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MODELLING OF DRILLING - PREDICTING MAIN CUTTING FORCE

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ABSTRACT

The purpose of this work is to present investigation of the torque generated during drilling process. The torque acting on drill is the sum of three components: the cutting component, the torque attributed to ploughing at the chisel edge and the torque resulting from friction at the margin. A new model for calculating main cutting force is developed. The model is based on torque structure and applicable to twist drill. The torque structure is determined by experimental decomposition of the drilling process. The result of the simulation study has shown a very good agreement between the theoretical predictions and experimental evidence.

Keywords: drilling, torque, main cutting force

1. INTRODUCTION

Drilling is the most commonly used machining operation. However, it is also one of the most complex cutting processes. The basic principles of drilling are now well understood. The typical cutting process of a twist drill is threedimensional and oblique. Cutting characteristics of the drilling process are fundamentally nonlinear because of the complex physical phenomena of built-up edges, temperature variations, strain hardening and tool wear.

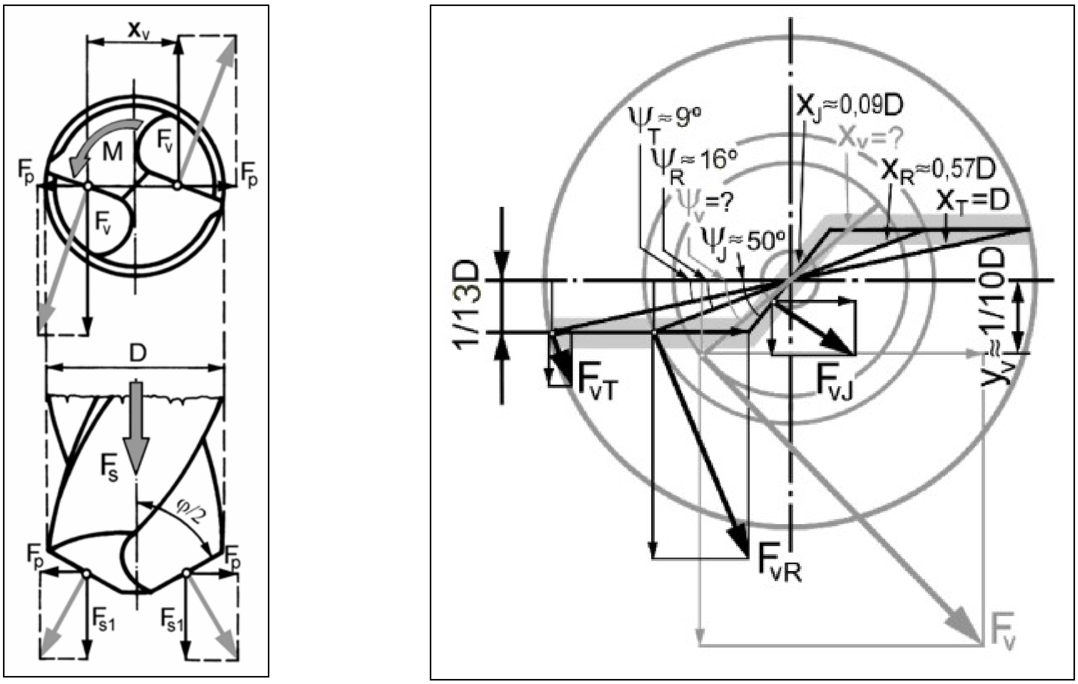
It is known that a drill consists of two cutting edges: the chisel edge and the cutting lips. The main feature that distinguishes it from other processes is the fact that cutting is combined with extrusion in the centre of the drill, at the chisel edge. The chisel edge extrudes into the workpiece material and hence, contributes substantially to the thrust force but little to the torque.

There has been a large variety of approaches to model the main mechanics of drilling such as the generation of torque and forces. Many analytical and numerical models have been developed by many researchers in the past 50 years for predicting torque and thrust force in drilling [1]. According to the literature, there are at least 10 different drilling proces models [2].

In this paper, experimental decomposition of drilling process is applied to develop the main cutting force model for twist drilling.

2. THE CUTTING FORCE MODEL

By analyzing the plan of cutting forces in drilling (Fig 1a) it is possible to conclude that the twist drill is affected by the following loads: torque, which is the result of the two main cutting forces F_v, and thrust force as the sum of the two feed forces F_{s1}. The sum of penetration forces F_p is zero, only if two main cutting lips are identical and are symmetrical upon the drill axis. Measurement of the main cutting force with dynamometer in drilling is technically unfeasible, because they cancel each other out (Fig 1a). The main cutting force cannot be determined from the torque M because its leg x_v is not known.



a) b)

Figure 1. A plan of cutting forces in drilling

The model that will be studied in this work is based on the assumption that there are three distinct cutting edges on a typical drill: the main cutting edges, the chisel edge and the margin cutting edges. Various investigators have studied contribution of these cutting edges to the thrust and torque. Their results are very different.

In the model, the cutting forces in drilling are composed of three elements: the force generated by the main cutting edges, the force generated by the chisel edge and the force generated by margin cutting edges.

3. DETERMINATION OF MAIN CUTTING FORCE

The main cutting force F_v in drilling can be divided (similar to torque M) on the friction force F_{vT} (on the margin cutting edge), the real cutting force F_{vR} (on the main cutting edge) and the chisel edge force F_{vJ} (on the chisel edge) as it is shown in Figure 1b. Values of these forces can be calculated from the previously determined partial torques and legs of force. Thus, friction force is $F_{vT} = M_T : x_T$, the real cutting force is $F_{vR} = M_R : x_R$ and the chisel edge force is $F_{vJ} = M_J : x_J$.

The main cutting force cannot be determined by simply adding components F_{vT}, F_{vR}, F_{vJ} because they don′t have the same direction as shown in Figure 1b. Therefore, these cutting forces are projected on to the two mutual normal directions:

$$F_v \cos\psi_v = F_{vT} \cos\psi_T + F_{vR} \cos\psi_R + F_{vJ} \cos\psi_J \tag{1}$$

$$F_v \sin\psi_v = F_{vT} \sin\psi_T + F_{vR} \sin\psi_R + F_{vJ} \sin\psi_J \tag{2}$$

If partial cutting forces by the torques which they make, equations will get the following form:

$$\frac{M}{x_v}\cos\psi_v = \frac{M_T}{x_T}\cos\psi_T + \frac{M_R}{x_R}\cos\psi_R + \frac{M_J}{x_J}\cos\psi_J \tag{3}$$

$$\frac{M}{x_v}\sin\psi_v = \frac{M_T}{x_T}\sin\psi_T + \frac{M_R}{x_R}\sin\psi_R + \frac{M_J}{x_J}\sin\psi_J \tag{4}$$

Values of partial torques can be expressed by the total torque, therefore $M_T = p_T \cdot M$, $M_R = p_R \cdot M$ and $M_J = p_J \cdot M$. Parameters p_T, p_R and p_J present participation of partial torques in the total torque. In order to determine the values of partial torques, special experimental decomposition was develop which is based on breaking down the drilling process into basic phases. An experiment was prepared which consisted of four sub-experiments, as shown in Figure 2.

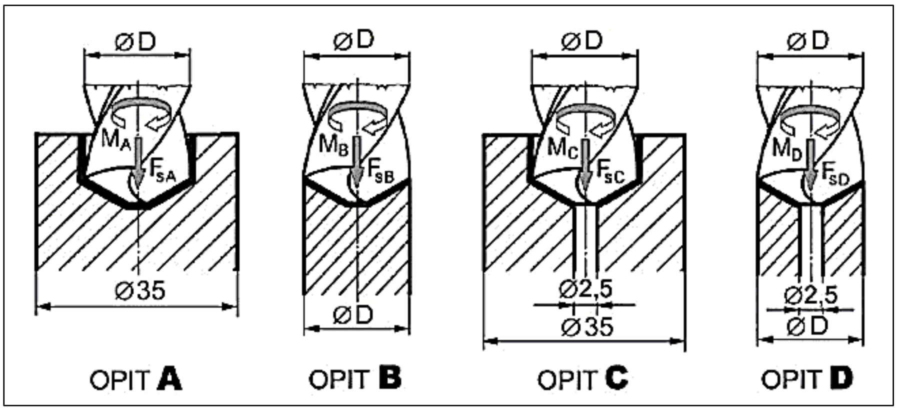


Figure 2. Experiment plan with four sub-experiments

Friction torque can be determined by experiments A and B, using $M_T = M_A - M_B$, the real cutting torque is given by experiment D so it is*:* $M_R = M_D$, and finally the torque from chisel edge was obtained from experiments A and C like*:* $M_J = M_A - M_C$.

The total torque will be the sum of the partial values generated by the margin cutting edge, the main cutting edge and the chisel edge:

$$M = M_T + M_R + M_J \tag{5}$$

The legs of partial cutting forces can be calculated by geometric dimensions of twist drill (Figure 1b), hence x_T=D, x_J=0,09D and x_R=0,57D. As illustrated in Figure 1b, angles between legs of partial cutting forces and drill axis which parallel on the main cutting edges can also be determined by drill geometry. Angle ψ_v can be calculated using the equation below:

$$tg\psi_v = \frac{p_T \cdot sin\psi_T + {}^{1}\!/_{0,57} \cdot p_R \cdot sin\psi_R + {}^{1}\!/_{0,09} \cdot p_J \cdot sin\psi_J}{p_T \cdot cos\psi_T + {}^{1}\!/_{0,57} \cdot p_R \cdot cos\psi_R + {}^{1}\!/_{0,09} \cdot p_J \cdot cos\psi_J} \tag{6}$$

The leg x_v can be expressed as the function of component torques within the total torque, as expressed below:

$$0{,}99 \cdot p_T + 1{,}69 \cdot p_R + 7{,}14 \cdot p_J = \frac{cos\psi_v}{k_1} \tag{7}$$

where, $k_1 = x_v/D$

Based on the angle ψ_v and ratio k_1, exact position of the main cutting force can be calculated:

$$y_v = k_2 \cdot D = \frac{x_v}{2} \cdot sin\psi_v = \frac{k_1 \cdot D}{2} \cdot sin\psi_v \rightarrow k_2 = \frac{k_1}{2} \cdot sin\psi_v \tag{8}$$

4. EXPERIMENTAL RESULTS

The drilling tests were conducted on Index GU600 machine tool. The experiment conditions are summarized in Table 1. HSS drill bits with different diameters have been used for drilling the steel workpiece under different cutting conditions (six different feed rates were used; spindle speed was kept constant at 21-22 m/min). During the experiments, the torque was measured using Kistler dynamometer and sampled using a PC based data acquisition system with LabVIEW software. Component values were obtained by taking allowed average of the signal at the ¼ and the ¾ stage of each drilling phase.This technique allowed the signal components that correspond to the entry and exit of the drill.

Table 1. The cutter, workpiece and cutting conditions

Cutter	Type: twist drill; Material: HSS Diameter: 10 mm, 12 mm, 15 mm
Workpiece	Material: Č1220 (C15)
Machine tool	Type: Index GU600
Cutting conditions	Speed: 450-710 rpm; Feed: 0,056-0,179 mm/rev ; Coolant: Without

The structure of torque determined from experiments (A, B, C, D) is summarized in Table 2. Using the previously mentioned structure, component torques were determined (p_T=0,19; p_R=0,73; p_J=0,08). Then, the value of angle ψ_v=28° was determined using equation (6).

Table 2. Structure of torque in drilling with twist drill

	The contribution of the margin cutting edge			The contribution of the main cutting edge			The contribution of the chisel edge		
	D, mm	%ΣM	Average %	D, mm	%ΣM	Average %	D, mm	%ΣM	Average %
Torque	10	18,62	18,79	10	70,96	73,18	10	10,40	8,00
	12	18,40		12	74,75		12	6,81	
	15	19,35		15	73,85		15	6,80	

Using equation (1), the main cutting force function is found as:

$$F_v \approx 1{,}12 \cdot F_{vT} + 1{,}09 \cdot F_{vR} + 0{,}73 \cdot F_{vJ} \qquad (9)$$

Variation of the main cutting force with feed, for different diameters, presented in Figure 3. It is obvious that this dependency is linear and it can be interpreted by linear function with high correlation coeficient R. Value of leg x_v was determined by using equation (7) and it amounts $x_v=0{,}443 \cdot D$. Exact position of the main cutting force was determined by using equation (8) and it amounts $y_v=1/10 \cdot D$, as shown in Figure 1.

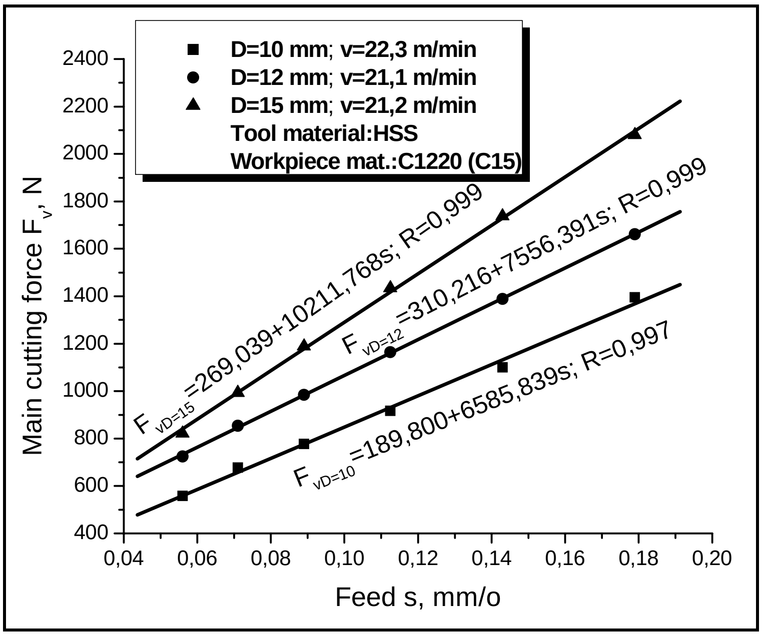


Figure 3. Variation of the main cutting force with feed

5. CONCLUSION

The paper presents a new model for calculating the main cutting force for drilling. The new model includes contribution of the three distinct cutting edges of the drill to the main cutting force. The model is based on decomposition of the drilling process. The modeling approach presented here represents only the first step toward approximation of the main cutting force using genetic algorithm.

6. REFERENCES

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