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DYNAMIC EVALUATION OF THE VIBRATING DRILLING SYSTEM

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Abstract: *New materials technologies have led to new composite materials solutions to replace existing conventional materials. The compliance of the quality and the life span of drilling tools becomes difficult, these two being considerable reduced. The constraints generated during the drilling process are very important in amplitude and complexity. For this purpose, an adopted machining solution based on vibration assisted drilling was presented. This paper aims to dynamic study of a new drilling solution assisted with vibration. This system is the subject of a patent. To evaluate the dynamic behaviour of the drilling vibration system an experimental setup was designed and built. The study allowed the identification of natural frequencies and determination of dynamic parameters: stiffness, damping and mass. These parameters are required in the further development of a dynamic model to optimize the reel cutting conditions. For this purpose a dynamic evaluation of drilling system assisted with forced-vibrations was imposed.*

Key words: *drilling, vibratory system, vibrations, dynamics, evaluation.*

1. INTRODUCTION

New materials technologies have led to new composite materials solutions to replace existing conventional materials. According with the new trend in aeronautic industry, the hybrid structure is being used composed by different type of materials: aluminium, titanium, carbon fibres etc. Large industrial companies have adopted such solutions significantly decreasing the total weight of the aircraft. But reducing weight and getting the benefits of integrating the multilayer materials was penalized by the increasing complexity of problematic phenomena during the cutting process, respectively during the drilling operation [1].

The respect of the quality and the life span of drilling tools becomes difficult, the two being considerable reduced. The constraints generated during the drilling process are very important in amplitude and complexity. Therefore, it is necessary to drill simultaneously the different layers while respecting associated quality criteria: roughness, bur height, composite pushing, damage and rupture etc. [1]. Obviously, drilling composite material together with metallic material will lead to specific technical issues [1, 2].

Processing such materials have needed the investigation of a number of technologies in the field. Some results are considering the study of drilling tools, material and surface quality, geometry and cutting system. For this purpose, an adopted machining solution based on vibration assisted drilling is presented. Currently, in the industry certain vibration assisted drilling system are users having advantages and disadvantages [1, 3].

This paper aims to dynamic study of a new drilling solution assisted by vibrations. This system is the subject of a patent [4].

2. DESCRIPTION OF THE NEW DRILING VIBRATING SYSTEM

The technological solution provides the possibility of varying the amplitude of forced vibrations, feed and rotational speed. These targets were the main criteria underlying the patent proposed by the research team of Materials Process Interaction Laboratory (MPI) of Institute of Mechanics and Materials Bordeaux (I2M) [4].

The new vibration system has been initially designed for portable semi-automated drilling units. Such drilling machines work on the following principle: a single pneumatic motor generates both spindle speed and feed rate; obtained by a specific mechanism [5, 6]. The spindle is brought into rotation through the upper gear set. A pin linking the upper and lower gear sets, allows the lower gear set to turn. The rotation of the screw joint gear makes the spindle move forward. The feed rate is set up by the velocity differential between the spindle and the screw joint. Unlike other existing vibration systems, this patent does not bring any additional components. The concept of the new mechanism is to make a periodical phase-shift between the two sets of gears. To do so, the axis of gear 2 is moved while maintaining contact between gears 2 and 3 (Fig. 1). The result is a misalignment or an eccentricity *E* (Fig. 1) between the axes of the first two gears.

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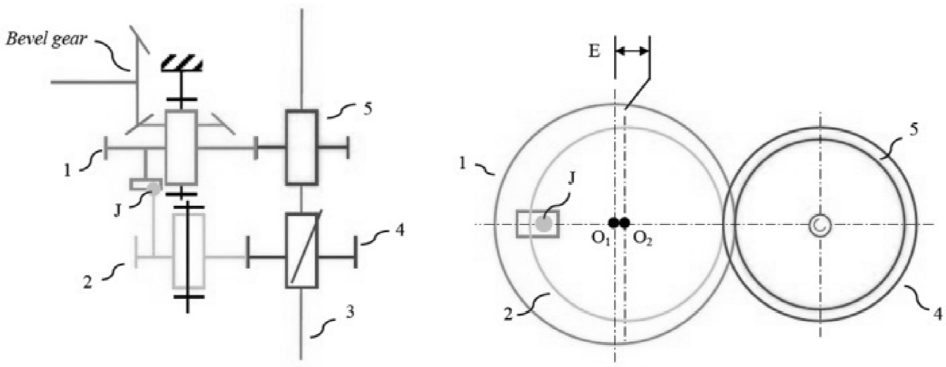

Fig. 1. The vibration system description [4].

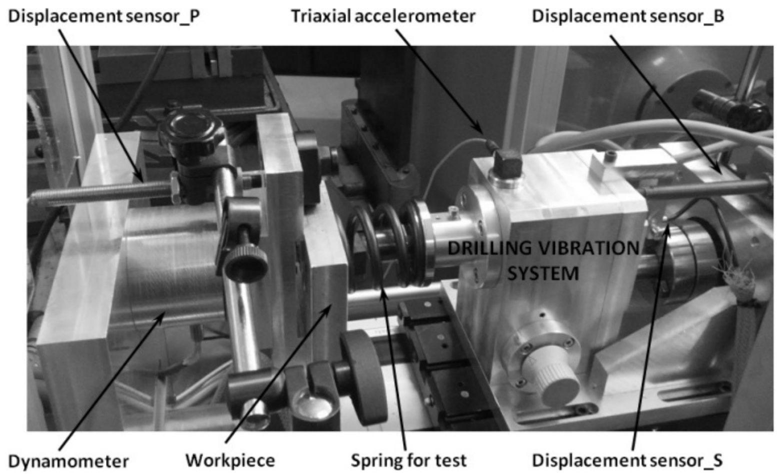

Fig. 2. Experimental setup for static case.

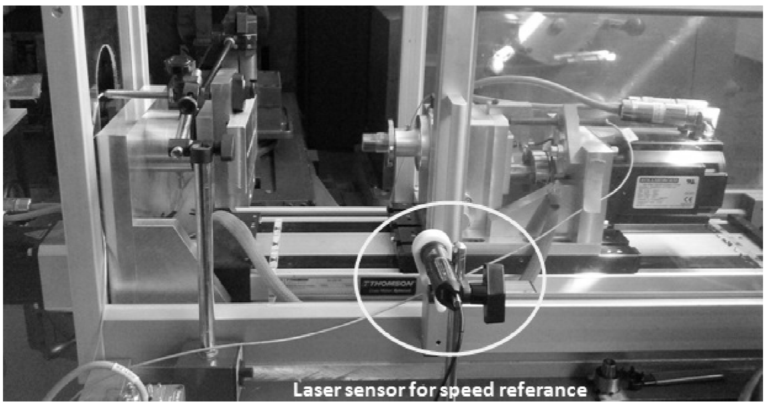

Fig. 3. Experimental setup for dynamic case.

This misalignment of axes represents a variation in the distance between the pin center (*J*) and the axis of 1 (O_1). Therefore, the angular position of 2 will fluctuate around the angular position of 1 [1, 3]. For deep knowledge of the drilling vibration system it is necessary to study the dynamic behaviour. It is intended to determine the dynamic characteristics in order to develop a model to optimize cutting parameters for drilling machining.

3. EXPERIMENTAL SETUP

To highlight the dynamic behaviour of the drilling vibration system, an experimental setup was designed and built. The dynamic analysis is divided into two parts: static and dynamic analysis. Static analysis is performed to determine the dynamic parameters: stiffness, mass and damping with the natural frequencies domain determination while dynamic analysis provides information on critical frequencies in the drilling process. Thus, in order to determine the stiffness value three non-contact displacement sensors, presented in Fig. 2 were used: a displacement sensor is positioned on the workpiece *(displacement sensor_P)*, another sensor is positioned to measure the relative displacement of the *spindle-screw (displacement sensor_S)* and the third one is used to measure the overall deformation of the entire frame *(displacement sensor_B)*. To obtain the elasticity of the system, a spring is used for the load test and no-load test (Fig. 2).

For dynamic case, a laser sensor for rotational speed of the drilling is used to make the synchronization between vibration signals and rotational speed. Vibration measurement is performed through triaxial PCB accelerometer. The vibration axis of the accelerometer is in correspondence with drilling system axis.

To obtain the frequency response of the dynamic system, an impact hammer is used. Data processing and signal analysis is performed using Dewetron and National Instruments USB 4432, together with Dewesoft and Fastview software respectively.

3.1. Natural frequency determination

To evaluate the system, the frequencies determination is made on the impact test. Thus, for the natural frequency the FRF function is applied. In Fig. 4, the frequency domain with magnitude is presented and in Fig. 5, frequency domain with phase is shown. It can be seen that the main important frequency is located at 73.2 Hz observed in both magnitude (Fig. 4) and phase change of 180° (Fig. 5). Another frequency pick that needs attention is situated around 200 Hz, but it can be seen that the change of phase is less than 180°. For the determination of the fundamental frequency excitation, the frequency domain was obtained during the rotational speed. As shown in Fig. 6, the natural frequency is excited to 74 Hz during the speed test.

Figure 6 presents the frequencies measured during the speed test. The tests are performed at variable speed were forced vibration frequency is visible. The frequency spectrum presented in Fig. 6 is obtained for 1384 rpm speed.

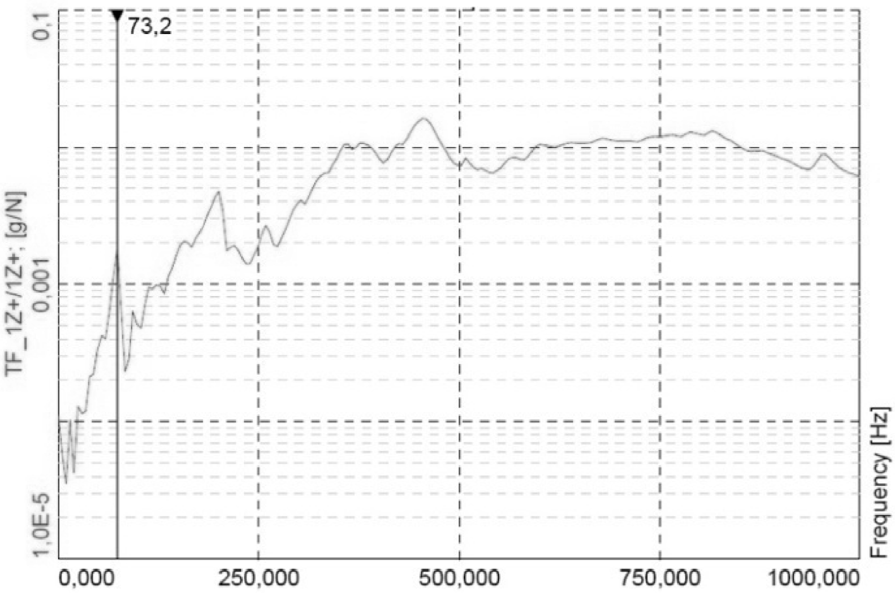

Fig. 4. The frequency response on magnitude.

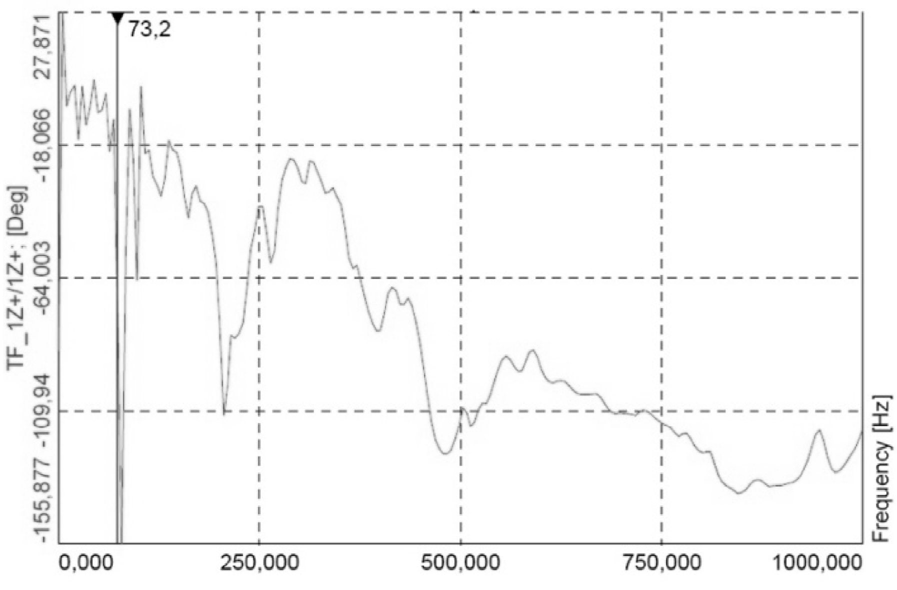

Fig. 5. The frequency response on phase.

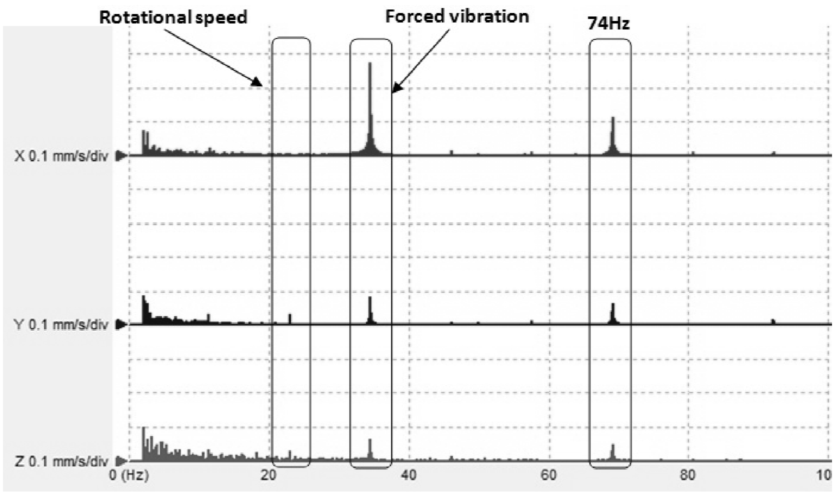

Fig. 6. Frequency analysis during the speed.

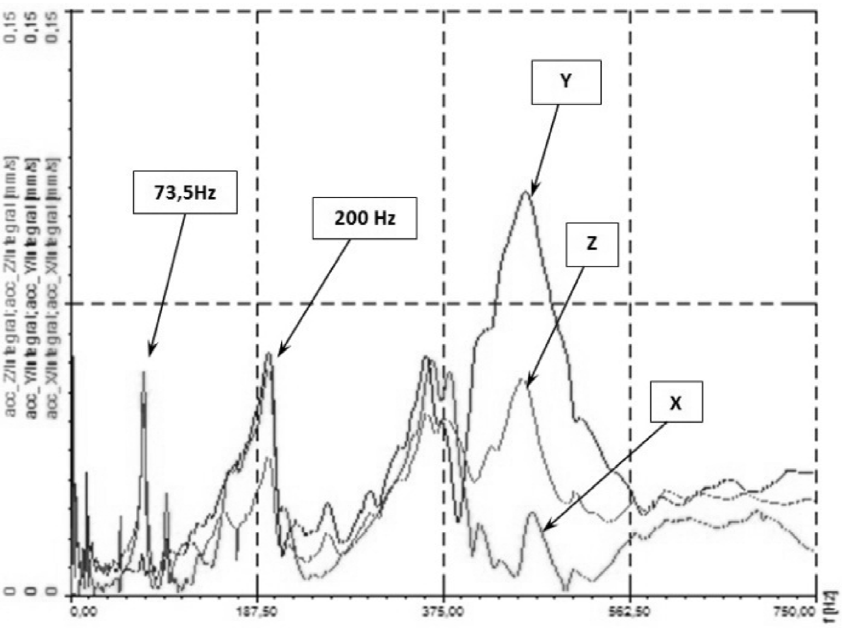

Fig. 7. The frequency spectrum after impact test.

For detailed knowledge of the entire frequency range, a series of impact tests are performed. In Fig. 7, the frequencies revealed by the accelerometer in three directions are shown. It highlights those frequencies of 73.5 Hz and 200 Hz subject of interest for analysis of drilling assisted vibration system. Also, the analyses of these tests show that 74 Hz is a characteristic frequency of the system. The importance of these frequencies is needed to reveal the harmonic frequencies to know the system resonance zones. The dynamic parameters will be determined for a frequency of 74 Hz.

3.2. Dynamic parameters determination

The vibratory drilling process is a definite solution for machining materials where current technologies do not provide optimal results for obtaining the parts. The technique of low-frequency vibration cutting is well adapted for deep drilling because vibration-assisted chip breakage allows an easier chip removal [7]. In these conditions, characterizing the dynamic drilling system assisted with vibration requires the determination of dynamic parameters. Moreover, dynamic parameters are indispensable in drilling process modelling in the drilling configuration assisted with vibrations. Mathematical models of vibration drilling system are commonly reduced to a one-dimensional linear or non-linear model in the axial direction governed by the mass, damping and stiffness of the considered system [8, 9]. Thus, the dynamic parameters of the vibration drilling system: stiffness, damping and mass are further determinated.

The stiffness parameter is determined in the static configuration using the experimental device presented in Fig. 2. To determine the stiffness of the system, a number of tests are performed. The application of force is performed on axial direction using the feed movement. To obtain a constant force, a metallic spring is fixed between drilling unit and workpiece. The force is measured by a Kistler dynamometer coupled to the workpiece and the displacement is measured by displacement sensors (Fig. 2). During the load and no-load tests, the three displacements are measured (Fig. 8).

Using the Eq. (1), the calculation of the stiffness is obtained after hysteresis evaluation (Fig. 9). The stiffness value in this case is 2×10^7 N/m:

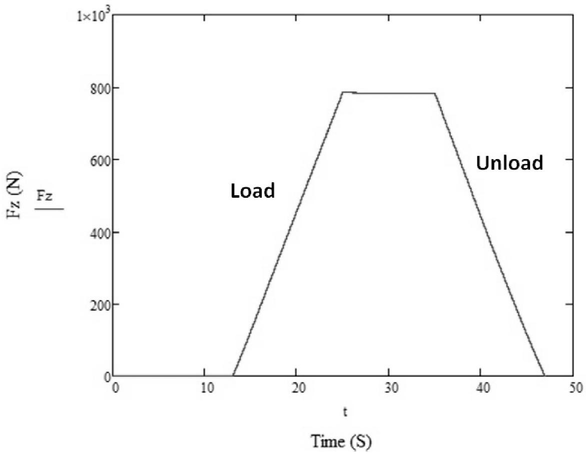

Fig.8. Load and unload test for stiffness determination.

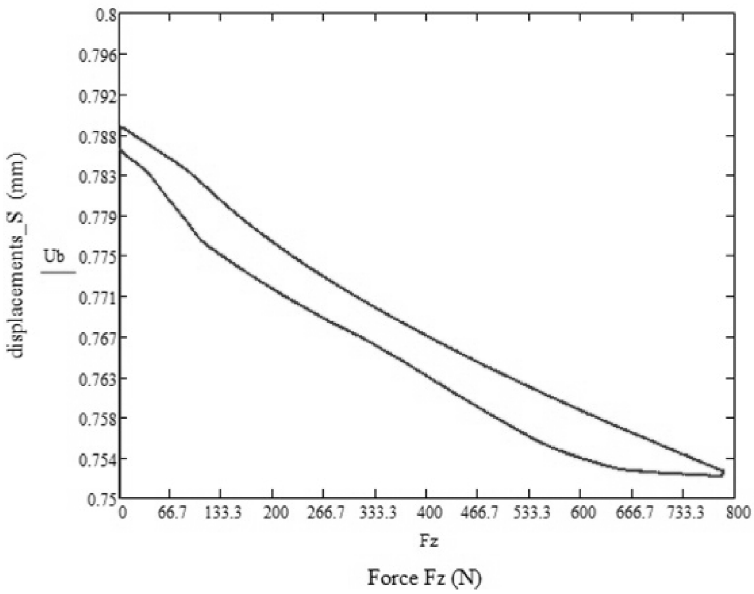

Fig. 9. Force and displacement measurement.

$$K = \frac{\Delta F}{\Delta u}. \quad (1).$$

Knowing stiffness parameter in axial direction and considering the natural frequency of the drilling system, one proceeds to determine the mass and damping parameters

The dynamic parameters mass and damping are determinated with:

$$\xi = \left(\frac{1}{2 \cdot n_x \cdot \pi}\right) \cdot \ln\left(\frac{x_1}{x_n}\right), \quad (2)$$

were ξ represents the damping percent, n_x − number of pick, x_1 − first amplitude, and x_n − last amplitude calculated.

$$\omega_n = \frac{\omega_d}{\sqrt{1-\xi^2}}, \quad (3)$$

$$\omega_d = 2 \cdot \pi \cdot f \quad (4)$$

$$m = \frac{k}{\omega^2}. \quad (5)$$

The damping coefficient is:

$$c = 2\xi\sqrt{k \cdot m}. \quad (6)$$

After applying the above mathematical relations, the following values are obtained: the mass coefficient is 94 kg and the damping coefficient is $3.9 \cdot 10^3$ N·s/m. The known dynamic coefficients − stiffness, mass and damping − will be be used in future to develop a dynamic model to predict drilling axial force in order to optimize the drilling cutting parameters.

4. DYNAMC ANALYSIS

Vibration-assisted drilling technologies are based on forced excitations generated by a specific power supply system implemented by a new drilling patent system [4]. This paper aims to achieve dynamic analysis to assess dynamic operating characteristics.

In this direction of study the natural frequency of the drilling system was determined verified in the dynamic case during the speed operation (Figs. 10 and 11). This spectral component is situated around the frequency of 74 Hz and it is evident throughout the speed range.

As can be seen from the FRF diagram, this frequency represents the critical frequency of the system. Dynamic analysis aims at highlighting the dynamic behaviour of the drilling system assisted with forced vibrations. The frequency domain obtained during the speed variation shows the existence of low frequency but also high frequencies. High frequency range is generated by gears and bearings of drilling system. Knowing these frequencies with geaing frequency and ball bearing defect frequencies is an important step for the optimal operation and also for predictive maintenance of the drilling system.

The measurement signals are made in the same conditions of sampling rate for acceleration and forced-vibration on axial direction. The time domain analysis shows the waveforms of displacement and acceleration synchronized with rotational speed (Fig.12). It can be seen that the forced vibrations are 1.5 times higher than the speed.

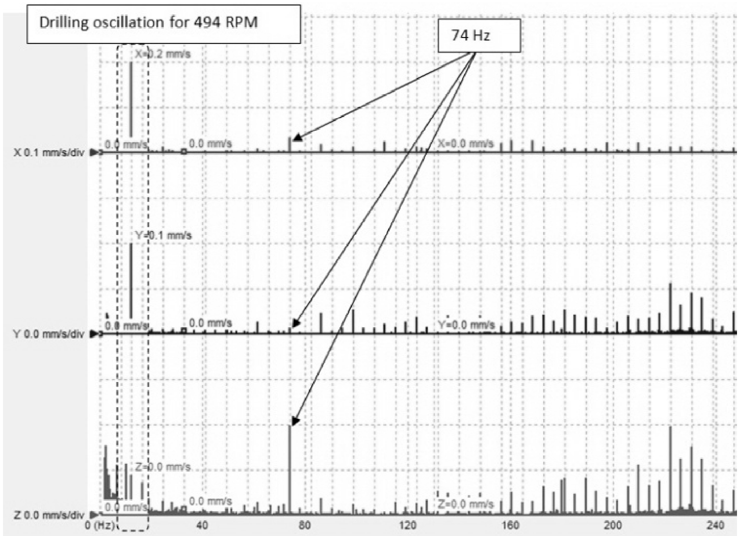

Fig.10. Frequency spectrum on the 494 rpm speed for *x*, *y*, and *z* directions.

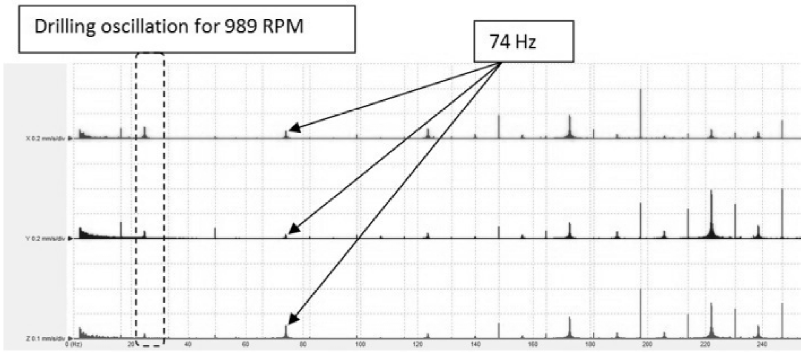

Fig. 11. Dynamic frequency on the 989 rpm speed for *x*, *y*, and *z* directions.

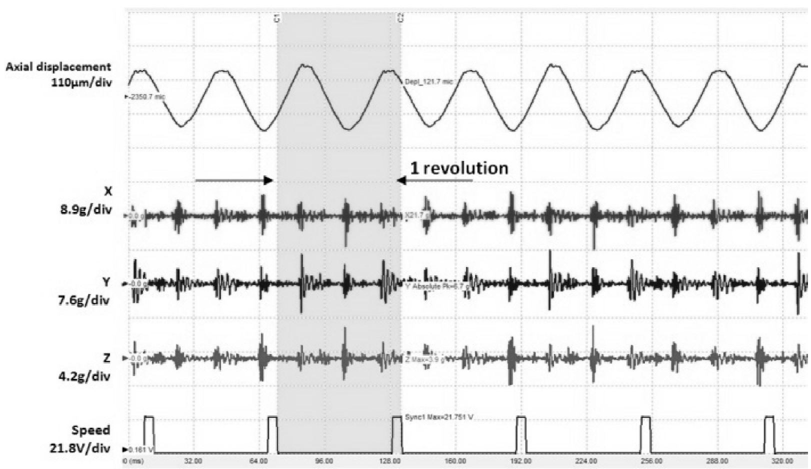

Fig. 12. Vibrations signal during the 989 rpm speed for *x*, *y*, and *z* acceleration and displacement on axial direction.

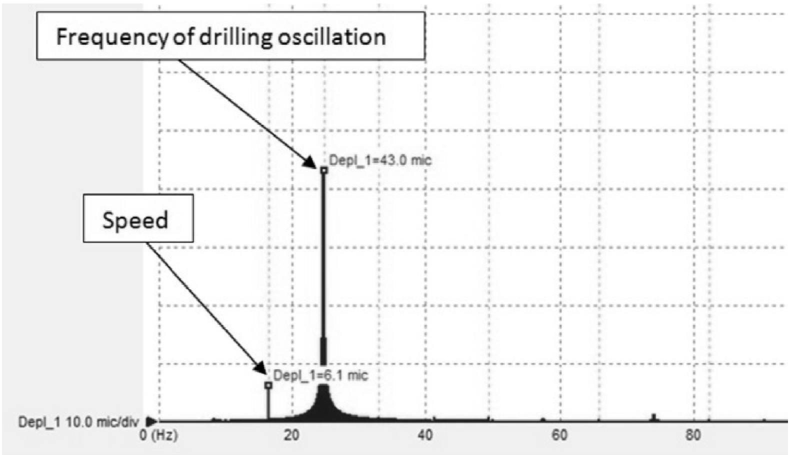

Fig. 13. The axial displacement spectrum for 989 rpm.

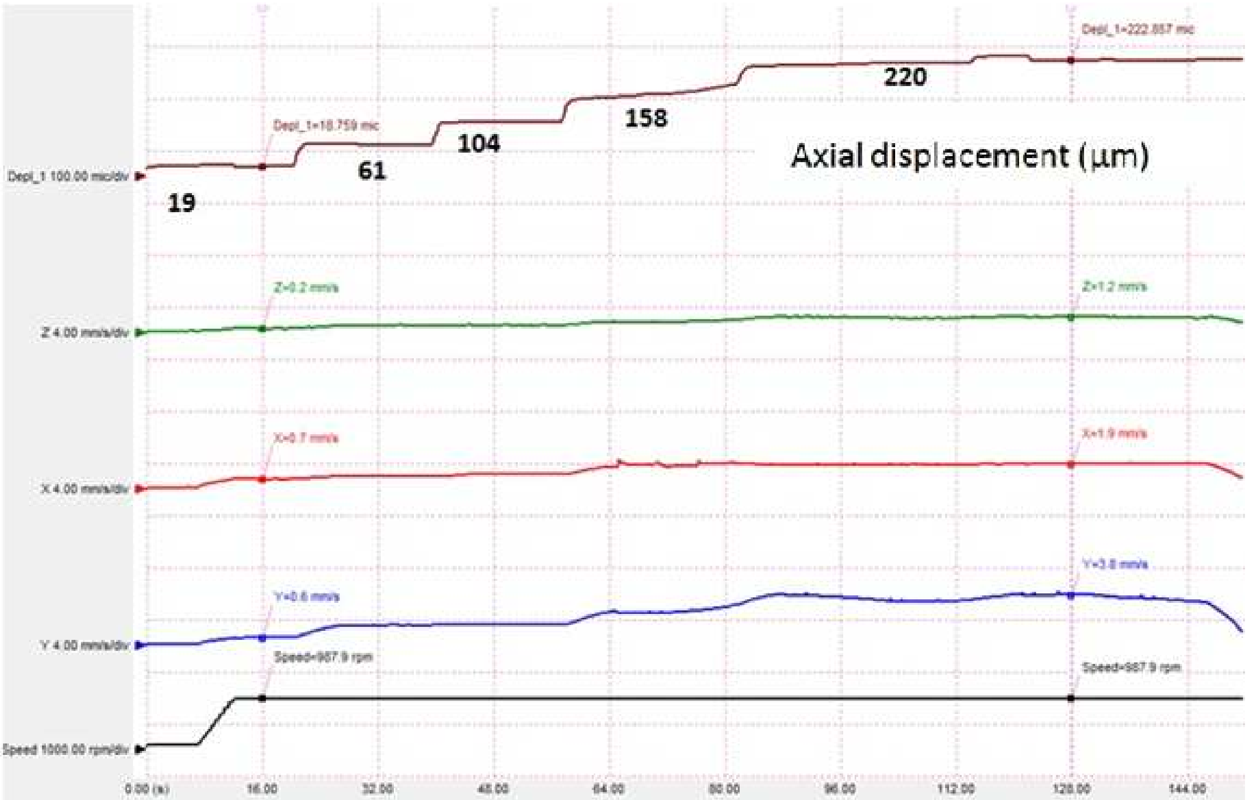

Fig. 14. The axial displacement variation.

Frequency range for the axial displacement measurement during speed operation reflects the amplitude of forced oscillation of the drilling tool (Fig. 13). The test is performed for 90 µm amplitude of oscillation. This new drilling vibration solution besides using usually parameters speed and feed, it provides also the possibility of varying amplitude shown in Fig. 14. The maximum amplitude of forced oscillation is obtained for 220 µm. The next step of research is to analyze the drilling process in terms of chip fragmentation.

5. CONCLUSIONS

Vibrating drilling represents a solution for drilling holes with high productivity and suppression of retreat cycles. Using the axial forced vibration, this technique decreases amplitude of forces and determines optimal chip fragmentation.

This paper presents an experimental approach designed to assess the dynamic characteristics of a drilling system with forced vibrations.

Highlighting of the dynamic characteristic of the drilling system was carried out using an experimental setup having several measurement devices for: vibration on three directions, speed, relative displacements and forces.

The study allowed the identification of natural frequencies and determination of dynamic parameters, stiffness, damping and mass.

These parameters serve for their further integration in the dynamic model which will be developed.

The approach provide dynamic information in frequency and time domain necessary to evaluate the drilling spindle for operation and also for monitoring during the drilling process.

In future research, the model should give solutions regarding the cutting parameters optimization for drilling process assisted with forced vibrations.

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