DETERMINATION OF CUTTING FORCES WHEN TURNING ON THE LATHE MODEL 1K62

PURPOSE OF THE LABORATORY WORK

Mastery of skills in determining cutting forces, processing experimental data and obtaining empirical dependences of cutting forces on cutting conditions.

1K62 LATHE MACHINE SPECIFICATIONS

- the largest diameter of the product installed above the bed – 400 mm;
- the largest diameter of the processed bar – 45 mm;
- the distance between centers – 1000 mm;
- the number of spindle speeds – 23 (from 12.5 to 2000 rpm);
- the number of working feeds – 42 (from 0.07 to 4.16 mm/rev).

BRIEF THEORETICAL PART

Cutting force – the total force spent on the chip formation process. It consists of the forces necessary to overcome elastic-plastic deformations in the cut layer and the friction forces of the chip on the front surface of the tool and the back surfaces of the tool on the workpiece. Thus, the distributed areas in the form of the resultant force R, the position and magnitude of which in space depend on the cutting pattern and processing conditions, act on the contact pads of the front and rear surfaces of the tool. It is decomposed into three mutually perpendicular components (Fig. 1): P_z – the main component of the cutting force, coinciding in direction with the speed of the main cutting movement, creating torque on the spindle, bending the product and the cutter in a vertical plane; P_y – the radial force directed at the top of the blade to the center from the rotation of the workpiece, bending the product together with the force P_z and the cutter, squeezing the cutter in the horizontal main plane from the product; P_x – axial force directed parallel from the main rotational cutting movement (feed force), bending the cutter in the main plane.

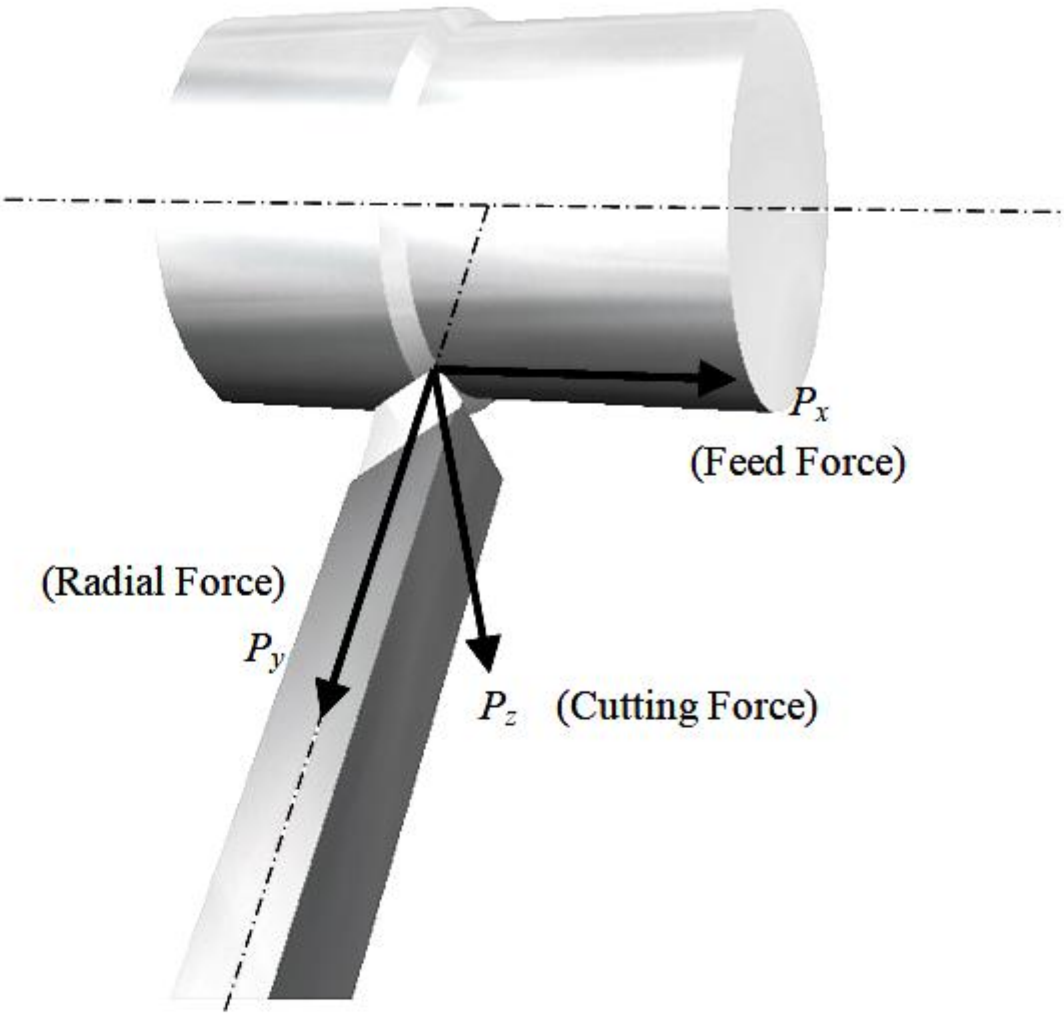


Fig. 1. The forces acting on the cutter

$$R = \sqrt{P_x^2 + P_y^2 + P_z^2} \qquad (1)$$

The radial axial and resultant forces are related to the main component force P_z by the following approximate dependencies:

$$P_x = 0{,}25\ P_z \qquad (2)$$

$$P_y = 0{,}4\ P_z \qquad (3)$$

$$R = \sqrt{(1{,}22\ P_z)^2} = 1{,}1\ P_z \qquad (4)$$

The value of the forces acting in the cutting process is necessary for the calculation and design of cutting tools, machines and devices, for calculating the rigidity of the machine-tool-workpiece-fixture system, and for determining the power spent on cutting.

Cutting forces can be calculated according to empirical formulas, measured with devices called dynamometers. Deformation of the elastic elements of the dynamometer directly or using the phenomena associated with them serve as the basis for measuring cutting forces. Dynamometers are divided into hydraulic, mechanical, electrical. Regardless of the design, dynamometers consist of three main parts: a load sensing sensor; the receiver registering it; auxiliary links between the sensor and receiver.

Dynamometers do not directly determine the magnitude of the cutting forces, their readings give values proportional to the effective force. Therefore, before working with such devices, it is necessary to tare them, to establish a graphical dependence of the readings of the recording device on the applied previously known load.

Cutting forces depend on the mechanical characteristics of the processed material, tool geometry, cutting conditions, processing conditions. The greatest influence on the cutting force is exerted by the width and thickness of the cut layer. With an increase in their size, it increases in direct proportion. However, with an increase in the thickness of the slice, the increase in force is slightly behind in comparison with the change in width. This is explained by the following. With an increase in the width of the cut, the volume of the most deformed metal layers adjacent to the front surface changes to the same extent, which does not occur with an increase in the thickness of the cut. These changes lead to a corresponding increase in normal forces on the front surface. Thus, with a constant cross-sectional area of the cut layer (the same cutting performance), different (ratios of width to thickness will correspond to different cutting values. To reduce the cutting force, it is necessary to reduce the width of the cut layer by increasing the thickness.

With an increase in cutting speed, the cutting force decreases significantly at low speeds and less significantly at high speeds (practically no effect). The increase in the rake angle facilitates the cutting and gathering of chips, reduces the deformation of the material being cut and, therefore, reduces the cutting force.

FAMILIARIZATION WITH THE DESIGN AND OPERATING PRINCIPLE OF THE DK-1 SINGLE-COMPONENT DYNAMOMETER

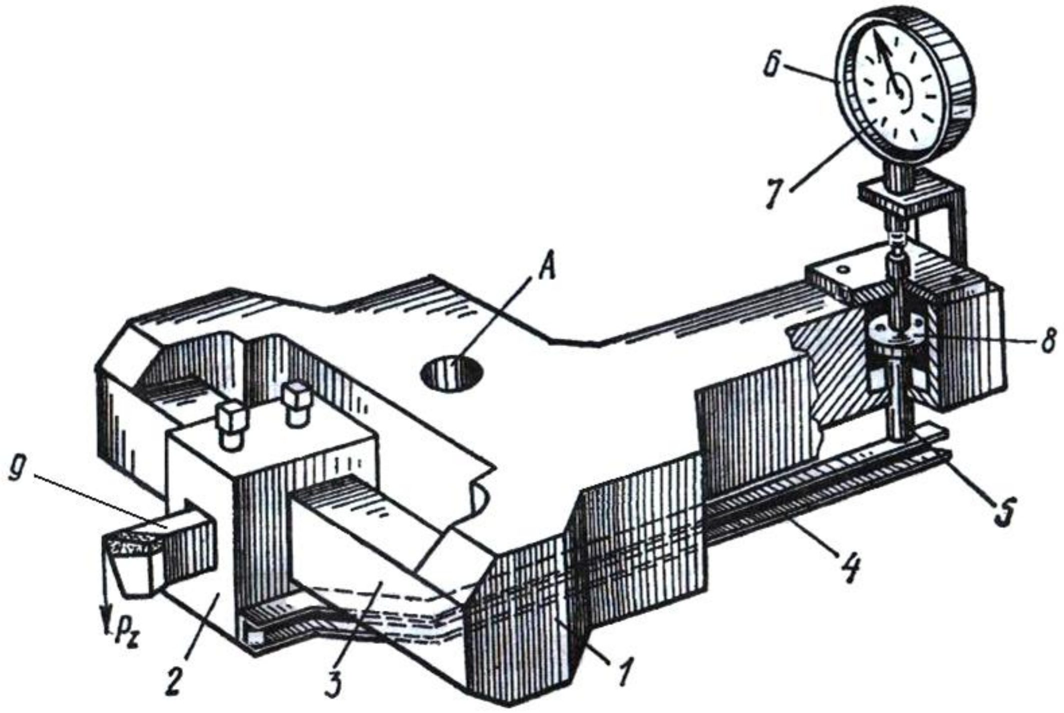


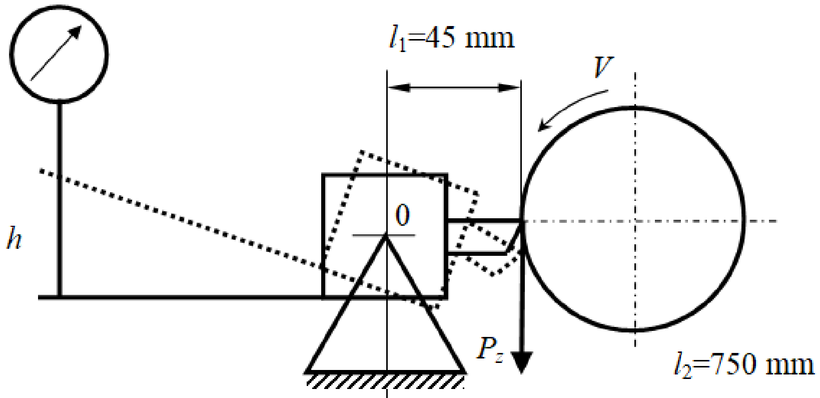
Fig. 2. Diagram of a single-component turning dynamometer DK-1

A – hole for mounting on a lathe, 1 – dynamometer housing, 2 – holder (cradle), 3 – square elastic torsion bars, 4 – strap, 5 – rod, 6 – dial indicator housing with foot, 7 – dial indicator, 8 – piston, 9 – cutter (offset length 45 mm, α=12, γ=0, φ=45^0)

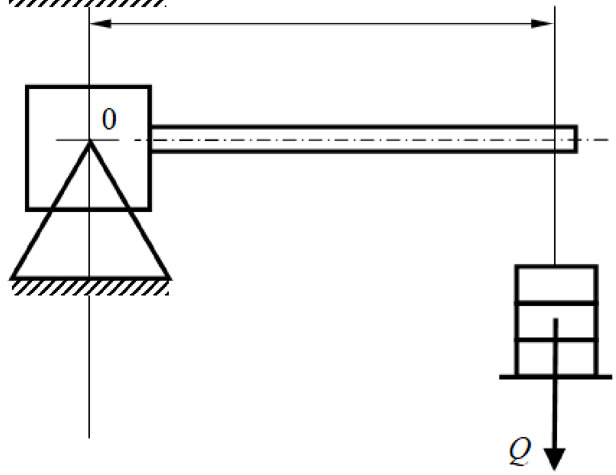
Dynamometer DK-1 is a mechanical turning dynamometer (Fig. 2), which allows measuring only one vertical component of the force P_z at a time. The measurement limit is P_z = 6000 N. The dynamometer is installed and fixed instead of the tool holder on the machine saddle. The cutter is placed in the holder (cradle) of the dynamometer, which is connected to the body by means of two elastic torsion bars of square section (torsion springs). Under the action of the force P_z applied to the tip of the cutter, if the bending influence of the component P_y is neglected, the torsion bars carrying the holder with the cutter are bent and twisted relative to the horizontal axis. Together with the holder, a lever is also rigidly connected with it, the free end of which moves up and presses the indicator leg through the oil damper rod. The movement of the indicator leg is proportional to the angle of rotation of the holder (that is, the elastic deformation of the torsion bars), and therefore the vertical component of the cutting force P_z. The oil damper is designed to eliminate the inevitable oscillations of the dynamometer lever due to the heterogeneity of the material being processed and the dynamic errors of the equipment.

DYNOMETER CALIBRATION

To establish the relationship between the force P_z and the amount of movement of the indicator leg (which is fixed by the number of divisions on the scale), the cutter is replaced with a rod-lever of a certain length. An increase in the shoulder of the application of bending force from 45 mm to 750 mm can significantly reduce the value of weights Q (Fig. 3) (lengths l_1 and l_2 correspond to this particular case).



Q, kg	h, div.	P_z, N
5		
10		
15		
10		
5		
0		



$$P_z \cdot l_1 = Q \cdot l_2 \quad ; \quad P_z = Q \frac{l_1}{l_2}$$

Fig. 3. P_z measurement scheme and dynamometer calibration

To exclude the influence of the weight of the rod and suspension for the cargo fixed on the rod, the indicator arrow is set to zero. Then, weights of a certain weight (load Q) are placed sequentially on the suspension one after the other, and in each case the indicator readings are recorded. In the reverse order of loading, the dynamometer is unloaded. Based on the indications h of the indicator and the forces P_z, which are directly proportional to the loads Q, the load and unload branches of the calibration schedule are built. According to Hooke's law, these branches of the graph do not coincide, form a «hysteresis loop» due to residual elastic deformation of the torsion bars and possible displacements at the joints.

The final calibration schedule will be an almost straight line drawn between the loading and unloading branches of the schedule (Fig. 4). Using the calibration graph, you can translate any value of the dynamometer indicator into the value P_z (h).

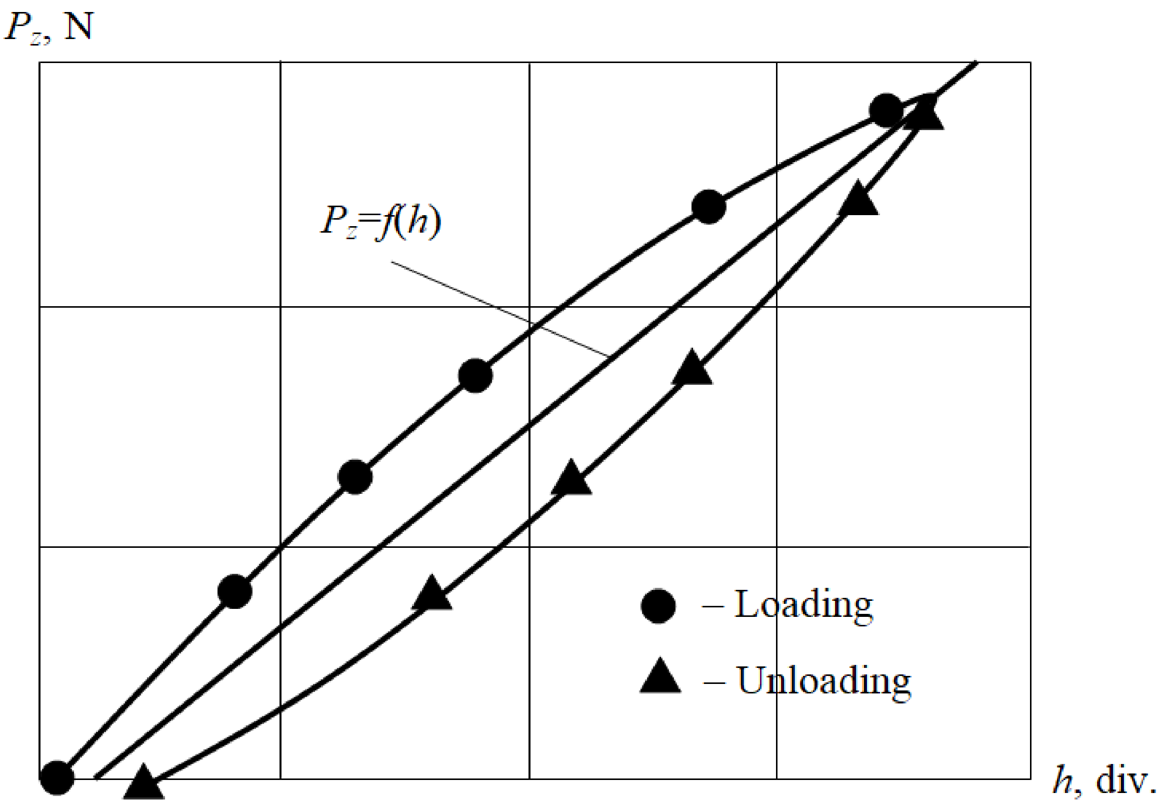


Fig. 4. Calibration graph $P_z = f\,(h)$

PROCESSING THE EXPERIMENTAL RESULTS

Numerous studies prove that the relationship of various quantities characterizing the cutting process can be accurately expressed by a power function of the form

$$y = Ax^m, \quad (5)$$

where y – dependent quantity, A – constant, x – influencing value, m – power index.

For our case, the dependence of the force P_z on the cutting conditions takes the form:

$$P_z = C_{P_z} \cdot t^{X_{P_z}} \cdot S^{Y_{P_z}} \cdot V^{Z_{P_z}}, \quad (6)$$

where P_z – vertical component of the cutting force, C_{P_z} – coefficient depending on the mechanical properties and structure of the processed material, the material of the cutting part, t – cutting depth, S – feed, V – cutting speed.

From the condition of a one-factor experiment, expression (6) can be represented by the following particular relationships:

$P_z = C_A \cdot t^{X_{P_z}}$ (7), where $C_A = C_{P_z} \cdot S^{Y_{P_z}} \cdot V^{Z_{P_z}}$ (10)

$P_z = C_B \cdot S^{Y_{P_z}}$ (8), where $C_B = C_{P_z} \cdot t^{X_{P_z}} \cdot V^{Z_{P_z}}$ (11)

$P_z = C_D \cdot V^{Z_{P_z}}$ (9), where $C_D = C_{P_z} \cdot t^{X_{P_z}} \cdot S^{Y_{P_z}}$ (12)

The determination of the parameters of these dependencies is significantly accelerated by the graph-analytical method. Using double logarithmic coordinates allows you to get a power function in the form of a linear relationship. Moreover, the value of the exponent corresponds to the tangent of the angle of inclination of the line to the abscissa axis, and the constant value is equal to the segment cut off by the line on the ordinate axis at $x = 1$ (Fig. 5).

Having built three graphical dependencies $P_z = C_A \cdot t^{X_{P_z}} = C_B \cdot S^{Y_{P_z}} = C_D \cdot V^{Z_{P_z}}$ in double logarithmic coordinates, determining the exponents and constants, we find the value of C_{P_z} by solving the dependences (10, 11, 12) with respect to the «common point» (the point at which the force is determined under the same cutting conditions, but in different experiments).

Arithmetic Mean C_{P_z} recorded in the final empirical dependence of the cutting force on the cutting conditions for specific processing conditions of this material.

a) $y = Ax^m$

$P_z = C_t \cdot t^{x_{P_z}}$

b) $\lg P_z = \lg C_t + x_{P_z} \cdot \lg t$

$y = A + mx$ $\quad$ $\mathrm{tg}\,\alpha = a/b = x_{P_z}$

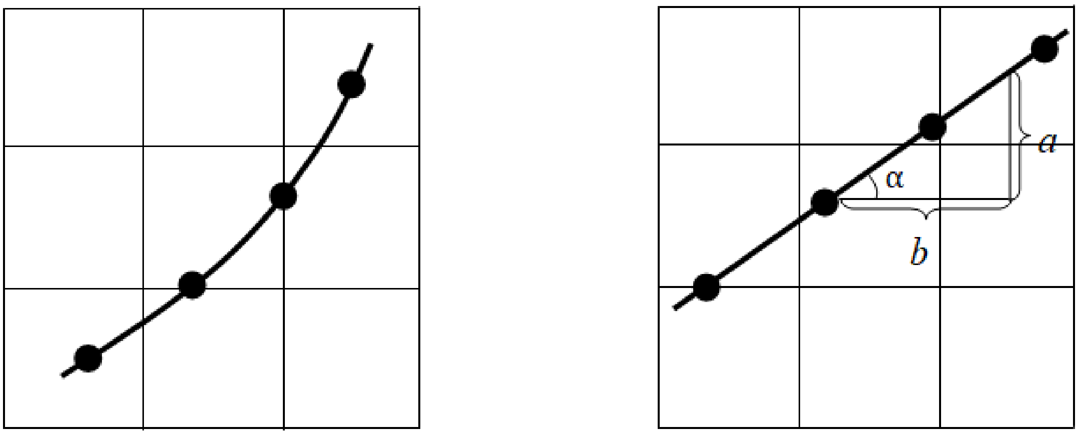


Fig. 5. The power dependence $P_z = f(t)$ in Cartesian (a) and logarithmic (b) coordinate systems

Experiment Order	Rotation frequency spindle *n*, rpm	Diameter of the processed product *d*, mm	Cutting speed *V*, m/min	Feed *S*, mm/rev	Cutting depth *t*, mm	Dynamometer readings *h*, div.	Cutting force P_z, N
$P_z=f(t)$							
$P_z=f(S)$							
$P_z=f(V)$							

REPORT REQUIREMENTS

The report on the work performed should contain:

1. A sketch of a dynamometer with a brief description of its action.
2. Dynamometer calibration scheme and calibration schedule.
3. The results of the experiments are summarized in table.
4. Graphic dependencies: $P_z = C_A \cdot t^{X_{P_z}}$, $P_z = C_B \cdot S^{Y_{P_z}}$, $P_z = C_D \cdot V^{Z_{P_z}}$, constructed in double logarithmic coordinates with the definition of components values of the empirical dependence of the cutting force on the cutting parameters.
5. Conclusions, i.e. comparing the obtained dependencies with literature data (C_{P_z}, X_{P_z}, Y_{P_z}, Z_{P_z}).