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# CUTTING TOOL VIBRODIAGNOSTICS ON CNC MACHINES

***В.П. Ларшин, Н.В. Ліщенко. Вібродіагностика ріжучого інструмента на верстатах з ЧПК.*** Представлено характеристику способа технологічної вібродіагностики ріжучого інструмента на верстатах з ЧПК, та результати експериментальних досліджень вібродіагностичної системи на основі вимірювального комплексу NI CompactDAQ при свердлінні отворів малого діаметра (до 5 мм).

***V.P. Larshin, N.V. Lishchenko. Cutting tool vibrodiagnostics on CNC machines.*** Characteristic of the cutting tools technological vibrodiagnostics way on CNC machines and results of experimental studies of the vibrodiagnostic system in drilling small holes (up to 5 mm in diameter) on the basis of measuring complex NI CompactDAQ are given.

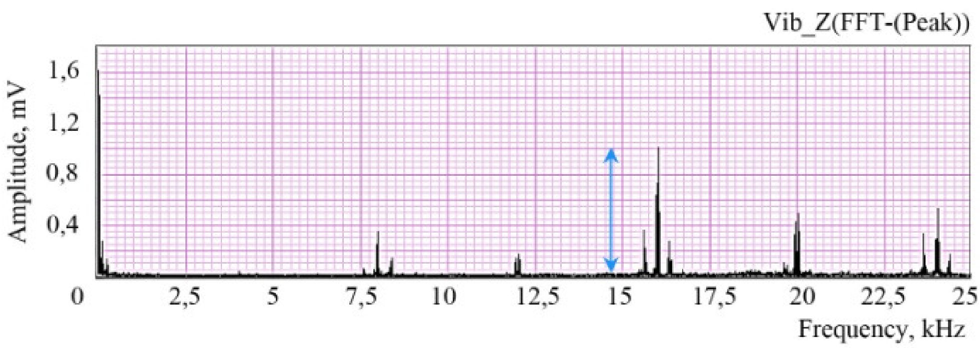
**Introduction**. This work is a continuation of experimental studies [1] for drilling small holes on the machining center 500V/5 type with SIEMENS SINUMERIC 840D CNC (nominal and maximum spindle speed is 1500 and 8000 min-1).

**The aim of research** is to develop a method of cutting tool (CT) vibration diagnostics and a cutting diagnostical system for CNC machining center 500V/5 type.

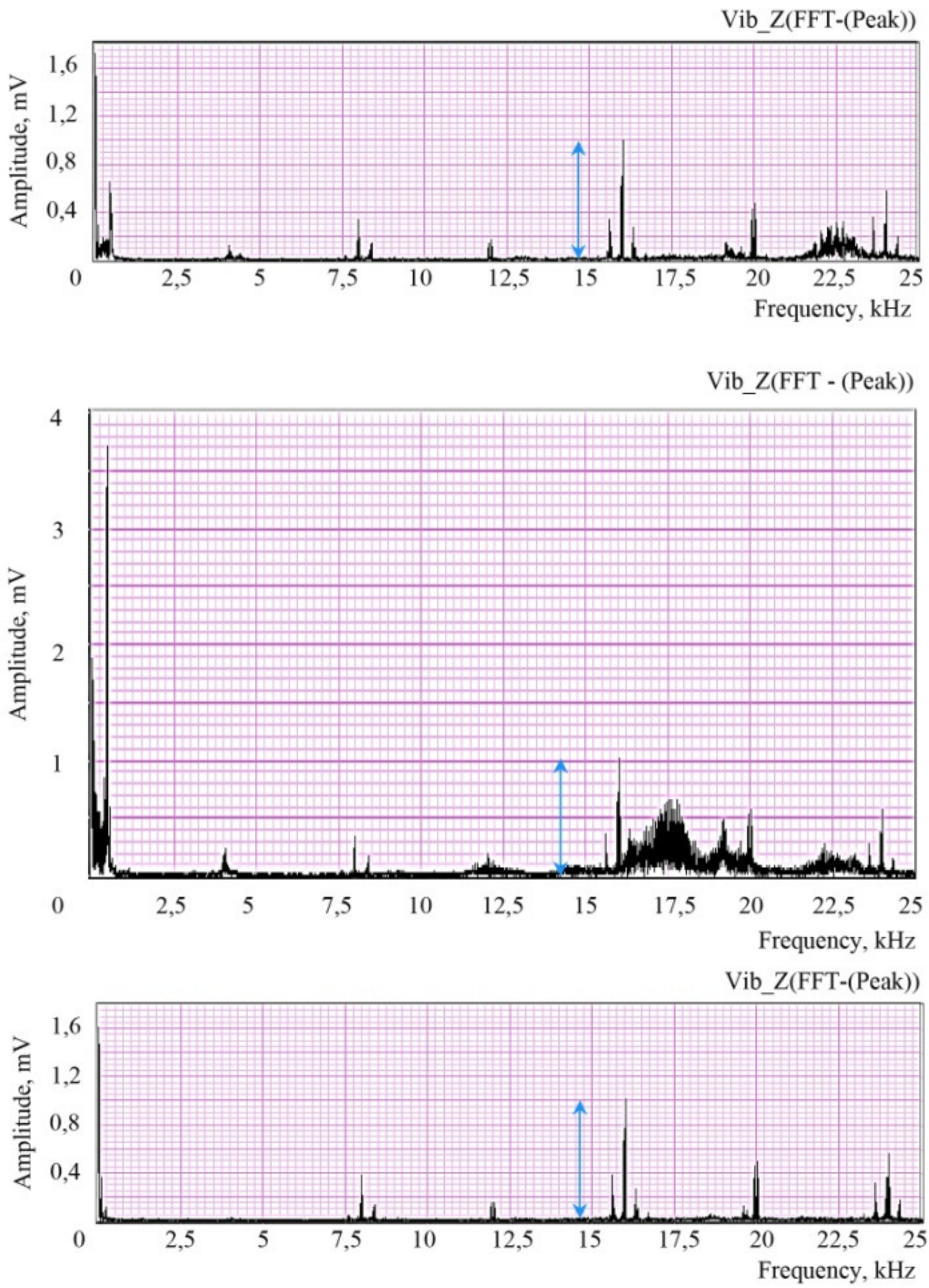
**The main material**. Experimental conditions are the following: twist drill 2.85 mm and 4.7 mm in diameter of high-speed steel P18, drilling depth 8 mm, prismatic workpiece 298 x 110 x 10 mm of stainless steel 14H17N2, HSK 63-2/20-100 mandrel with a collet. Drilling modes: the frequency of spindle rotation ***n***: 250, 500 and 600 rpm; axial feed 0.06 mm per revolution. This axial feed is provided by software i.e. by setting the minute feed with the rate of 15, 30 and 36 mm per minute, respectively, on CNC system mentioned above. To reduce testing time, drilling is produced without applying technological lubricant to the cutting zone. Each drilling experiment was performed at least 3 times, and the number of repetitions of the experiments was depended on the comparability of the obtaining results.

Scientific research measuring complex is a USB modular system NI CompactDAQ, which comprises an analog-to-digital synchronization unit, multi- chassis NI cDAQ-9172 connected to an industrial PC. Needed measurement system filter settings and gain coefficients were made with the help of the PC and LabVIEW 8.5 software environment for the AP2019 vibrosensor. There were three vibrosensors with the following characteristics: size of Ø3 x 3.6 mm, frequency range 0.5 ... 30 000 Hz, sensitivity 0.5 mV/ g (g = 9,8 m/s2), or 0,051 mV/( m/s2). All steps for setting up and operation of the measurement complex including the signal sampling frequency selection are controlled by the LabVIEW 8.5 applications, which are pre-drawn up in the block diagram form on the basis of independent functional programmable blocks. Feature of this complex is the ability to create and configure a measurement system for acquisition, processing, and displaying signals of vibrosensors mounted on the Z axis immovable face of the spindle unit and its immovable sides along the X and Y coordinates. Previously found spindle unit stiffness along the X, Y and Z axis is, respectively, 16.3, 21.6 and 48.5 N/m [2].

The measuring system allows not only to capture temporal changes of the X, Y and Z signals, but also display the signal spectrum (a signal form that is like an amplitude-frequency characteristic) of these signals, which is a more informative indicator of changes in the drill bit such as its bluntness and failure. As an example, Fig. 1 shows a spectrogram of axial vibration drill (i.e. Z axis): after switching on the motor spindle (a), in the middle of the time interval of the drill work (b), at time points up to (c) and after (d) the drill bit breakage.




*a*



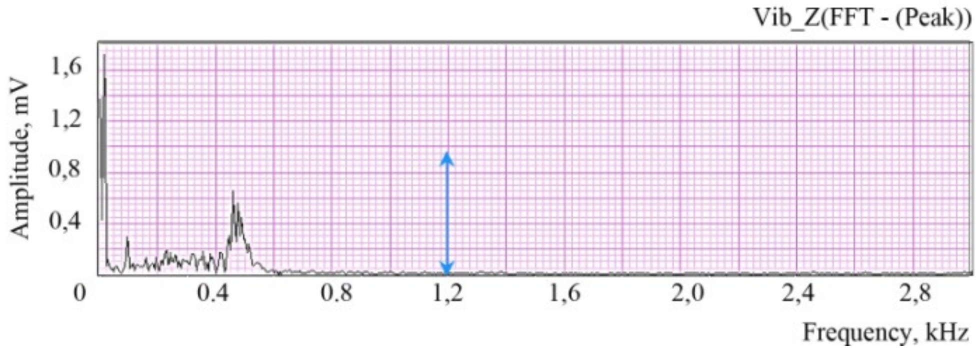

*b*

*c*

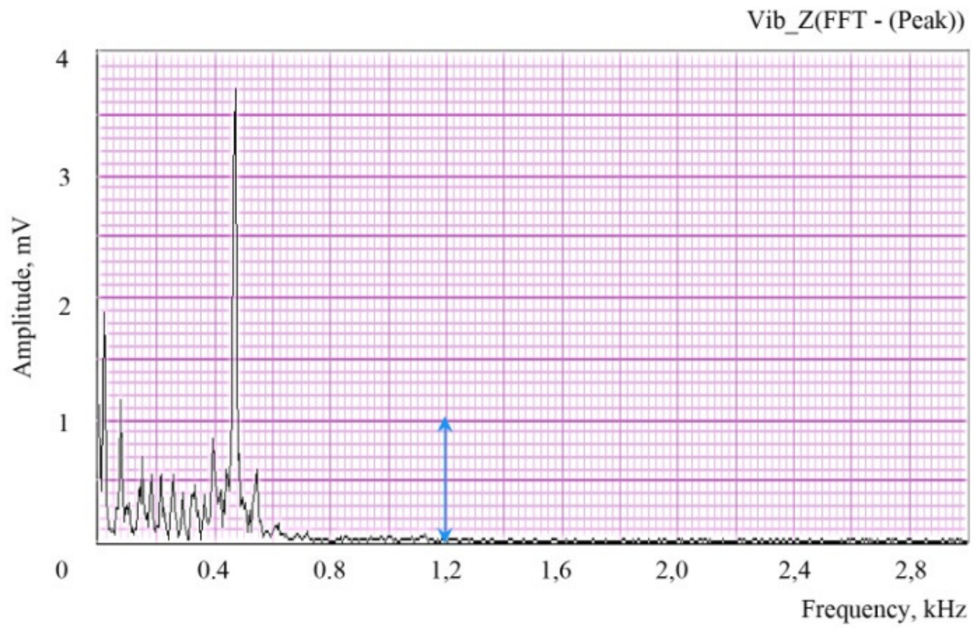
*d*

Fig.1. Spindle *Z* axis vibration spectrogram at drilling different times for the drill bit 2.85 mm in diameter and $n$ = 500 rpm.

Figure 2 shows some of these spectrograms in a more narrow frequency range.




*a*




*б*

Fig.2. Spectrogram in Fig.1, *b* (*a*) and Fig.1, *c* (*b*), but in a more narrow frequency range, that is, 0 ... 3 kHz (the arrow in Fig. 1 and Fig. 2 shows the same vertical scale unit).

Fig. 1 and Fig. 2 spectrograms analysis shows that as the drill works the some spectrum harmonic components are most sensitive in amplitude to wear of the drill bit. Besides it takes place for both individual spectrum frequencies and for individual spectrum bands. This is reflected in the increased harmonic amplitudes as the drill bit works and its wear appears.

It is found that for the drill 2.85 mm and 4.7mm in diameter a characteristic frequency $f_{wi}$ reflecting the drill bit wear is that of $f_{wi}$ = 500 Hz, as well as close-fitting to this frequency adjacent frequencies in the band of 450 ... 550 Hz.

Maximum vibration amplitudes are measured at frequency of $f_{wi}$ = 500 Hz (Table 1). Additionally, the processing time was determined at which the amplitude of the corresponding harmonic becomes maximal, i.e. $A_{wi}(500, \ _{w\max}) = A_{wi}$. Table 1 also shows the mean values of these parameters (i.e. $A^{ave}_{w\max}$ and $^{ave}_{w\max}$) as the results obtained by averaging 3 times repeated experiments for each of the three of spindle speeds: 250, 500 and 600 rpm.

Table 1 – Results of experimental determination of $A^{ave}_{w\max}$ and $^{ave}_{w\max}$ at the vibration frequency of 500 Hz along the Z axis of the machine

| $n$, rpm | Number of experience | $_{w\max}$, s | $^{ave}_{w\max}$, s | $A_{w\max}$, mV | $A^{ave}_{w\max}$, mV/(m/s$^2$) |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 250 | 1 | 183,8 | 187,1 | 2,25 | 1,95 /39,0 |
| | 2 | 124,8 | | 1,50 | |
| | 3 | 252,6 | | 2,10 | |
| 500 | 1 | 204,0 | 229,3 | 3,60 | 2,03 / 40,6 |
| | 2 | 206,6 | | 1,30 | |
| | 3 | 277,4 | | 1,20 | |
| 600 | 1 | 246,8 | 221,8 | 3,90 | 3,16 /63,2 |
| | 2 | 274,2 | | 3,10 | |
| | 3 | 144,4 | | 2,50 | |

The table shows that with increasing speed drill bit from 250 to 500 rpm the time value averaged over the three experiments increases slightly (from 187 s to 229 s). With further increasing speed up to 600 rpm, the value of $^{ave}_{w\max}$ decreases slightly up to 222 s.

At the same time as the speed $n$ increases from 250 to 600 rpm, the maximum vibroacceleration amplitude $A^{ave}_{w\max}$ averaged for the three experiments increases regularly from 39.0 to 63.2 m/s$^2$.

X, Y and Z vibration frequency spectrograms (spectrograms for X and Y coordinates on Fig. 1 and Fig.2 are not shown) other than characteristic frequencies, consist of harmonic components caused by the rotation of the machine spindle.

For the spindle rotation frequencies 250, 500 and 600 rpm in all spectrograms regardless of the X, Y, and Z coordinates and the drill bit diameter (2.85 or

4.7 mm) there are frequencies caused by the main spindle rotation frequency and other structural elements of the spindle unit, to wit 8 kHz, 16 kHz and 24 kHz. Furthermore, there are three additional low frequencies along Z axis, the numerical values of which depend on the main spindle rotation frequency (Table 2).

Table 2 – Additional spectrum vibration frequencies along the Z axis

| The main spindle (or drill bit) rotation frequency, rpm | | |
|---|---|---|
| 250 | 500 | 600 |
| Additional frequencies caused by the main spindle rotation frequency, Hz | | |
| 10, 50, 120 | 20,100, 250 | 20, 120, 290 |
| Note: additional frequencies are identified in the Z vibration spectrogram by zooming the LabVIEW 8.5 program frequency axis. | | |

**Conclusion**

1. A cutting diagnostics system is developed to investigate the cutting vibration on a CNC machine in the online machining. The system consists of hardware and software which is represented by research automated system on the basis of NI CompactDAQ measuring complex (National Instruments Company).

2. AP2019 type vibration sensors are used in this research automated system. These sensors are characterized by both a small size (Ø3 x 3.6 mm) and an easiness of embedding into the 500V/5 CNC machining center.

3. To increase the vibration sensor signal sensitivity to the tool cutting ability change when the tool works and wears, a time-frequency signal transformation is included into the diagnostic system functioning algorithm.

4. In the drilling small holes (2.85 and 4.7 mm in diameter) in the workpiece of stainless steel, the harmonic components of the time signal with the highest sensitivity to changes in the cutting ability of the drill bit are founded, to wit the harmonic of 500 Hz (a characteristic frequency) and the adjacent harmonics in the band of 450-550 Hz.

5. It is found that as a small-diameter drill bit blunting appears the signal amplitude of vibration acceleration significantly increases and the more, the higher the spindle speed. For example, if the spindle speeds range is 250 ... 600 rpm, the acceleration signal amplitude increases in the range of 39.0 ... 63.2 $m/s^2$. After reaching the maximum value of the signal amplitude (at a characteristic frequency) a drill bit breaks down. This phenomenon can be used to diagnose a drill bit state.

6. The time during which the drill bit operates to its full wear and breakage does not depend essentially on the rotational speed of the drill bit. For example, this time is equal to 187.1 ... 229.3 s as rotational speed of the drill bit changes in the range of 250 ... 600 rpm.

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