 2012).

The regenerative vibrations are still a very important topic in manufacturing research. This relevant persistence for many years can be explained by two main factors: the complexity of the phenomenon makes its study and its understanding not be trivial: and negative effects of regenerative vibrations stimulate interest in solving the problem (Quintana and Ciurana, 2011).

Regarding the first factor, regenerative vibrations are a highly complex phenomenon due to the diversity of elements that can make up the dynamics of the system and its behavior: the cutting tool, the tool holder, the workpiece material, the machine structure Tool and cutting parameters. Predicting its occurrence is still the subject of much research, even the regenerative effect, the main cause of regenerative vibrations, has been identified and studied long before. In addition, regenerative vibrations can occur in different metal removal processes: milling, turning, drilling, boring, broaching and grinding (Quintana and Ciurana, 2011).

The occurrence of regenerative vibrations has several negative effects like poor surface quality, unacceptable inaccuracy, excessive noise, disproportionate tool wear and damage to the machine tool (Quintana and Ciurana, 2011).

In external turning the vibrations occur in the roughing and finishing operations and in the internal turning the vibrations normally occur in operations aimed at increasing the diameter of holes. Long turning tools statically and dynamically deflect under shear forces during machining operations. Excessive static deflections can violate dimensional tolerance of holes, and vibrations can lead to poor surfaces, short tool life and chip adhesion to tool. Force, torque and power forecasts are required to identify the machine tool and the tool clamping system suitable for the turning operation (Atabey, Lazoglu and Altintas, 2003).

Regenerative vibrations are generally classified into two categories: primary and secondary. Primary vibrations can be caused by the cutting process (i.e. by friction between the tool and the part, by thermo-mechanical effects in the formation of the chip or by the coupling mode). Secondary regenerative vibrations can be caused by regenerative waves from the surface of the part. This regenerative effect is most important cause of vibrations. For this reason this has become a convention and has been followed by several publications that chatter only refers to regenerative vibrations. In addition, it has to be mentioned that it is possible to distinguish between vibrations due to friction, thermomechanical vibrations, vibrations due to coupling mode and regenerative vibrations depending on the self-excitation mechanisms that cause these vibrations (Siddhpura and Paurobally, 2012).

Regenerative vibrations are the most common of vibrations, usually occurring because many metal cutting operations involve overlapping cuts which can be a vibration amplification feature. The cutting vibrations leave a corrugated surface as shown in Fig. 1. The thickness of the chip and the force on the cutting tool vary due to the phase difference between the surface which is left after the previous rotation. This phenomenon can highly amplify vibrations, become dominant and build regenerative vibrations. The Figure 1 shows the influence of this phase difference on the thickness of the chip. If the relative phase difference is zero, the dynamic thickness of the chip is also zero (Fig. 1a). If the relative phase is π, the dynamic variation of the chip thickness is maximal (Fig. 1c) (Quintana and Ciurana, 2011).

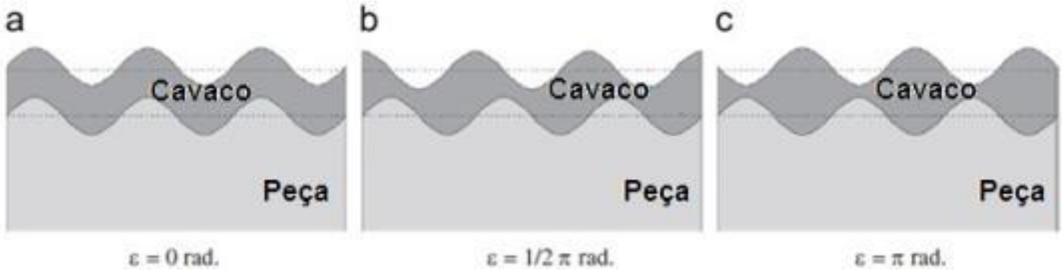

Figure 1. Effect of phase difference on chip thickness (Quintana and Ciurana, 2011)

Studies describe the damping process as the energy dissipation due to interference between the clearance surface of the cutting tool and the machined surface during the relative vibrations between the tool and the part. It has been shown in studies that, given a system with fixed dynamics, the influence of the damping process increases at low rotations, i.e. at low shear rates because the number of undulations on the machined surface increases, which also increases the slope of the corrugated surface. This, in turn, leads to increased interference and dissipation of additional energy (Tyler and Schmitz, 2013). This contact force causes energy dissipation and increases the permissible stable depth of cut at low cutting speeds.

This paper aims to analyze the influences of machining parameters such as cutting speed, spindle speed and depth of cut on the vibrations of the boring process of 6351-T6 aluminium alloy using a tool holder with a high length / diameter ratio (L/D).

2. METODOLOGY

2.1 Machine tool

The tests were carried out on a Hyundai-Kia Turning Center SKT160A. Iscar CCGT 09T304-AS IC20 insert with a nose radius of 0.4 mm and S16QSCLCL-09 tool holder with an overhang length of 96 mm and 16 mm diameter (L/D = 6) were used for the tests. The material used in the experiments was the 6351-T6 aluminum alloy as shown in Table1 shows its mechanical properties. Its chemical composition of aluminum is listed in Tab. 2. The specimens were of 32 mm in diameter and 20 mm in length with a central bore of 21 mm in diameter.

Table 1. Mechanical properties of Aluminum 6351-T6.

Tensile Strength (MPa)	Tensile Yield Strength (MPa)	Elongation in 50mm (%)	Hardness (HB)
290 – 350	255 - 330	4 - 8	95 - 110

Table 2. Chemical Composition of Aluminum 6351-T6.

Si (%)	Fe (%)	Mn (%)	Cu (%)	Mg (%)	Al (%)	Zn (%)	Ti (%)	Others (%)
0.70 – 1.30	0.50	0.40 – 0.80	0.10	0.40 – 0.80	96,.50 – 99.00	0.20	0.20	0.05 – 0.15

Through the impact test the frequency response function was obtained at the tip of the tool. For this, a Piezotronics 352C68 SN77121 PCB accelerometer was fixed to the tool holder end and excited by a hammer equipped with a piezoelectric force transducer type ICP 086C03. The analysis of the signals was later performed with the ITA-Toolbox software. In this way, the natural frequency necessary for the interpretation of the experimental results was identified.

The evaluation of the process stability was carried out by analyzing the frequency spectrum of the audio signals and the workpiece surface roughness. A system composed by a microphone (Special Measurement Microphone Rosenberger MCE212 - Company 01Db - GRAS with Type 26CA Preamplifier), signal acquisition board (Roland Quad- Capture, Analog 2x2 Digital 2x2) as shown in the Fig. 2, microcomputer and ITA-Toolbox software was used for the measurement of the audio signal during machining.

Figure 2. Set-up of experiments

Several tests were performed, with feed rate of 0.104 mm / rev, spindle rotation ranging from 1,000 rpm to 5,000 rpm and cutting depth (a_p) ranging from 0.25 mm to 2 mm with increments of 0.25 mm as shown in the Tab. 3. After the tests and with the data generated, an individual analysis was performed for each parameter used. Results in the time and frequency domain were analyzed in order to observe the differences between the stable and unstable processes, thus allowing the determination of points for the stability chart.

Table 3. Machining parameters.

Spindle speed (rpm)	Depth of cut – a_p (mm)
1,000 to 5,000	0.25 to 2.00 mm - varying from 0.25 to 0.25 mm

3. RESULTS AND DISCUSSIONS

The graph of Figure 3 shows a Frequency Response Function (FRF) measured at the end of the tool holder. The peak of magnitude occurs in the natural frequency (f_n) and corresponds to 969.9 Hz.

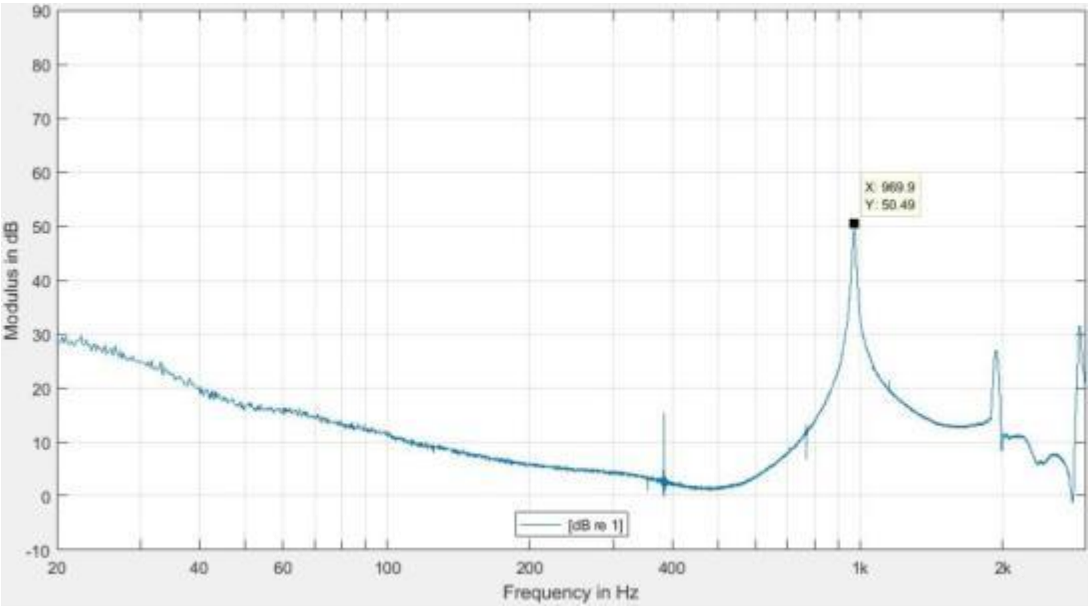

Figure 3. Frequency response function for L/D = 6

Figure 4 shows the surface profile for a stable condition (n = 1,500 rpm, a_p = 1.5 mm, f = 0.104 mm/rev). The distance between the marks observed in the profile corresponds manly to the feed per revolution.

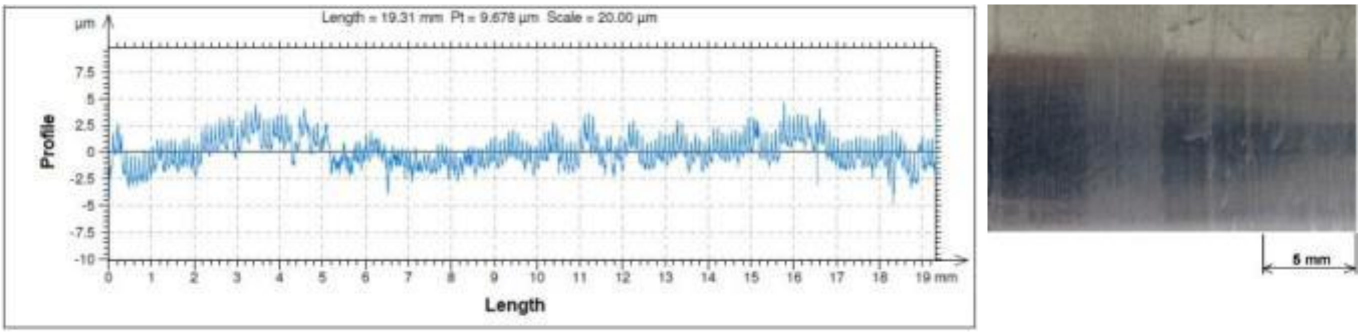

Figure 4. Surface profile for a stable cut

Figure 5 shows the surface profile for an unstable cut (n = 2,000 rpm, a_p = 1.5 mm, f = 0.104 mm/rev). The profile still displays the leading marks, but not the same with each rotation.

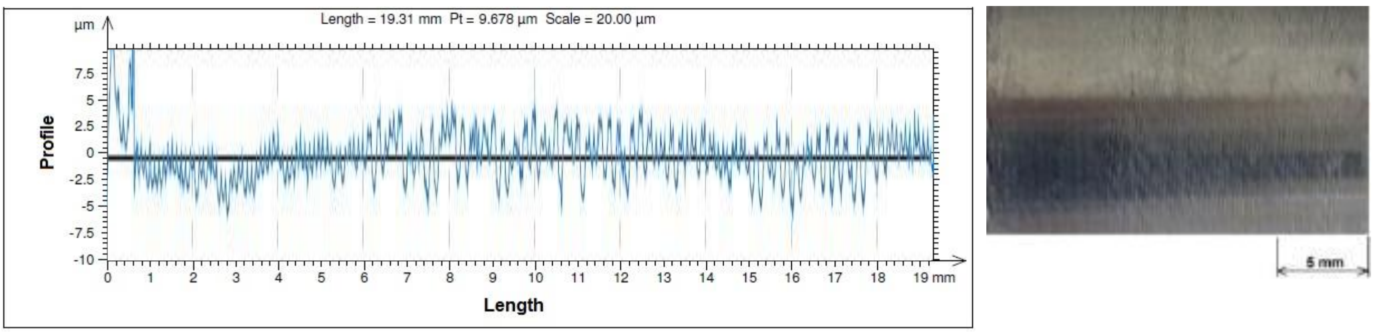

Figure 5. Surface profile for an unstable cut

Figure 6 shows the audio signal measured during the machining performed in a stable condition (n = 1,500 rpm) and an unstable condition (n = 2,000 rpm).

Stable process - n = 1,500 rpm   Unstable process - n = 2,000 rpm

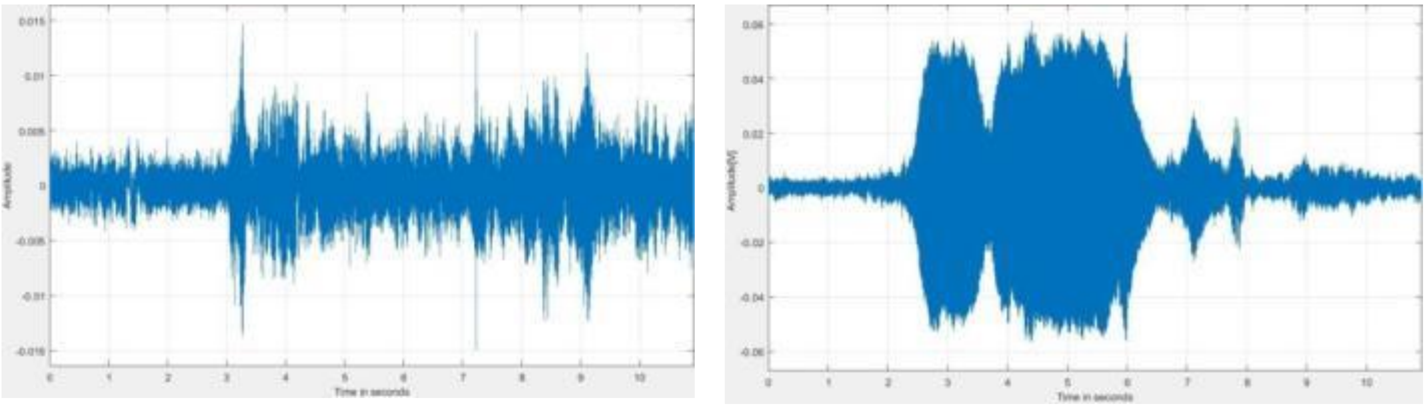

Figure 6. Audio signal for a_p = 1.5 mm

The audio signal level is considerably higher for the unstable condition that can contribute significantly to noise pollution on the shop floor. The spectra corresponding to these conditions are shown in Figure 7.

n = 1,500 rpm   n = 2,000 rpm

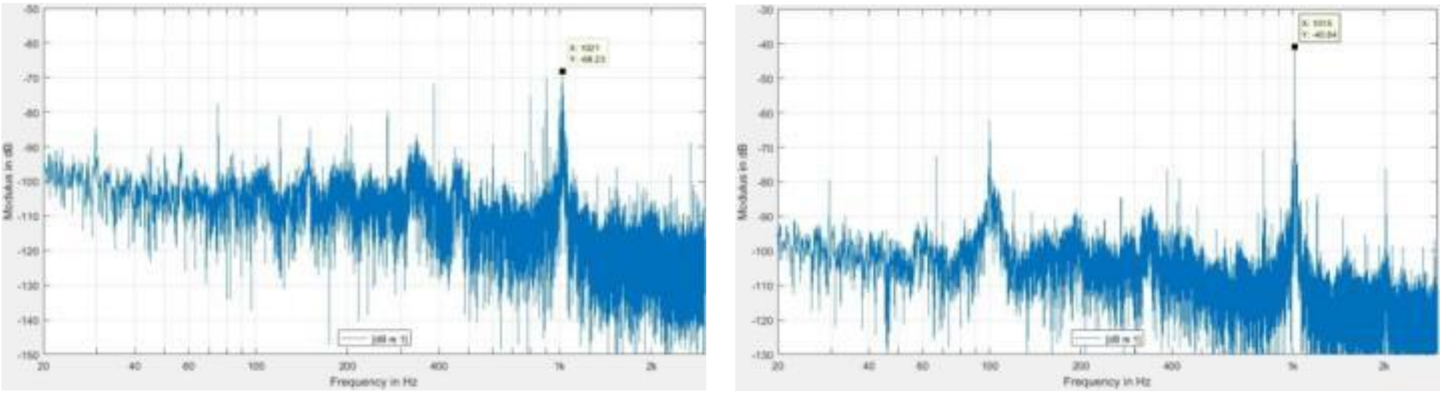

Figure 7. Audio signal spectra for a_p = 1.5 mm

For the stable cut the peak in the spectrum occurs in the frequency of 1,021 Hz, which is a frequency close to the natural of the system and the difference between the peaks is not very high. For the unstable cut the peak in the spectrum occurs in the frequency of 1,015 Hz that is a near to the natural frequency of the system and the difference between the peaks is high.

The limit depth of cut was determined for each spindle rotation allowing the construction of the stability chart of Fig. 8. Above n = 2,000 rpm there is a region of instability at ap = 0.25 mm. Process instability occurs because the depth of cut is lower than the tool nose radius that is 0.4 mm. Below 2,000 rpm there is a region of process stability due to the damping effect at low rotations.

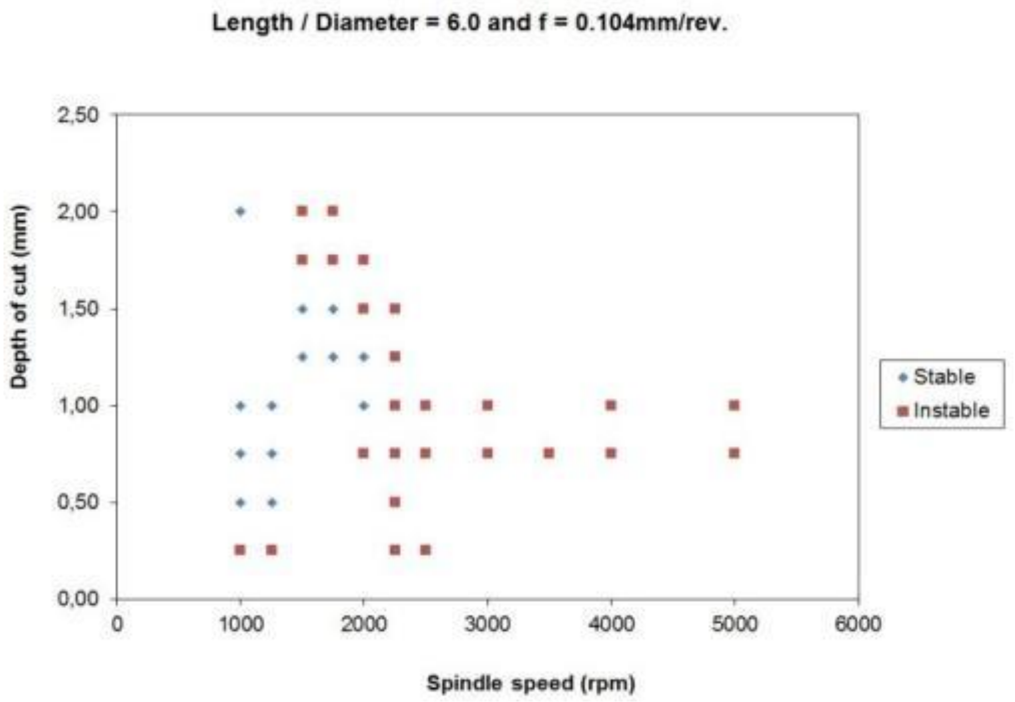

Figura 8. Stability diagram for L/D = 6

As shown in Figure 9 for the spindle rotations that resulted in unstable cuts the vibration frequency is close to the natural frequency of the system and the magnitude is considerably higher in comparison to stable cuts.

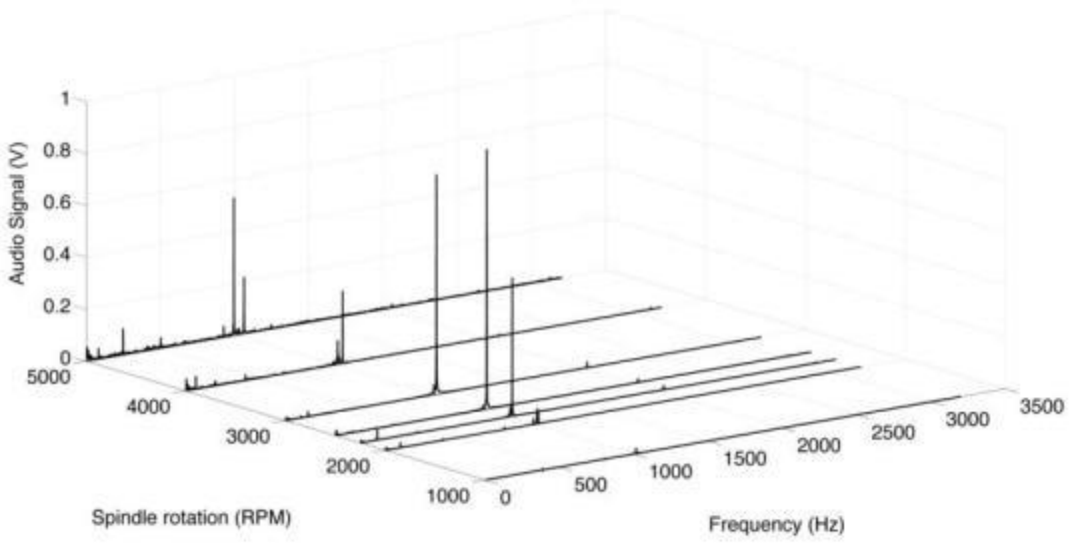

Figure 9. Audio signal spectra for a_p = 1mm and L/D = 6

4. CONCLUSIONS

In the tests it was proved that it is impossible to machining with acceptable surface quality when the self-excited vibrations are present. The surface of the machined part presents irregular appearance and vibration marks, which result in very high roughness values when compared to a stable process. During the trials the difference between stable and unstable processes became evident. Audio signals in the time domain have a significantly lower amplitude when the process is stable. In the frequency domain, very high peaks are observed in the natural frequency of the system, characterizing the instability of the machining process. At lower spindle rotations the amplitudes of vibrations are lower and the difference between the peaks of frequency of vibrations is smaller, which characterizes a stable machining process. This phenomenon is related to the damping effect that occurs in the machining process at lower rotations. In boring operations the highest limitation are the regenerative vibrations. For unstable cuts the audio signal spectrum is dominated by the regenerative vibration frequency.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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