Imitation Modeling of the Cutting Force During Turn-Milling

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Abstract: The cutting forces generated in the course of metal processing constitute a fundamental characteristic of the cutting process. On the basis of their readings, machines, tools and devices are designed; the process of swarf formation is investigated; and the regularities of tool wear are explored. Preliminary assessment of the cutting forces would facilitate undertaking corrective actions in advance. This article provides a model of the turn-milling process, taking into account the parameters of the workpiece and the cutting tool, their relative positions and cutting modes. The resulting model demonstrates how the cutting depth affects cutting forces. The formula for calculating the cutting force includes conventional machining parameters and incorporates the number of teeth of the cutting tool, which are simultaneously in contact with the workpiece, and the cutting depth, corresponding to a specific position of the tool tooth.

Keywords: cutting force, solid of revolution, cutting depth, turn-milling, cutting length, tool position.

Introduction

Turn-milling is a technology, which has gained great popularity worldwide in recent years. The main differences of this type of machining, compared with turning, include the formation of elemental shavings and a greater durability of the cutting tool [1–7]. Also, in the course of turn-milling process, the directions of the cutting force components change. Knowing their directions and numerical values, it is possible to increase the efficiency of the turn-milling process.

Modeling the Turn-Milling Process

Modeling cutting forces in turn-milling

The ratio of cutting forces for turning process is known as:

$P_Z : P_Y : P_X = 1 : (0.2 \div 0.3) : (0.3 \div 0.4)$ (Figure 1) [8].

Applied to turn-milling, the position of the cutting forces would change (Figure 2).

Turn-milling has the same kinematic characteristics as milling. Hence, to calculate the cutting force, we could use the Formula 1:

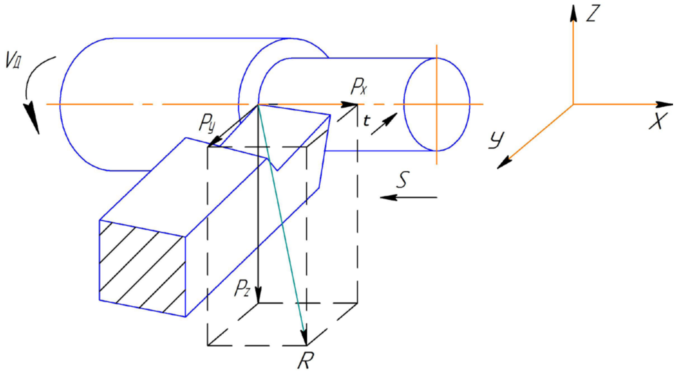


Figure 1. Distribution of cutting forces during turning

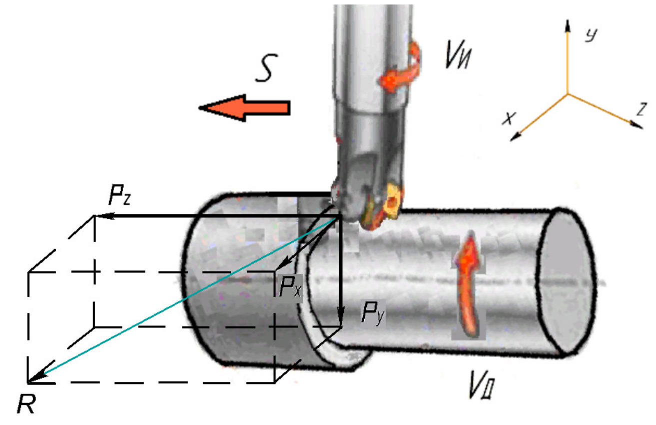


Figure 2. Distribution of cutting forces during turn-milling

Notes: P_X is the axial component of the cutting force; P_Y is the radial component of the cutting force; P_Z is the tangential component of the cutting force; **R** is the resultant cutting force

$$P_Z = \frac{10 \cdot Cp \cdot t^X \cdot S_Z^y \cdot B^m \cdot z}{D^q \cdot n^w}, \qquad (1)$$

where Cp is the coefficient taking into account the tool material; B is the milling width; t is the cutting depth; S_z is the feed per tooth; z is the number of teeth in the tool; D is the tool diameter; and n is the number of revolutions of the tool [9].

However, due to the presence of a radius in the workpiece undergoing milling, the contact of the tool with the workpiece occurs simultaneously only for a fraction of the cutting teeth. Also, there is a constant change in the cutting depth t over the cutting length of the tooth Lp (Figure 3). This continuously changes the cutting force P_Z.

Identifying processing modes

To achieve the best technical and economic parameters for machining a part (direction of instantaneous cutting forces P_Z, effective cutting width H, and cutting length Lp), it is necessary to determine the optimal position of the tool relative to the workpiece.

To do so, let us use the diagram in Figure 3.

The contact length (L) of the tool with the workpiece along the half chord is determined by the Formula 2:

$$L = \sqrt{(0.5 \cdot D_З)^2 - (0.5 \cdot D_З - t)^2}. \qquad (2)$$

The position of the tool relative to the end face of the part is calculated by the Formula 3. In this case, the distribution of the resultant tangential and radial components of the cutting force P_Z is taken into account [10]:

$$E = \sqrt{(0.5 \cdot D_И)^2 - \left(0.5 \cdot D_И - \left(L/4\right)\right)^2}. \qquad (3)$$

The total cutting width is calculated according to Formula 4:

$$B = \sqrt{(0.5 \cdot D_И)^2 - (0.5 \cdot D_И - L)^2} + E. \qquad (4)$$

The effective cutting width for the selected case depicted in Figure 3 is calculated using Formula 5:

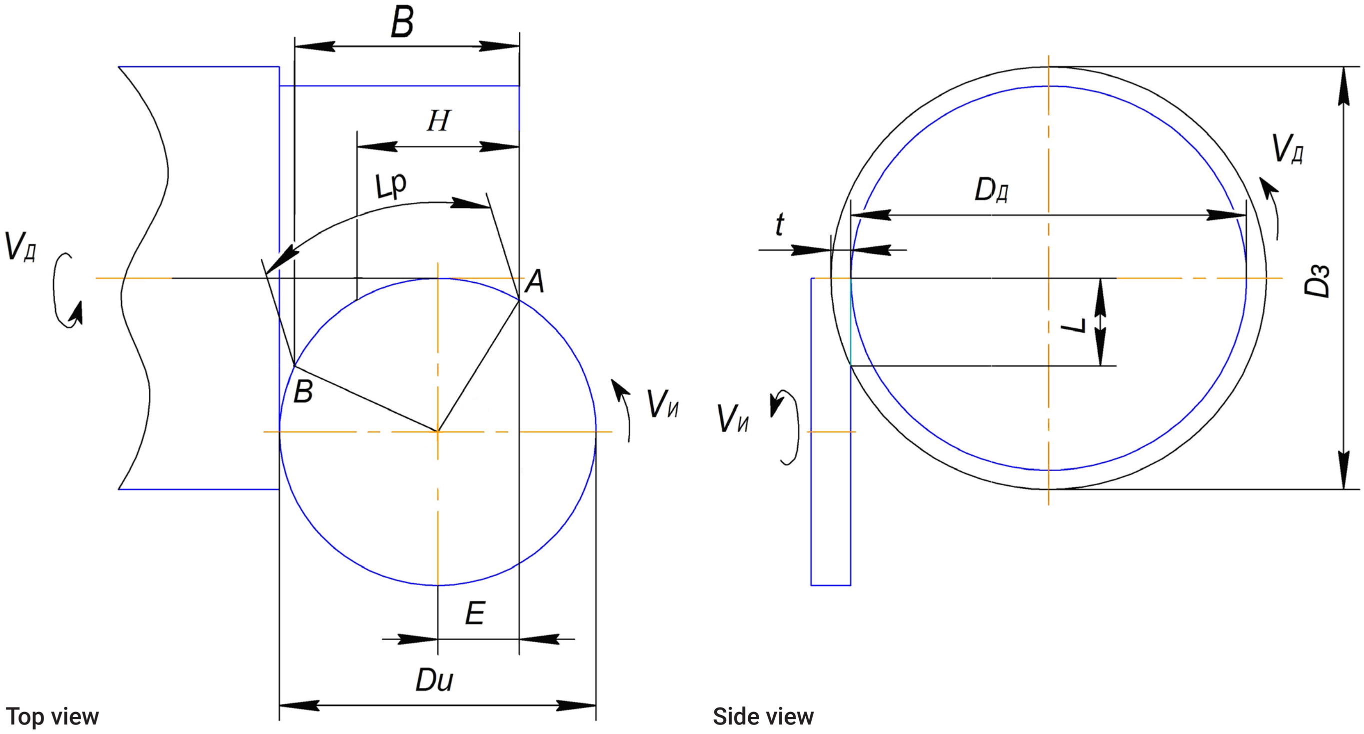
$$H = 2 \cdot E. \qquad (5)$$

Determining cutting force

Because, in the course of turn-milling, the cutting depth t has a variable value (Figure 4), the cutting force P_Z would also vary from maximum to zero values.

It is possible to calculate the cutting depth in a separate section of the cutting length Lp_i using the Formula 6:

$$t_i = \frac{0.5 \cdot D_Д - \sqrt{(L_i)^2 + (0.5 \cdot D_Д)^2}}{90 - \frac{L_i}{\sqrt{(L_i)^2 + (0.5 \cdot D_Д)^2}}}, \qquad (6)$$



Top view

Side view

Figure 3. Tool setting diagram for turn-milling

Notes: D_3 is the workpiece diameter; $D_д$ is the part diameter, **Lp** is the cutting length; **t** is the cutting depth; **H** is the cutting width; **A** is the starting point of contact between the tool and the workpiece; **B** is the end point of contact between the tool and the workpiece

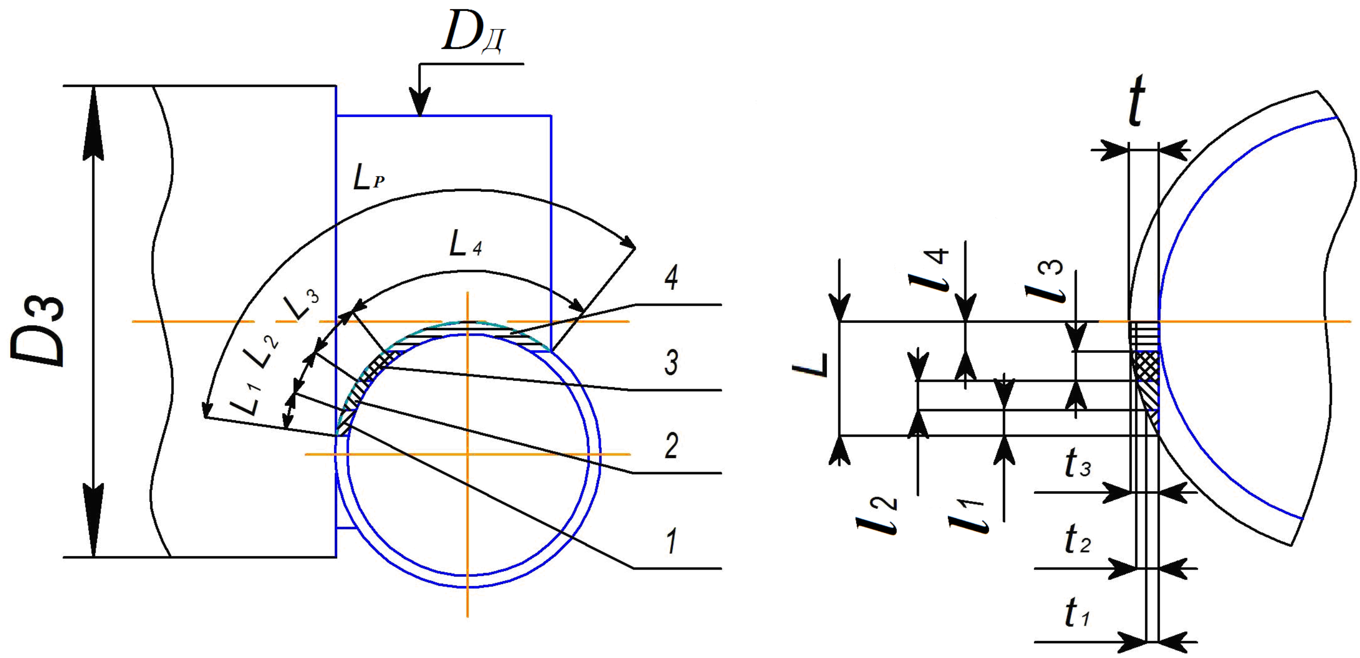


Figure 4. Change in cutting depth along the length of the cutting path

Notes: D_3 is the workpiece diameter (mm); $D_д$ is the part diameter (mm); Lp_i is the part of the section of the cutting path corresponding to the *i*-th interval from 1 to 4 along the length **L** (mm); t_i is the cutting depth at the *i*-th point along the half chord length **L** (mm).

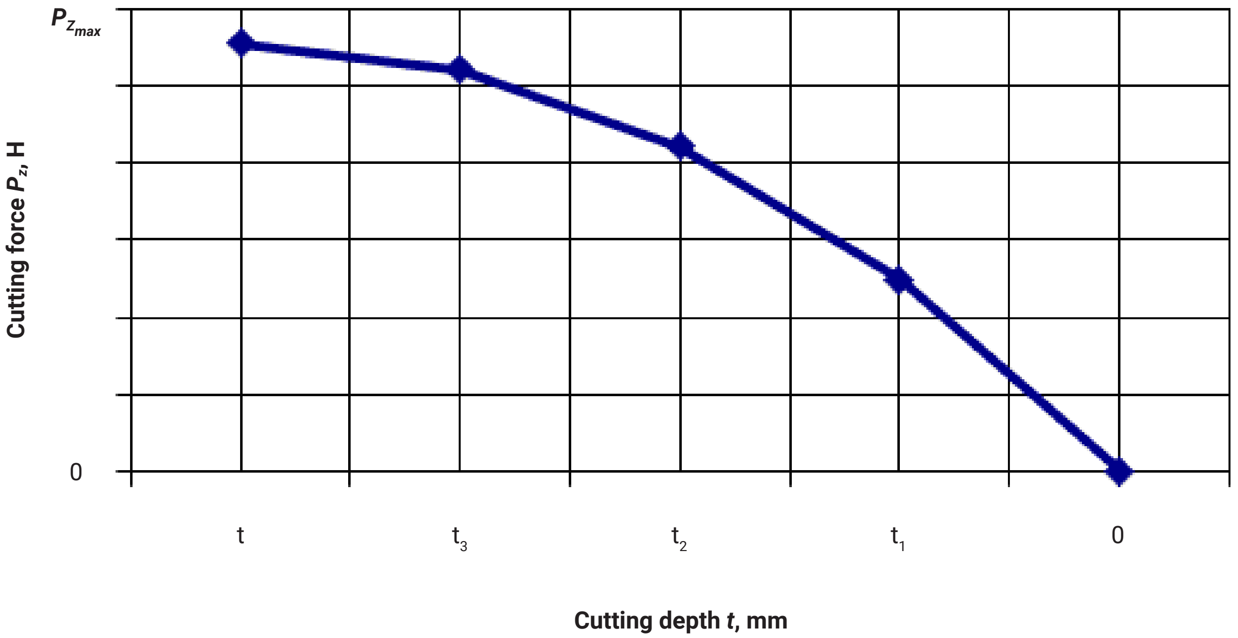


Figure 5. **Cutting force P_z versus cutting depth t**

where: $r_{\text{Д}}$ is the radius of the part (mm), L_i is the part of the section corresponding to the i-th point from 1 to 4 along the length L (mm); t_i is the cutting depth at the i-th point along the length L (mm).

The general regularity of the cutting force P_z dependence on the cutting depth t is shown in Figure 5.

Knowing the location of the cutting blade of the tool in the corresponding section of the cutting length Lp, we can calculate the local force Pz_i for one cutting blade according to Formula 7:

$$P_{Z_i} = \frac{10 \cdot Cp \cdot t_i^X \cdot S_Z^y}{D^q \cdot n^w}, \tag{7}$$

where: Cp is the coefficient taking into account the tool material; B is the milling width; t_i is the cutting depth in a separate area; S_z is the feed per tooth; z_i is the cutting tooth of the tool located on the i-th section of the cutting length Lp; D is the tool diameter; n is the number of revolutions of the tool.

The resulting cutting force P_Z can be calculated using the Formula 8:

$$P_Z = \sum_{i=1}^{z} P_{Z_i}, \tag{8}$$

where: P_{Z_i} is the cutting force in a separate section of the cutting length Lp; z is the number of tool teeth, which are simultaneously in contact with the workpiece.

Conclusions

As a result of our project, the formula was obtained allowing to calculate the cutting force emerging in the process of machining via milling. This formula takes into account the number of cutting teeth (z) of the tool, which are simultaneously in contact with the workpiece, and the cutting depth (t) corresponding to a specific position of the tool tooth.

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