EFFECTS OF MATERIAL PROPERTIES, COOLANT HOLES, WEB TAPER AND FLUTES ON DRILL VIBRATIONS

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INTRODUCTION

This report summarizes the progress on our drill vibration project since the last report [1]. Drill dynamics may be studied using a mathematical model of transverse and torsional vibrations of the drill bit. Such a model has been developed and validated [2-5]. The equations of motion were derived using Euler-Bernoulli beam theory and Hamilton's principle [2]. Finite element methods were utilized to discretize and solve the equations. Cross sectional properties (i.e., area and principal moments of inertia) were calculated by using adaptive mesh generation methods.

This model has been utilized in parametric sensitivity studies. The effects of web size, drill flute helix angle, drill rotational speed and thrust force on the fundamental frequency of the drill bit were investigated [3].

The model was recently modified to handle more complex drill geometries [1]. The modified cross sectional representation may accommodate two, three or four fluted drill geometries as shown in figure 1. Coolant holes, taper and different materials along the drill length may also be specified.

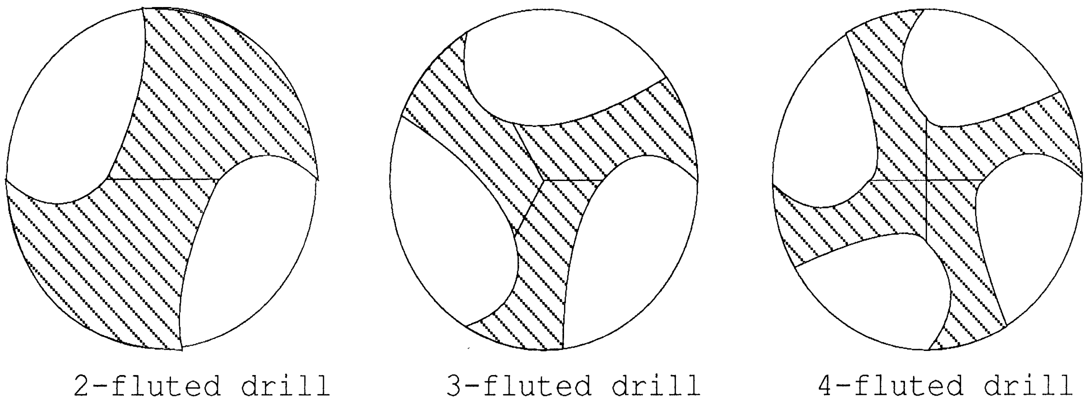

Fig. 1 Cross sectional geometries

Sensitivity studies have been performed with the modified model. The effects of different material properties along the drill bit length, coolant holes, web taper and different number of flutes on the fundamental bending frequency were evaluated. The results of these studies will be presented and briefly discused in this report.

RESULTS

Studies of four factors that effect the drill bit bending frequencies are discused here. These factors include: (1) different material properties, (2) coolant holes, (3) web taper, and (4) the number of flutes. For these parametric sensitivity studies a nominal two-fluted drill with diameter, D=9.525mm, length, l=0.1m, helix angle, β=94 rad/m, thrust force, F_z=1730kN, and rotational speed, ω=10Hz is used. The nominal drill has been used in previous parametric studies [3]. Drill bit tracings of a three-fluted Mohawk drill provided by General Motors were used to define a nominal case for additional examples. All finite element solutions are obtained for clamped-pinned boundary conditions. The normalized frequencies reported are obtained by dividing all natural frequencies by the fundamental frequency of the nominal drill. The nominal case is indicated by a vertical line in each plot. Points indicate predictions of the model. Quadratic or linear curves are fitted to these points.

Material Properties

Drill bits are often manufactured of two different materials. The effect of using two different materials along the length of the drill on the bending frequencies can be observed in Figures 2-3. The two materials used in this study are carbide and steel. The carbide used at the cutting end of the drill bit has elastic modulus, E=6.19E13 Pa. and density, ρ=14,944 kg/m^3. The properties of steel are E=2.07E13 Pa and ρ=7,700 kg/m^3. As can be seen from the plots, using more carbide increases the bending stiffness. The all steel two-fluted drill has a fundamental frequency of 2042Hz while the all carbide two-fluted drill has a frequency of 2576Hz. This is an increase in the frequency of approximately 26%.

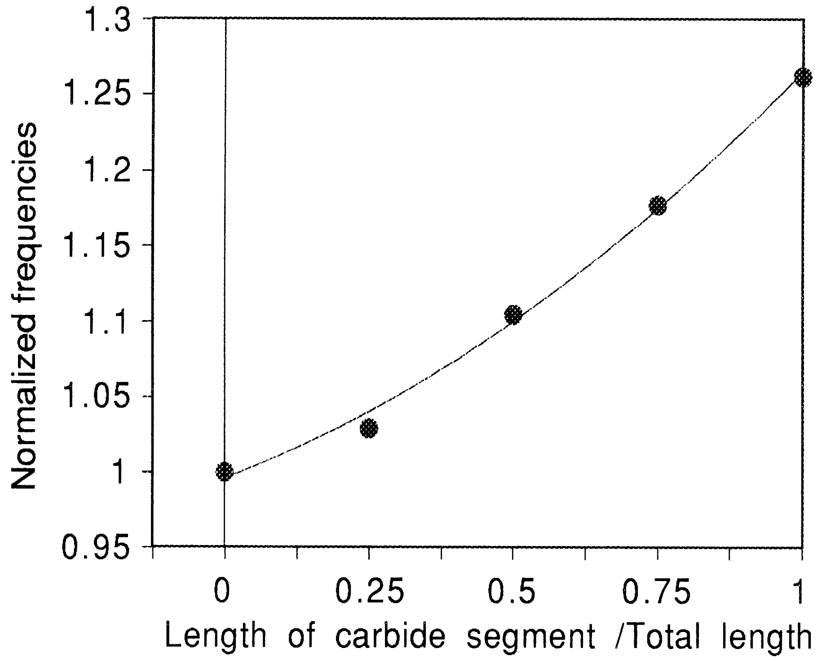

Fig. 2 Change in fundamental frequency with respect to material properties (2-fluted drill). D=9.525mm, l=0.1m, ß=94rad/m, F_z=1730kN, w=10Hz.

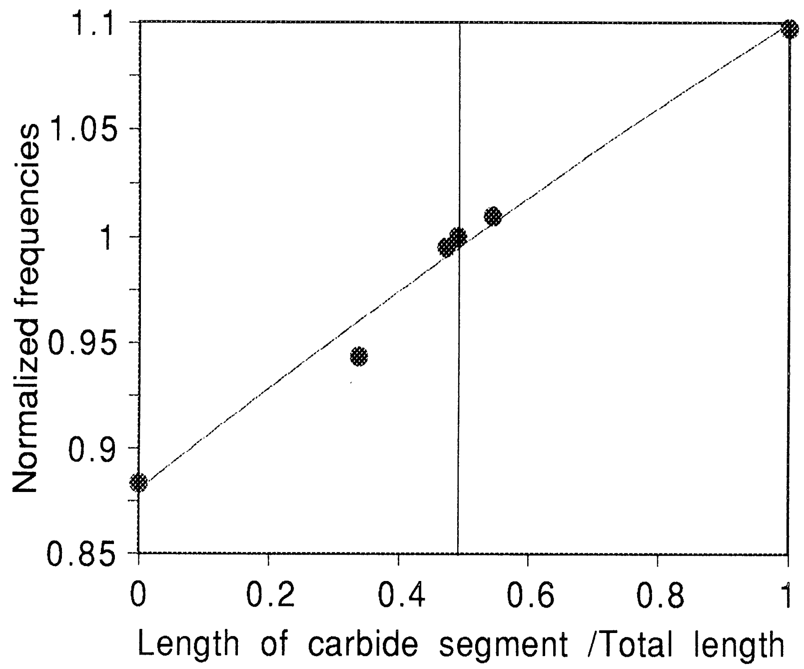

Fig. 3 Change in fundamental frequency with respect to material properties (3-fluted Mohawk drill). D=14.29mm, l=0.21m, ß=31rad/m, F_z=1730kN, w=10Hz

Coolant Holes

The effect of the size of a single coolant hole centered on the cross section of the drill bit on the bending frequency is given in Figures 4-5. The dimensionless hole parameter equals the coolant hole diameter divided by the maximum coolant hole diameter. The maximum coolant hole diameter is determined by the cross section of the drill bit, more specifically by the web of the drill. The nominal cases are again indicated by vertical lines. As the size of the centered coolant hole increases, the fundamental bending frequency of the drill also increase slightly.

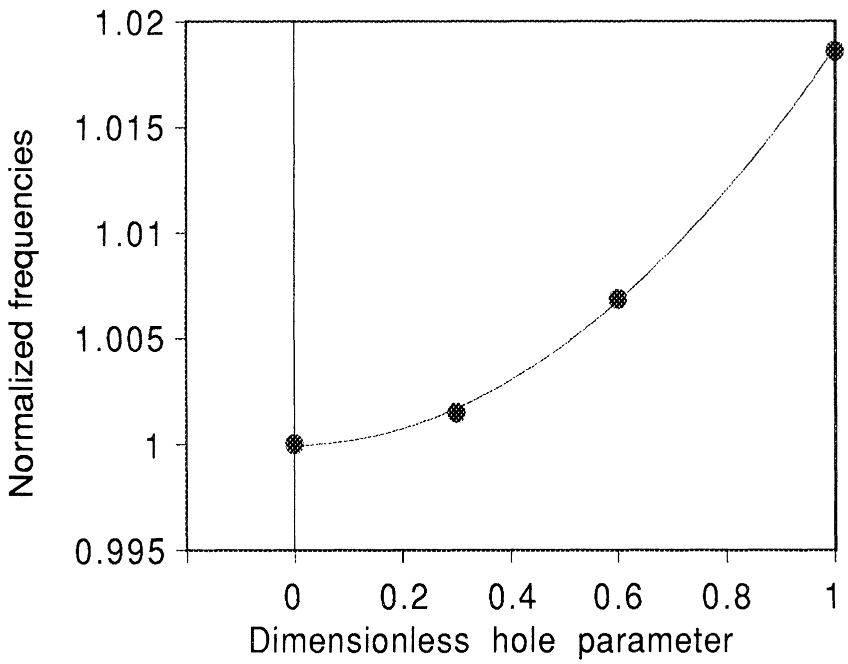

Fig. 4 Change in fundamental frequency with respect to coolant hole size (2-fluted drill). D=9.525mm, l=0.1m, ß=94rad/m, F_z=1730kN, w=10Hz.

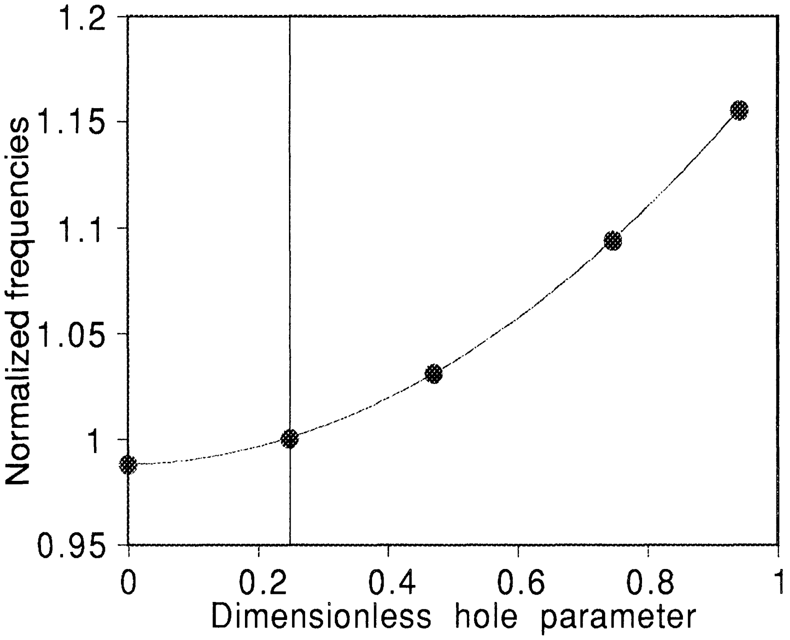

Fig. 5 Change in fundamental frequency with respect to coolant hole size (3-fluted Mohawk drill). D=14.29mm, l=0.21m, ß=31rad/m, F_z=1730kN, w=10Hz

<u>Web Taper</u>

The web taper parameter is related to the entanglement of chips. In Figure 6 the effect of web taper on the bending frequency is shown. The dimensionless web taper parameter is defined as the change in the web divided by the tapered length of the drill. The web is increased away from the cutting end. Half a cross section of the drill bit is presented in Figure 7. The nine points shown determine the cross section. Points 3, 5, and 6 were shifted radially away from the center by the same amount. The radial shift is defined as the change in the web. The web taper is constant throughout the length of the drill. The total length of the drill bit is fluted (2 flutes), i.e. no solid shaft segment is included, and the cross section at the cutting end of the drill bit was kept constant for all cases. An increase in the web taper results in a decrease in the fundamental bending frequency. The effect is not very significant. Qualitatively this effect is in agreement with Tekinalp & Ulsoy [3] who showed a slight decrease in frequency with increasing web. Physically this effect is due to the added mass at the center which has a larger effect on the total mass relative to the effect on the inertial properties.

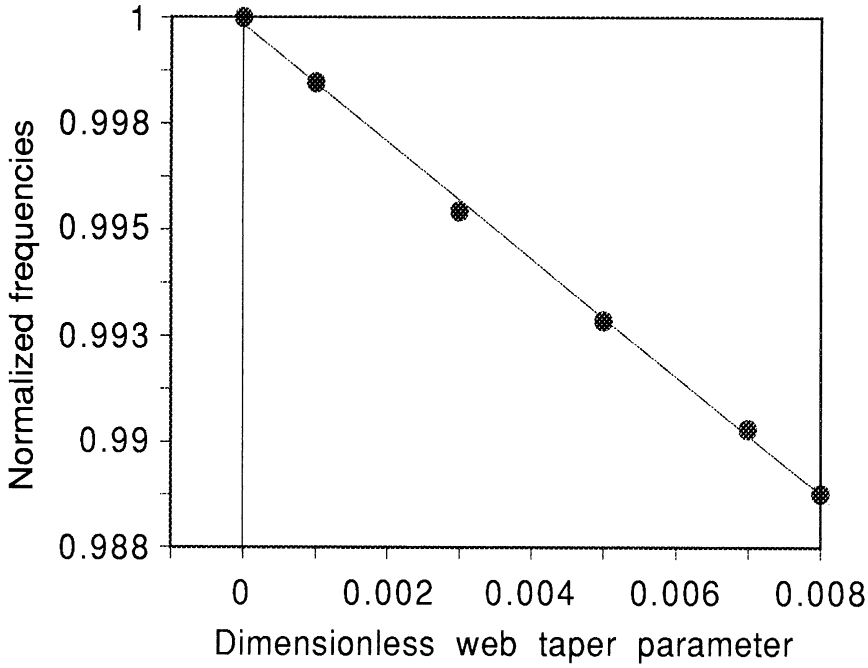

Fig. 6 Change in fundamental frequency with respect to coolant hole size (2-fluted drill). D=9.525mm, l=0.1m, ß=94rad/m, F_z=1730kN, w=10Hz.

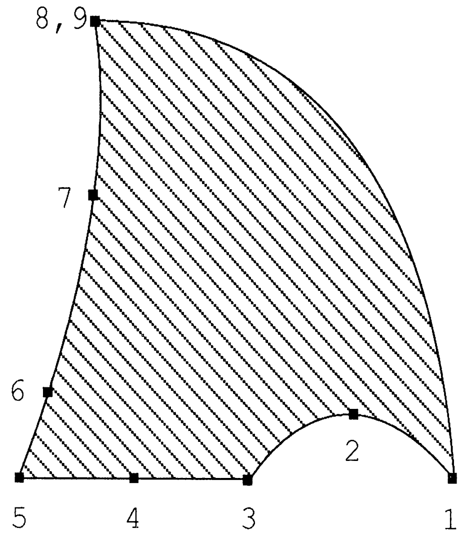

Fig. 7 Half of a two-fluted drill geometry cross section.

Number of Flutes

The effect of the number of flutes on the natural bending frequency is given in Table 1. The nominal two-fluted drill is converted into corresponding three-fluted and four-fluted drills by conserving the basic geometry of the flute and providing comparable removal rates for all three drills. The conversion procedure required all three drills to have the same outer diameter, equal cross sectional areas, and approximately the same flute geometry as illustrated in Figure 8. All other parameters were identical for the three drills. Increasing the number of flutes in the range from two to four stiffens the drill bit considerably. The fundamental frequencies were 49% and 54% greater for the three and four-fluted drills compared to the two-fluted drill.

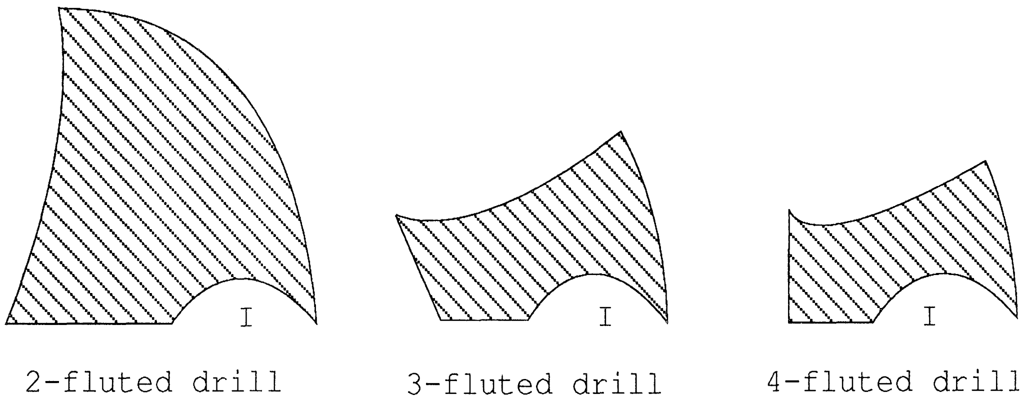

Fig. 8 Conversion procedure required the two three and four-fluted drills to have approximately the same cutting curve labeled I

Number of flutes	Frequencies (Hz)	Normalized frequencies
2	2042	1
3	3045	1.49
4	3238	1.54

Table 1. Change in fundamental frequency with respect to the number of flutes. D=9.525mm, l=0.1m, β=94rad/m, F_z=1730kN, w=10Hz.

CONCLUSIONS

The importance of four parameters on drill bit vibrations is demonstrated through the use of a model described in previous studies [1-6]. Specifically, the effects of different material properties, coolant holes, web taper and the number of flutes were investigated. The effect of different material properties can be substantial depending on the materials used. Using steel and carbide the natural frequencies increased by at most 23% compared to an all steel two-fluted drill. Coolant holes had an almost negligible effect. Less than a 2% increase on the fundamental frequency was observed. Increasing the web taper decreased the natural frequency by up to 20%. Three and four-fluted drills were significantly stiffer than the two-fluted drill. The fundamental frequencies were approximately 50% higher.

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