VERIFICATION OF VIBRATION SIGNAL SENSIBILITY ON THE TOOL WEAR EVOLUTION IN DRILLS

José Augusto Zermiani dos Santos, jaugusto@tupy.com.br
Carlos Eduardo Turino, ceturino@tupy.com.br
Tupy SA – Rua Albano Schmidt, 3400 – CEP 89227-901 - Joinville – SC

Ulisses Borges Souto, ulisses.souto@sociesc.org.br
Instituto Superior Tupy – Rua Albano Schmidt, 3333 – CEP 89206-001 - Joinville - SC

Abstract. *The present paper aims to study the evolution of the wear in drills through sensor vibration signal sensibility. The testings were made in a Compacted Graphite Iron (CGI) engine block production line, in a horizontal machining center ISO-40. The cutting speed and the feed were kept constant (v_c = 90 m/min and f = 0.25 mm/rev) and were used according to the line cutting parameters. Solid carbide stepped straight flute drills with aluminum titanium nitride were used. The sensor signals were acquired in three maximum flank wear conditions of the tool: condition 1 (VB_{Bmax} = 0), condition 2 (VB_{Bmax} = 0,2 - 0,3 mm), condition 3 (VB_{Bmax} = 0,4 - 0,7 mm). They were then analyzed in the time domain through the four statistical parameters (RMS, kurtose, skewness and crest factor), and the sensibility of these parameters were analyzed using the box plot graph. The vibration signals were also analized in the frequency domain with the aim of finding a frequency range which differs the wear conditions of the tool in order to further on study the sensibility of the statistical parameters of this range. The results have shown that the vibration signal of the frequency range of 6.0 - 6.5 kHz indicates better wear sensibility through RMS and kurtose parameters.*

Keywords: *drilling, vibration signal, tool wear.*

1. INTRODUCTION

The drilling is an operation with large effective cutting time in the engine block machining, possessing great influence on the tools costs. These costs increase in CGI engine block machining, due to its smallest machinability when compared to GI (Gray Iron) (ANDRADE, 2005).

As technique of tool wear measurement there are direct (off-line) and indirect (on-line) method. In the direct measurement, the process has to be interrupted to measure the wear directly in the tool using an appropriate equipment. In the indirect method the process is accompanied in real time through a physical parameter that can be correlated, for instance, with the tool wear (JANTUNEN, 2002).

In drilling operation, the tool life presents a great dispersion, therefore is necessary the use lower values as tool life criterion to prevent breakages, consequently a lot of tools are not totally used, increasing the production cost (SOUTO, 2007). With the monitoring system implantation, the tool life criterion is an index generated by that system and it is based on sensor signals and machine internal datas.

The present paper aims to verify the vibration signals sensibility on the tool wear evolution in drills, analyzing the vibration signals in the time and frequency domain through statistical parameters.

2. VIBRATION TOOL WEAR MONITORING

Vibrations are produced by cyclic variations in the dynamic components of the cutting forces. These vibrational motions start as small chatter responsible for the serrations on the finished surface and progress to what has come to be commonly termed vibration. Mechanical vibrations generally result from periodic wave motions (DIMLA, 2000)

The vibration measurements advantages are in its simple implantation, because the sensor can be installed in the spindle without modifications in machine and in fixture device (JANTUNEN, 2002).

El-Wardany, Gao and Elbestawi (1996) comment that vibration signal is sensitive to the flank wear in drilling process, mainly in the radial direction. With the increase of the tool wear the signal begins to grow and immediately before the breakage it presents amplitude peaks.

2.2. Signals analysis techniques

In general, the signals analysis techniques can be based on the time and frequency domain.

The time domain analysis are simple application, being the analysis of RMS, crest factor, kurtose and skewness levels normally used.

a) RMS (V_{RMS}): Root mean square allows to evaluate the energy contained in the signal, indicating the system vibration severity. It is calculated as Eq. (1).

$$V_{RMS} = \sqrt{\frac{1}{\Delta T}(\int_{0}^{\Delta T} V^2(t)dt)} \tag{1}$$

Where:
V(t) = Signal function;
ΔT = Time constant.

b) Crest factor: The parameter crest factor is the reason between the peak value and the RMS value and it indicates if the signal is homogeneous during the time (CUNHA, 2005). Great values for the crest factor indicate the presence of some outstanding peak in the signal. It is calculated as Eq. (2).

$$FC = \frac{Peak}{V_{RMS}} \tag{2}$$

c) Kurtose (K): The kurtosis value is useful in identifying transients and spontaneous events within vibration signals. The kurtosis value is a measure of its peakedness (EL-WARDANY, GAO AND ELBESTAWI, 1996). In the drilling process, when the wear increases the kurtose value decreases, due to the increase of the peaks number in the signal. It is calculated as Eq. (3).

$$K = \frac{1}{N}\sum_{i=1}^{i=N}\frac{(x_i - \overline{x})^4}{(\sigma^2)^2} \tag{3}$$

Where:
N = Number of samples;
x_i= The instantaneous amplitude of the vibration signal;
$\overline{x}$ = The average vibration amplitude;
σ^2 = Variance of the signal

d) Skewness: it measures the function symmetry around the average value. According to Macário (2006), skewness values distant of zero can be related with flaws in the system or problems in the signal acquisition. It is calculated as Eq. (4).

$$S = \frac{1}{N}\sum_{i=1}^{i=N}\frac{(x_i - \overline{x})^3}{(\sigma^2)^{\frac{3}{2}}} \tag{4}$$

The vibration signal analyzes techniques in the frequency domain is based that when the excitement forces are constant, the machine vibrations levels also stay constant. Starting from the moment that the system vibrations level changes, the frequency spectrum also seedling. With the comparison of the damaged system frequency spectrum with a correct system frequency spectrum, the nature and the location flaws can be detected (CUNHA, 2005).

Each system element generates identifiable frequencies in the frequency spectrum, where it is possible to detect changes in the signal frequency caused, for instance, for the tool wear, defining a range in frequency spectrum corresponding to the phenomenon (ELBESTAWI, DUMITRESCU e EU-GENE, 2006).

3. MATERIALS AND METHODOLOGY

CGI engine blocks were used. The hardness and mechanical resistance specification of are the following ones:

- Hardness: 215 a 265 HB;
- Mechanical strength: 420 MPa minimum;
- Yield strength: 310 MPa minimum;
- Elongation: 1,0 % minimum;
- Elasticity modulus: 140 GPa minimum.

The 5 solid carbide stepped straight flute drills with aluminum titanium nitride were used. It was fixtured in ISO 40 taper. The tools possess point angle (σ) = 140 °, incidence angle (α) = 13 ° and edge angle (ψ) = 3 °. Figure 1 illustrates the drill used and the hole characteristics..

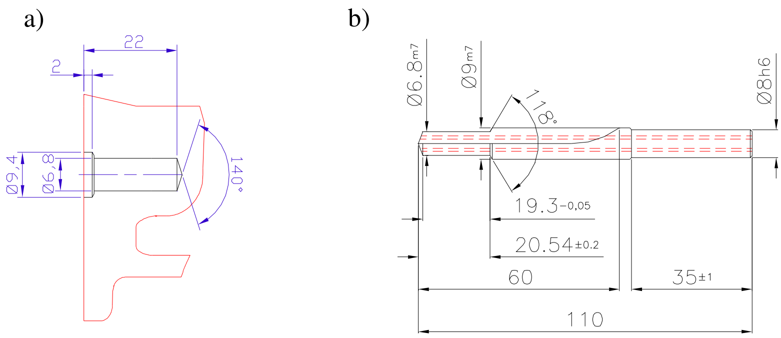


Figure 1. a) Hole characteristics b) Drill characteristics.

The holes were machined in a Horizontal Machining Center (HMC) Heller MC-16, with GE-Fanuc - 180i command, maximum rotation of 10.000 rpm and available potency of 30 kW. The cut parameters used were: vc = 90 m/min and f = 0,25 mm/rotation. Coolant emulsion was used, with concentration from 5 to 7%.

The engine blocks were standed in a hydraulic device with fixation pressure of 60 bar and located by two manufacturing holes. This fixation guarantees stability, rigidity and precision during machining.

The tool life criterion was the maximum flank wear (VB_{Bmax}). The flank wear were measured on the two cutting edges, being the largest representative value for the results.

The flank wear states were nominated in the following way:

- State 1: VB_{Bmax} = 0 mm;
- State 2: VB_{Bmax} = 0,2 a 0,3 mm;
- State 3: VB_{Bmax} = 0,4 a 0,7 mm.

The vibration sensor characteristics are the following:

- Type: Piezoelectric accelerometer;
- Model: 8341 Brüel & Kjaer
- Amplitude response: 0,5 a 50000 Hz;
- Temperature range: -50 ºC a 100 ºC;
- Weight: 41 gram.

The sensor was assembled in a 1020 steel ring installed on spindle. The ring is bi-party, fastened by two M12 screws, as show Fig. 2.

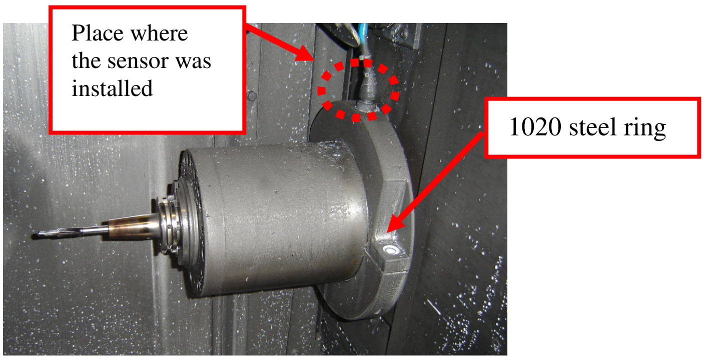


Figure 2. Vibration sensor installed.

The vibration signal was acquired with an acquisition rate of 50 kHz.

The hole machining time was 1,26 seconds, according the process parameters used (vc = 90 m/min, f = 0,25 mm/rot, hole diameter = 6,8 mm and hole depth = 22 mm), therefore for each monitored hole there were 63000 points.

The acquired sensor signals were sent for a National Instruments acquisition card A/D, model NI create-9002, that it possesses acquisition frequency of 200 MHz, for later they be stored in the computer memory. Figure 3 illustrates the system.

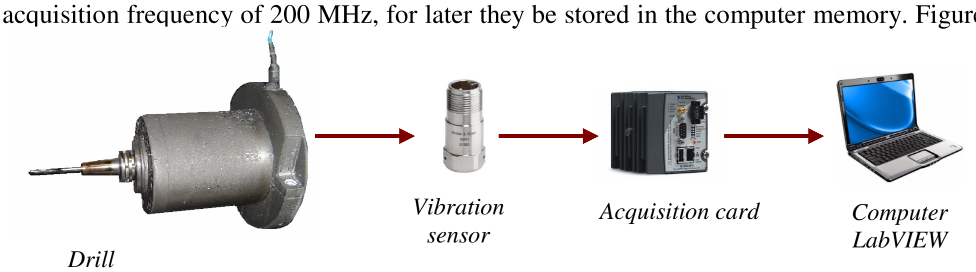


Figure 3. System representation.

In each tool wear state (State 1, 2 and 3) they were acquired the vibration signals of 10 holes for each drill. As 5 tools were used, in each flank wear state there were signals of 50 monitored holes (10 of each tool).

The acquisition signals methodology is showed in the Fig. 4.

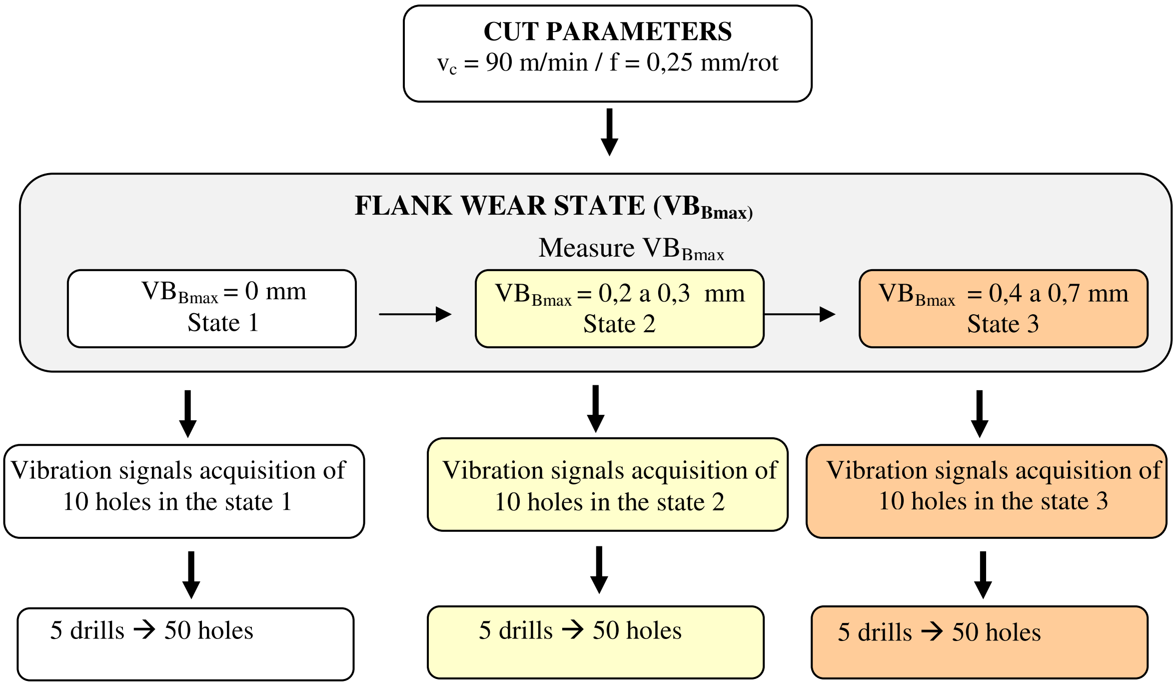


Figure 4. Acquisition signals methodology.

To extract information from the signals they were applied the RMS, kurtose, skewness and crest factor statistical parameters as filters for each monitored hole (50 in each flank wear state), using the software MATLAB 7.0 and the parameters sensibility were analyzed using the box plot graph.

The vibration signals were also analyzed in the frequency domain, through Fast Fourier Transform (FFT) using the software MATLAB 7.0, with objective of detecting changes in the signals frequency caused by the flank wear. The frequency range considered more sensitive was those that presented larger distinction among the curves of flank wear state 1, 2 and 3. For each tool were printed the frequency spectrum.

After finding a sensitive frequency range, the RMS, kurtose, skewness and crest factor statistical parameters were applied again in each flank wear state, analyzing its sensibility with boxplot graphs.

4. RESULTS ANALYSIS

Figure 5 presents the vibration signal behavior during the hole machining, that it takes 1,26 seconds.

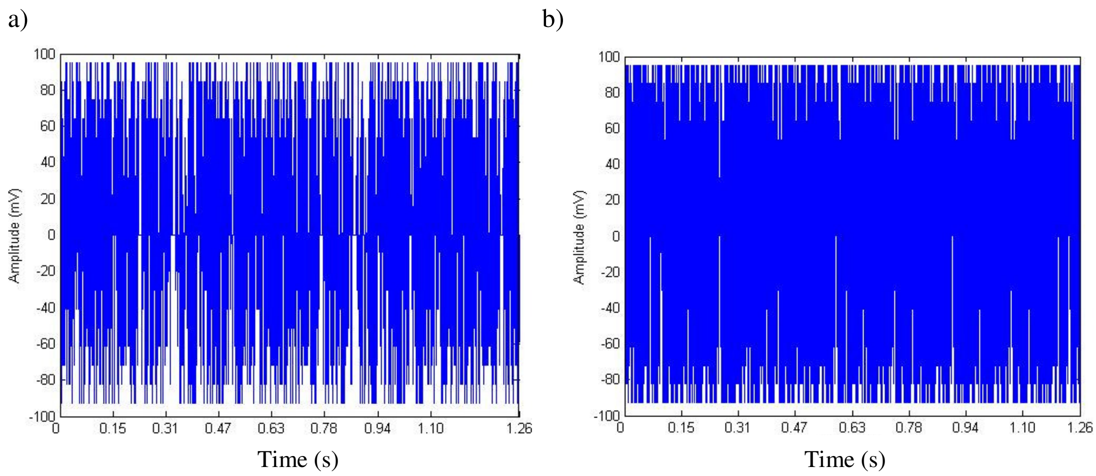


Figure 5 - Vibration signal in 1,26 seconds of drill 1: a) Tool in the state 1; b) Tool in the state 3.

Due to the acquisition card of 50 kHz, it is not possible to visualize the signal characteristics in the 1,26 seconds interval, therefore the signal was printed in the 0,1 seconds interval, as Fig. 6 shows.

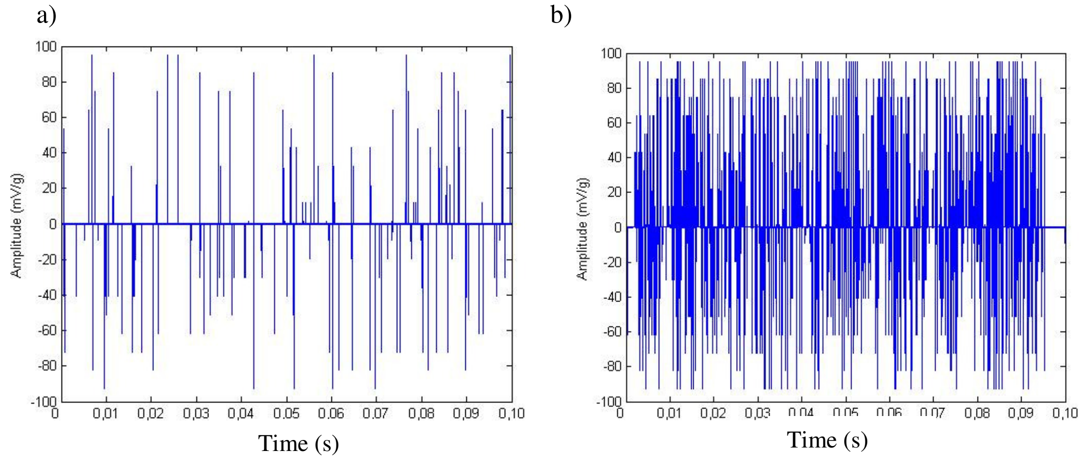


Figure 6 - Vibration signal in 0,1 seconds of drill 1: a) Tool in the state 1; b) Tool in the state 3.

It is possible to observe that the peaks number in the signal increased with the tool flank wear. This characteristic repeated in the 5 tools used. During the machining, firstly the signals present small pulses and later they progress, due to the growth of the flank wear that increases the cut force components value and consequently it increases the present peaks number in the signal.

The RMS, kurtose, skewness and crest factor statistical parameters were applied in time domain, as Fig. 7.

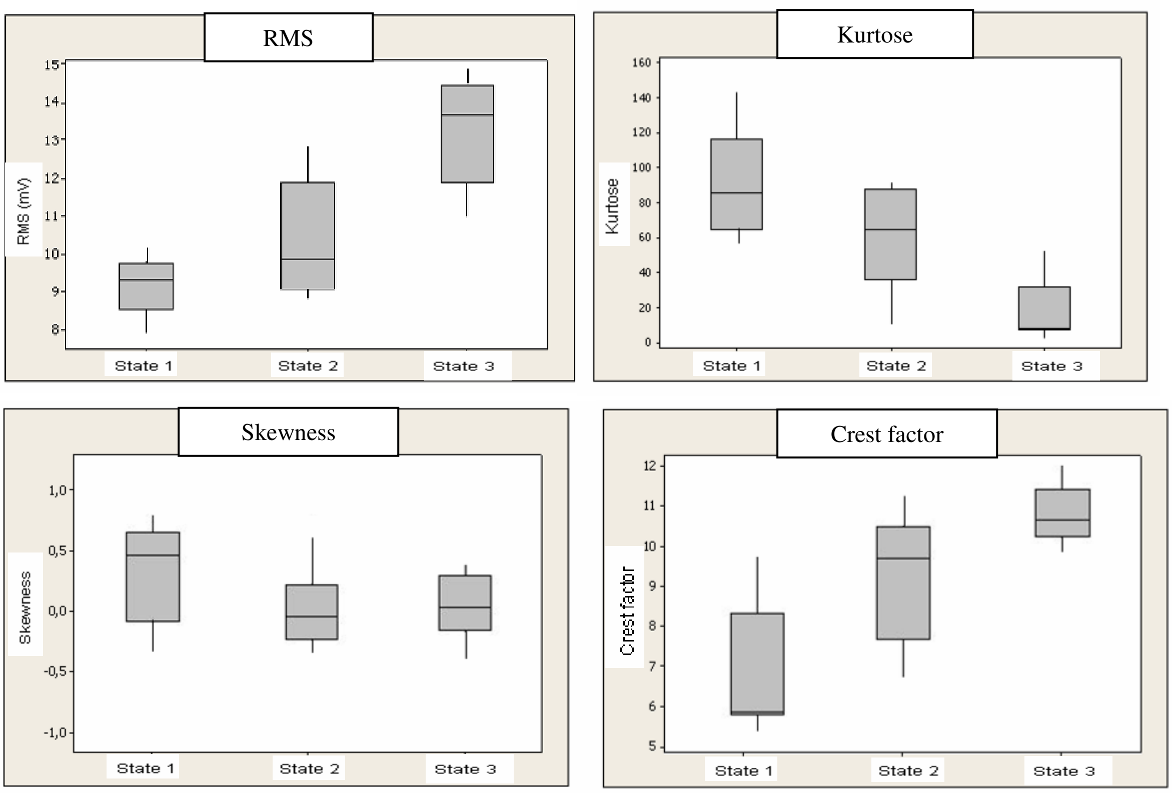


Figure 7. Time domain results.

The RMS signal variation with the tool wear indicates that it possesses a good sensibility, because it gets to capture the energy originating from each tool wear state.

The kurtose value decreased with the tool wear increase. These decrease indicates that the peaks number increased with the flank wear increase. The peaks number growth can be related with the fact of the flank wear is not symmetrical in the cutting edges, increasing the vibration value and consequently the peaks number.

Analyzing the skewness parameter, the results were close of zero, indicating that the signals acquired follow a normal curve, showing that there were not noises during the data acquisition.

The crest factor increased with outstanding peaks presence in the signal, mainly in the end of tool life, originating from the excessive flank wear.

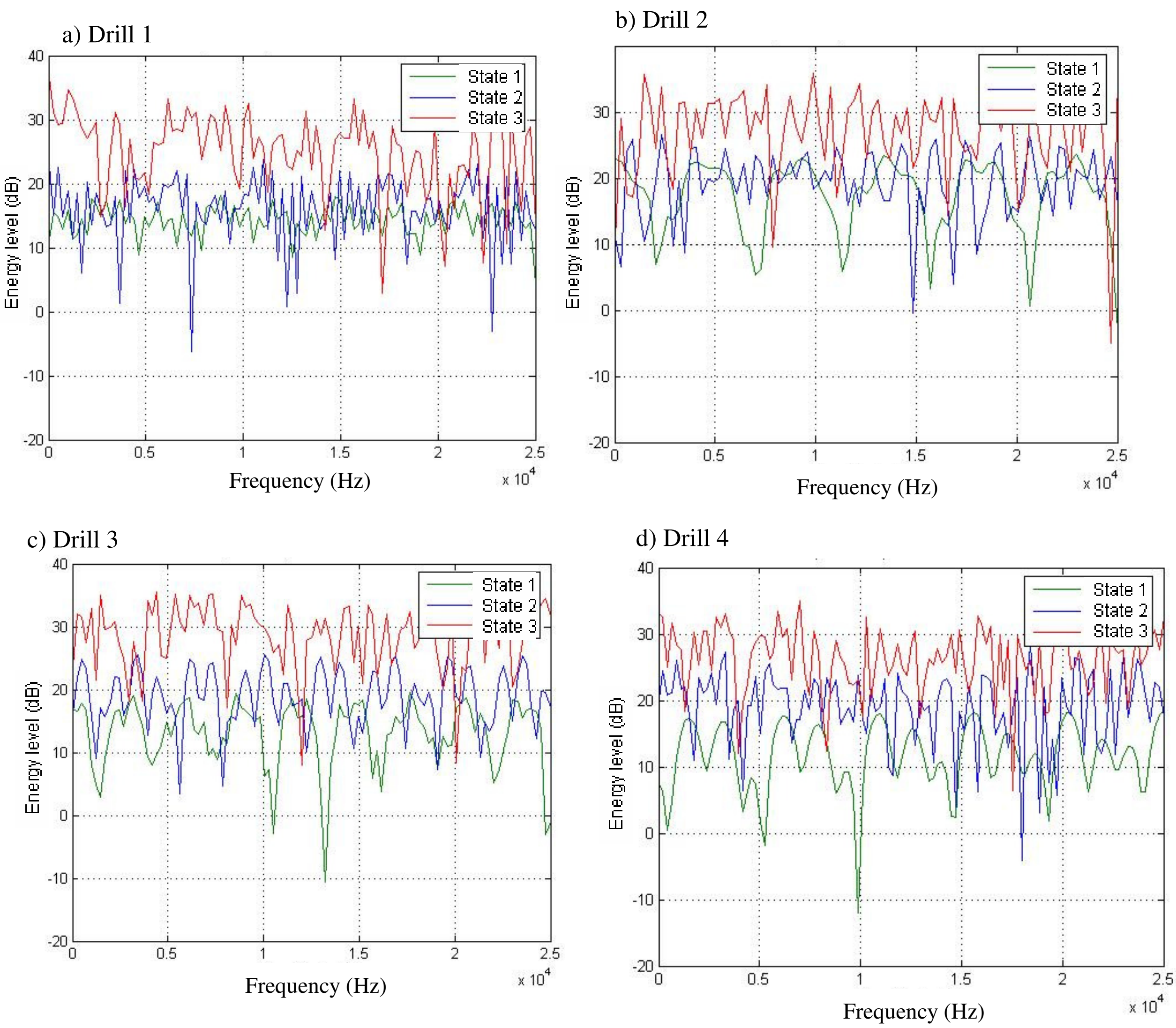
Table 1 presents summarize of results found in the time domain.

Table 1. Vibration signal results in time domain.

Statistical parameters	Variation	Meaning
RMS	It increased between flank wear states	Signal energy increased
Kurtose	It decreased between flank wear states	Peaks number increased
Skewness	It kept constant	Signal without noises
Crest factor	It increased between flank wear states	Outstanding peaks number increased

The vibration signs were also analyzed in the frequency domain.

Figure 8 presents the frequencies spectrum of the 5 drills used. The spectruns are in frequencies range from 0 to 25 kHz.



e) Drill 5

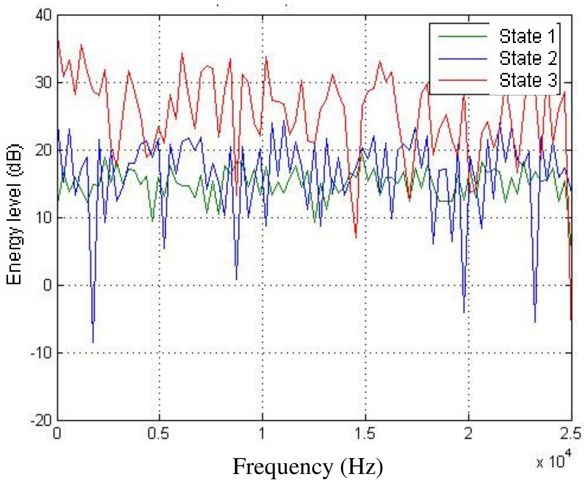
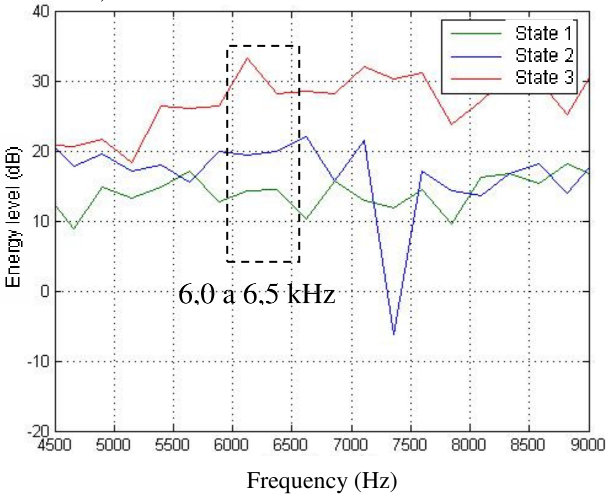


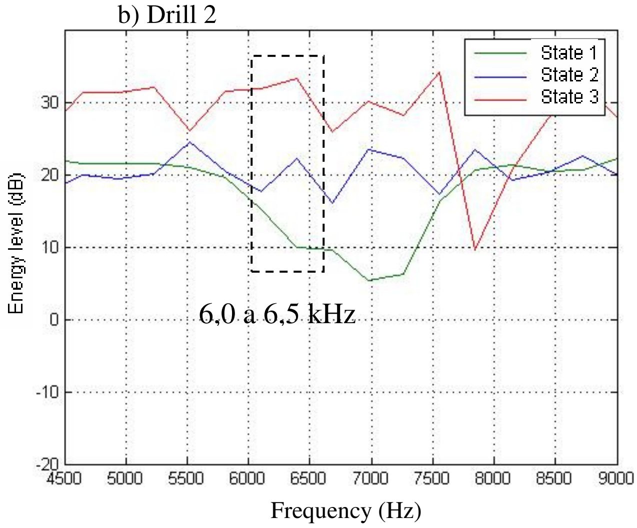
Figure 8. Spectrums in frequencies range from 0 to 25 kHz.

The frequency spectrums from 0 to 25 kHz were amplified to facilitate the visualization of the ranges considered more sensitive. Figure 9 presents details of range frequency from 4,5 to 9,0 kHz.

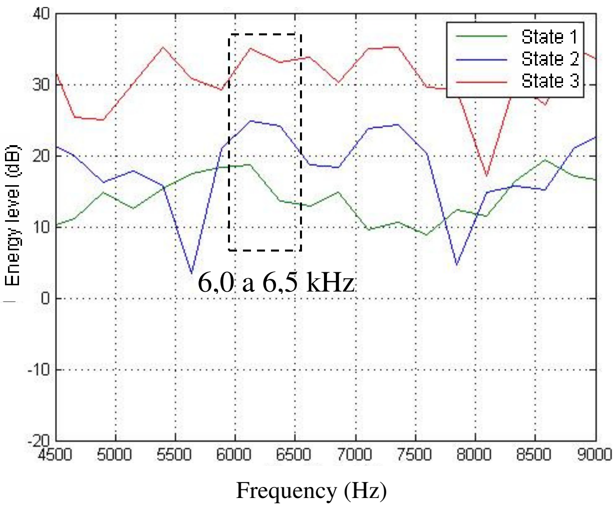
a) Drill 1



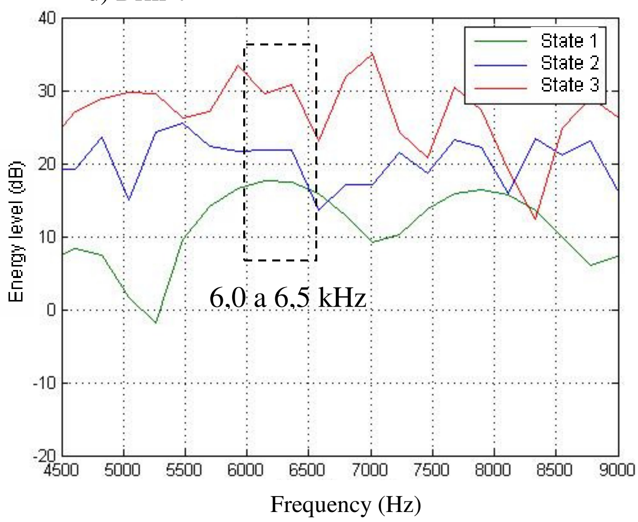
b) Drill 2



c) Drill 3



d) Drill 4



e) Drill 5

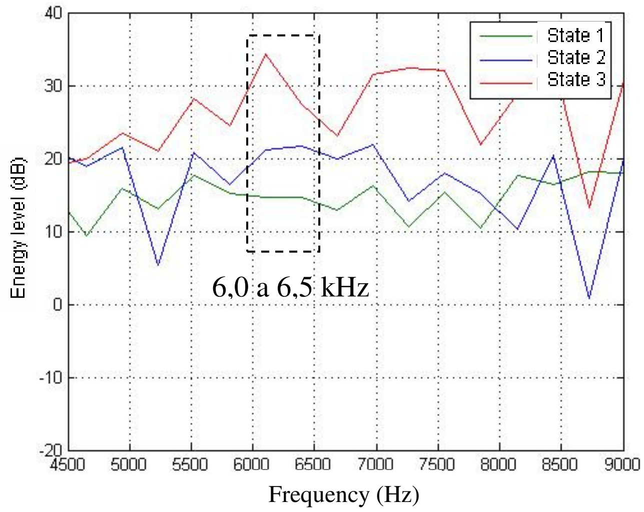


Figure 9. Spectrums in frequencies range from 4,5 to 9,0 kHz.

In the 5 analyzed tools, in frequency range from 6,0 to 6,5 kHz there is a distinction between the state wear curves. Consequently the statistical parameters sensibility was applied in the range from 6,0 to 6,5 kHz for the 50 holes of each wear state.

The RMS, kurtose, skewness and crest factor statistical parameters were applied in frequency domain, as Fig. 10.

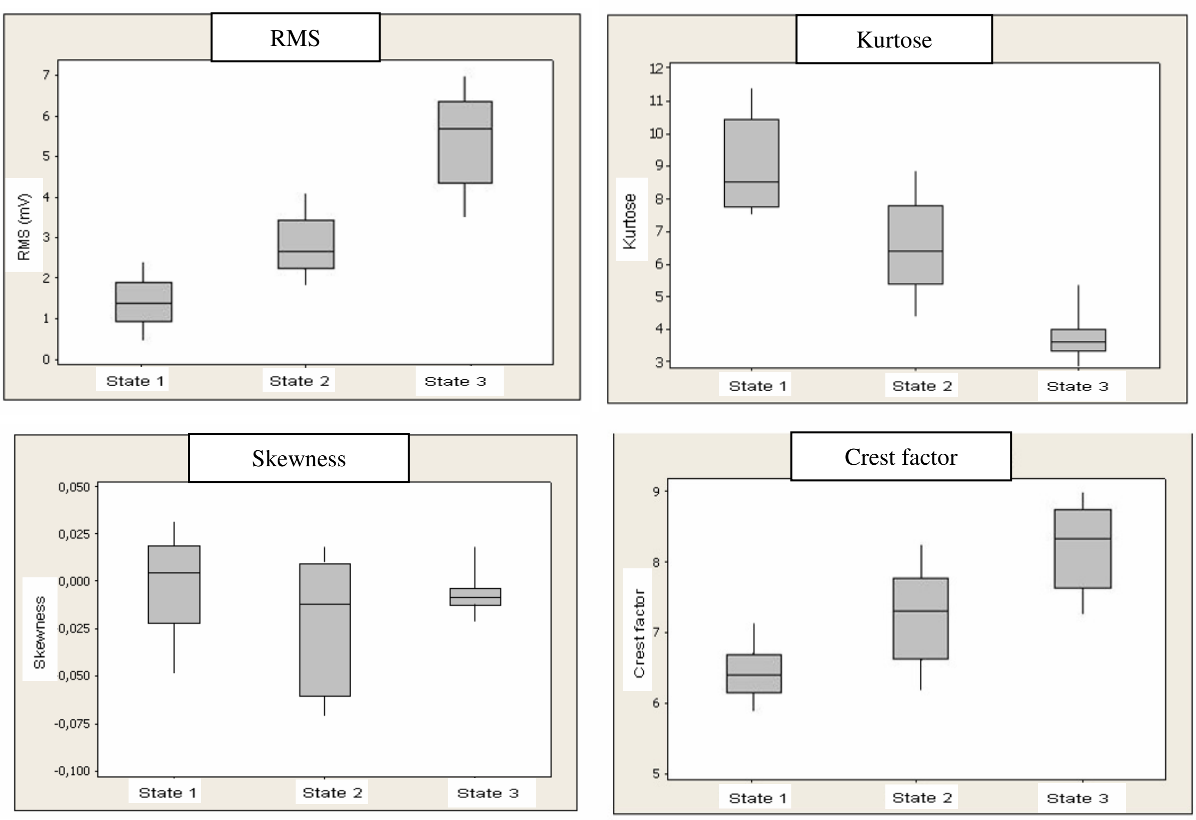


Figure 10. Frequency domain results.

The RMS signal variation with the tool wear in the frequency range from 6,0 to 6,5 kHz indicates that vibration signal gets to differentiate in a clearer way the system energy originating from the intermediate tool wear state variation, improving the sensibility when compared with the analysis in all frequency range.

The kurtose, skewness and crest factor results in frequency range from 6,0 to 6,5 kHz also showed better results when compared with the analysis in the time domain.

Table 2 presents summarize of the results obtained with the vibration signs in the frequency domain.

Table 2. Vibration signal results in frequency range from 6,0 to 6,5 kHz.

Statistical parameters	Variation	Meaning
RMS	It increased between flank wear states	Signal energy increased
Kurtose	It decreased between flank wear states	Peaks number increased
Skewness	It kept constant	Signal without noises
Crest factor	It increased between flank wear states	Outstanding peaks number increased

4. CONCLUSIONS

The results obtained allow the following conclusions:

1. The vibration signals in the time domain shows sensibility on the tool wear evolution when the RMS, kurtose and crest factor were analyzing.
2. The signal in the frequency domain in range from 6,0 to 6,5 kHz also shows sensibility on the tool wear evolution when the RMS, kurtose and crest factor were analyzing.
3. After analyzing the signals in the time and frequency domain we noticed a better results in the frequency domain. The RMS and kurtose statistical parameters presented better sensibility on the tool flank wear evolution.

5. ACKNOWLEDGEMENTS

The authors are grateful to Tupy SA and Instituto Superior Tupy.

6. REFERENCES

Andrade, C.L. “Análise da furação de ferro fundido vermicular com brocas de metal-duro com canais retos revestidas com TiN e TiAlN”. Florianópolis, 2005. 133 f. Dissertação (Mestrado em Engenharia Mecânica) - Departamento de Engenharia Mecânica, Universidade Federal de Santa Catarina.

Cunha, R.C. “Análise do estado de conservação de um redutor de velocidade através da técnica de partículas de desgaste no óleo lubrificante auxiliada pela análise de vibração”. Ilha Solteira, 2005. 156 f. Dissertação (Mestrado em Engenharia Mecânica) - Departamento de Engenharia Mecânica, Faculdade de Engenharia de Ilha Solteira.

Dimla , D.E. “Sensor signals for tool-wear monitoring in metal cutting operations – A review of methods”. International Journal of Machine Tools & Manufacture. pp. 1073-1098, 2000.

Elbestawi, M.A.; Dumitrescu, M. and Eu-Gene, N. “Tool condition monitoring in machining. Condition Monitoring and Control for Intelligent Manufacturing”. Springer London. 2006. p 55 -82.

El-Wadarny, T.I. and GAO, D.; ELBESTAWI, M.A. “Tool condition monitoring in drilling using vibration signature analyses”. International Journal of Machine Tools & Manufacture. 36 (6), p. 687-711, 1996.

Jantunen, E. “A summary of methods applied to tool condition monitoring in drilling”. International Journal of Machine Tools & Manufacture. 2002.

Macário, C. C. L. Utilização de filtros adaptativos para detecção de falhas em mancais de rolamentos. Uberlândia, 2006. 134 f. Dissertação (Mestrado em Engenharia Mecânica) - Departamento de Engenharia Mecânica, Universidade Federal de Uberlândia.

Souto, U. B. “Monitoramento do desgaste de ferramenta no processo de fresamento via emissão acústica”. Uberlândia, 2007. 168p. Tese (Doutorado em Engenharia Mecânica). Universidade Federal de Uberlândia.

5. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.