A DYNAMIC ANALYSIS OF THE DRILL VIBRATIONS FOR VIBRATORY AND VIBRO-SHOCK DRILLING

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Abstract The paper presents a finite element analysis of the drill for vibratory and vibro-shock drilling operations. These types of drilling are used to obtain fragmented chips, which is very useful for long drills and also for high plasticity material which has a low machinability. The analysis is focused on finding the drill's eigenfrequencies and the drill's response to variable motor torques.

1. INTRODUCTION.

Modern metal cutting techniques are using high speed machining, multiple tool machining and automation [1]. Large scale development of these methods had highlighted problems regarding vibrations born during the cutting process. In order to better understand drilling vibration processes both induced and naturally born during cutting experimental and simulation methods had been developed [2]. Mainly, the goal of the simulation of drill vibrations is on one hand to eliminate the vibrations which has a negative effects on the process and on the other hand to use proper vibrations in chip fragmentation purposes, which is useful in automated cutting and deep drilling processes where the chips has to be removed from the process area [3], [4]. Also in the manufacturing of deep holes has to face problems to evacuate chips, especially for small diameters. Such problems induce frequent tool breakage and poor surface quality. The vibratory drilling enables the chip to be split into small elements thanks to the axial vibrations of the drill, self-maintained by the cutting energy. Thus, chips are easily evacuated from the hole. The use of vibration and vibro – percution can be a method to enhance machining of high plasticity materials machining like stainless steels, low carbon rate steels (ARMCO, CARBONIL), or other metals like pure copper (OFHC), aluminum, aluminum alloys and titanium. Usually these materials which are giving long chips and which, in general, are turned around the tools producing damage to the tools and the machined surfaces.

A specific tool holder with an adapted axial stiffness has been developed in order to investigate this drilling process. Chip fragmentation can also contribute to increase surface quality by avoiding long chips to scratch the processed surface and also avoiding material buildup on the tool edge. Experiments on using vibration of the drill and vibro–shocks in metal cutting had been made by the authors, with different cutting parameters on high plasticity material probes, in drilling operations on CNC machine tool. The vibro-shocks in the mentioned cases are generated by a specially built tool holder described in [5]. For generating sinusoidal vibrations other similar devices can be used. As the vibro-shock drilling process had been known well enough, there are no studies published on the behavior of the drill in these conditions. This paper presents some investigations on how the drill is supporting the shock and vibration in this kind of machining.

2. MODELING AND EXPERIMENTAL STUDIES OF DRILLING VIBRATIONS.

In order to simulate the vibrations of the tool, different methods can be used [6], [7], [8], [9]. These models are developed in order to study the effects of drill vibration on the cutting process. The cutting conditions are predetermined in order to lead to axial vibrations with a stable frequency and amplitude. During a period of the motion, the amplitude of the vibrations is higher than the feed per revolution, which enables the cutting edges to jump out of the work material. The vibrations are self-maintained and remain stable if some disturbances are absent or very limited such as the friction of the drill against the work material along its margins. Some of the researchers developed dynamic models for chatter in drilling based on transverse vibration due to bending, and the axial vibration due to torsion.

There are researches in which a dynamic model is developed to obtain the limit of stability for the bending vibration mode. The equations of motion are formulated based on a lumped representation of the drill, and the gyroscopic effect due to the rotation of the tool is included. It is shown that, including this gyroscopic effect has a profound effect on the resulting stability lobes, especially at very high speeds; it makes the lobes wider but at the same time lowers the minimum stability boundary. A time domain simulation model is also developed that combines both bending and torsion modes. This model is verified using experimental cutting tests.

A well known method used for structural studies is the Finite Element Analysis. This uses the partitioning of the drill body in small finite regions connected by quasi joints with certain elasticity and damping components. In this paper we used this method to analyze drill body response to vibrations.

3. FINITE ELEMENT ANALYSIS OF DRILL NATURAL VIBRATION

In order to complete the finite element analysis the simulation parameters of the model must be defined. Selection of cutting parameters (tab. 1) had been made considering the percussion device design and also the machinability of OFHC copper [9]. Actual feed rates had been selected smaller than in literature.

Table 1. Cutting parameters.

Speed [m/min]	19,3773					17,8849					15,5571					14,0492					11,6364				
RPM [rot/min]	771					686					619					559					463				
Feedrate [mm/min]	1	2	4	6	8	1	2	4	6	8	1	2	4	6	8	1	2	4	6	8	1	2	4	6	8

The model had been designed for the actual values used in the experiments described in [3], [4], [5].

The analysis was made using the COMSOL Multiphysics programming environment, the Structural Analysis module.

In figure 1 the 3D geometrical model of the drill is presented. The finite element mesh is than defined on this geometrical model.

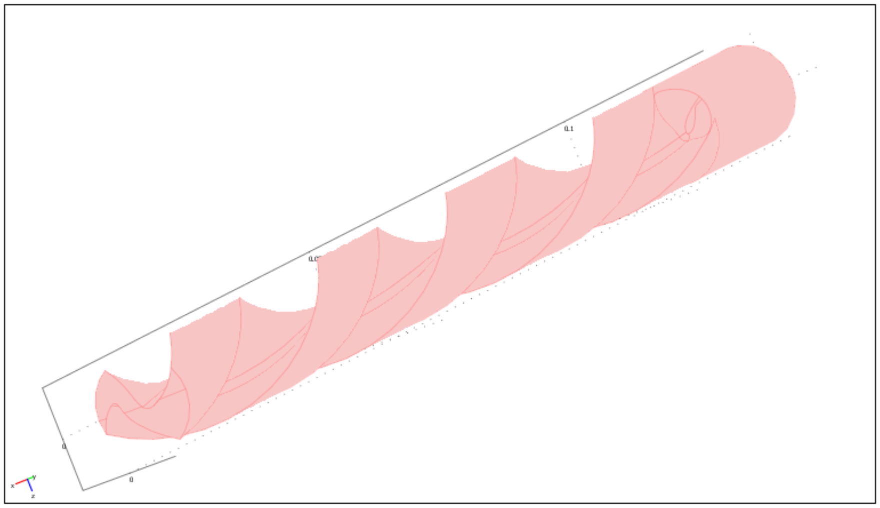


Fig. 1. Geometrical 3D model of the drill body.

In figure 2, the finite element mesh is presented and the mesh parameters are given in table 2.

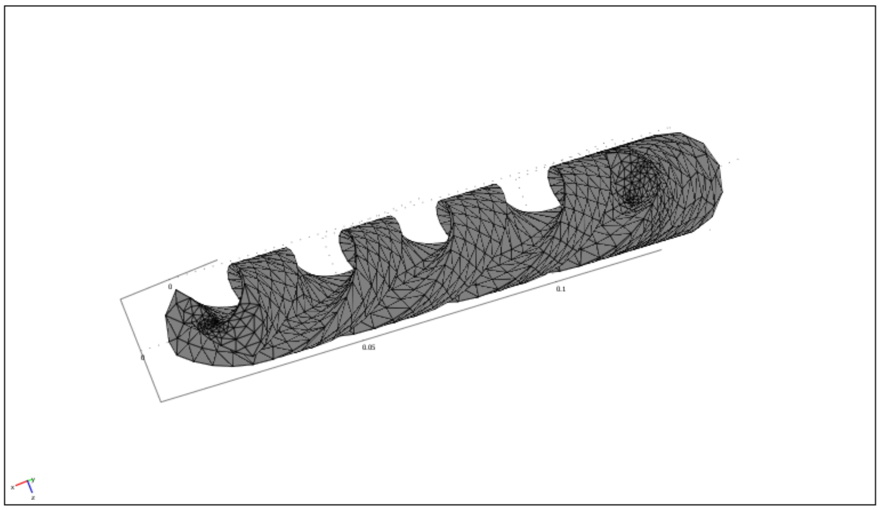


Fig. 2. 3D finite element mesh model of the drill body.

Tabel 2. Mesh parameters

Nr.crt.	Parameter	Value
1	Number of degrees of freedom	30696
2	Number of mesh points	1657
3	Number of tetrahedral elements	5598
4	Number of triangular boundary elements	2642
5	Number of edge elements	557
6	Number of vertex elements	37
7	Minimum element quality	0.2262
8	Element volume ratio	$3.09x10^{-5}$

In order to find the eigen frequencies for the drill body, under vibrations the free vibration mode analysis was used. Results are given in figure 3 and eigen frequency values for 6 major vibration modes are presented in table 3. Simulation results regarding total displacements at a frequency of 2029 Hz is shown in figure 4.

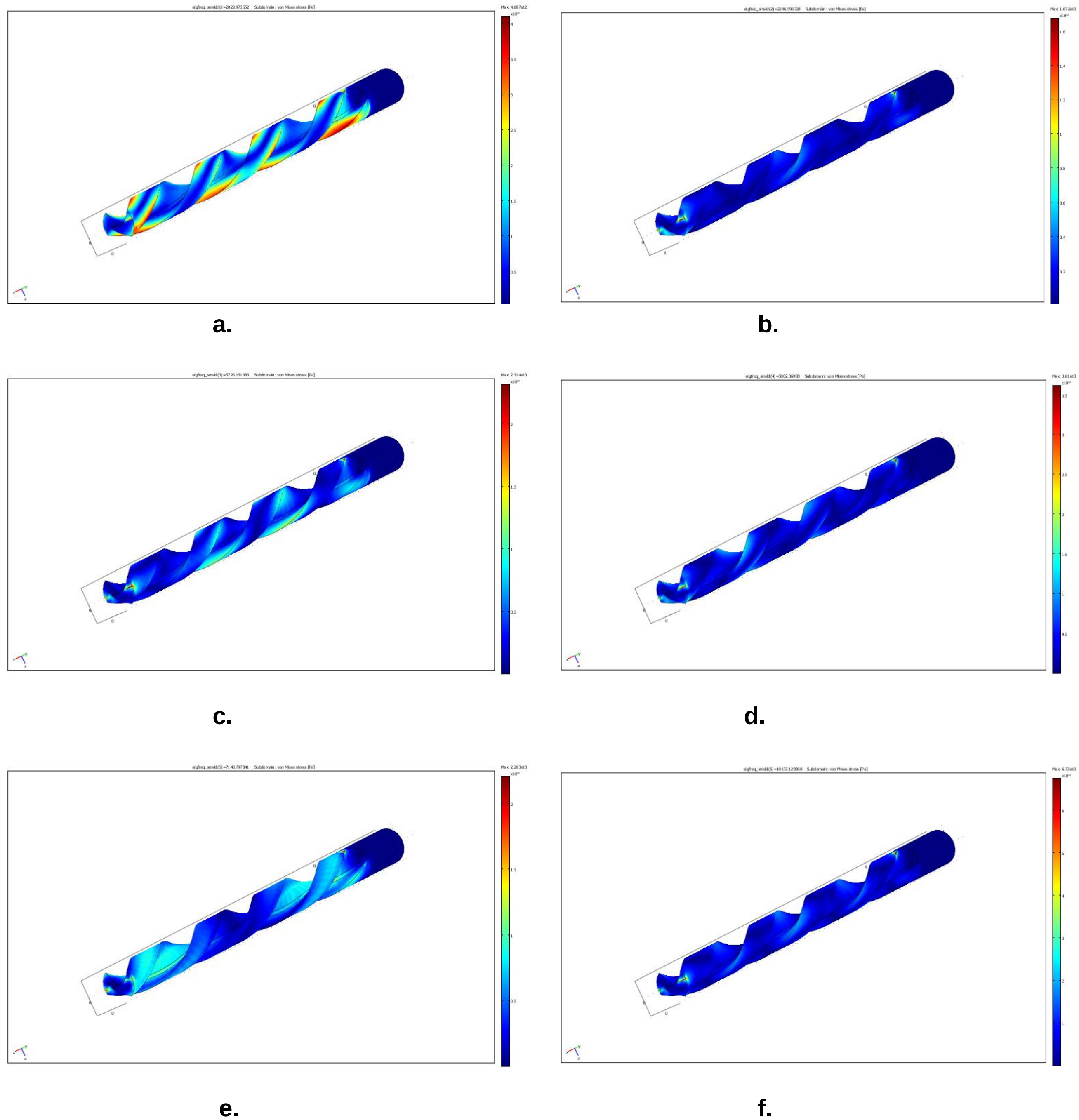


Fig. 3. 3D finite element analysis results (von Mises stress) for 6 major natural modes: a. 2029 Hz; b. 2246 Hz; c. 5726 Hz; d. 5802 Hz; e. 7140 Hz; f. 10137 Hz .

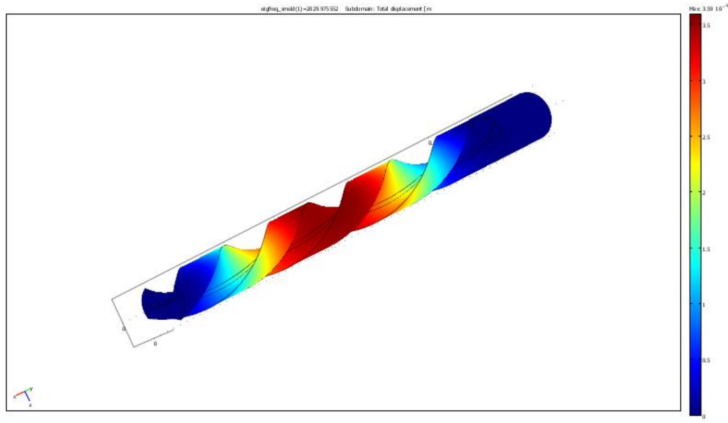


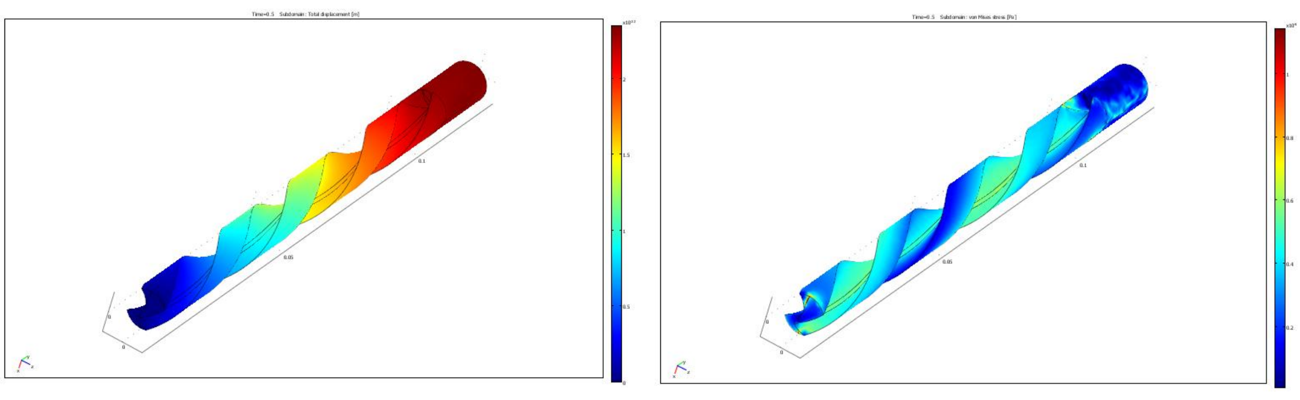
Fig. 4. 3D finite element analysis of the drill total displacement for the natural frequency of 2029 Hz..

4. FINITE ELEMENT ANALYSIS OF DRILL VIBRATION UNDER IMPACT LOAD

The second analysis was conducted in the conditions of loading with an impact type load having the amplitude of 2000 [N] and also with a load defined by the expression:

$$F = A * abs(\sin(2\pi f t)) \quad [1]$$

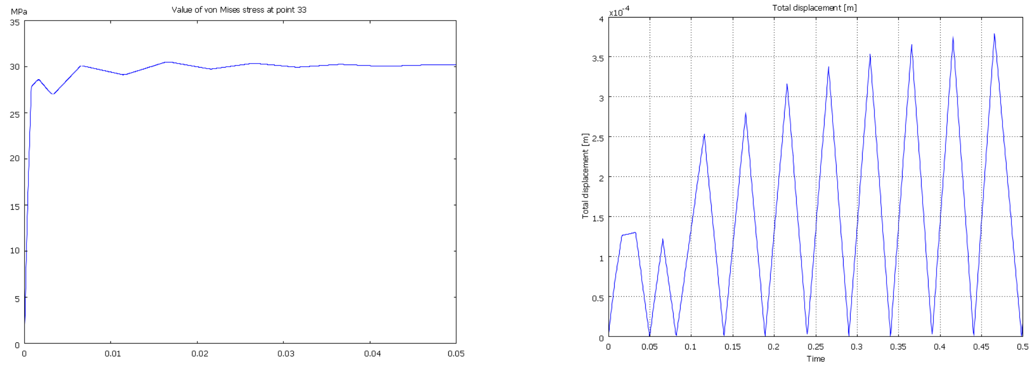
A – amplitude of force: A = 2000 [N]'
f – frequency f = 20 [Hz] corresponding to a speed of 600 RPM;
t – time - defined as the variable for time dependent analysis with a step of 0.00001 seconds.



a. **b.**

Fig. 5. 3D finite element time dependent analysis results: a. total displacement; b. von Mises stress.

In order to study the drill body response to the loads defined above some points can be picked at different locations and plotting the diagrams of displacement, stress or strain as a function of time. Two samples of such diagrams are shown in figure 6.



a. **b.**

Fig. 6. Result diagrams for central point of the drill: a. von Mises stress diagram as function of time for impact load; b. total displacement diagram as function of time for load defined by expression [1].

5. CONCLUSIONS

Finite element analysis of natural vibrations of the drill body in vibro-cutting processes shows that the major modes of vibrations occur in a higher frequency range of 2000-10000 Hz for the drills used in experiments described in [4].

The analysis results for impact load for the same drill parameters show that the vibrations generated by the impact are rapidly absorbed partial by the base material and partially by the drill body. In the case of periodic load (as it can be seen in figure 6.b) there are no other frequencies generated than those born as a result of the load.

These results show that in the studied cases the occurrence of resonance phenomena has a low probability. These results are supported also in the experiments conducted previously and described in [4].

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