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PHYSICAL BASIS OF METAL CUTTING

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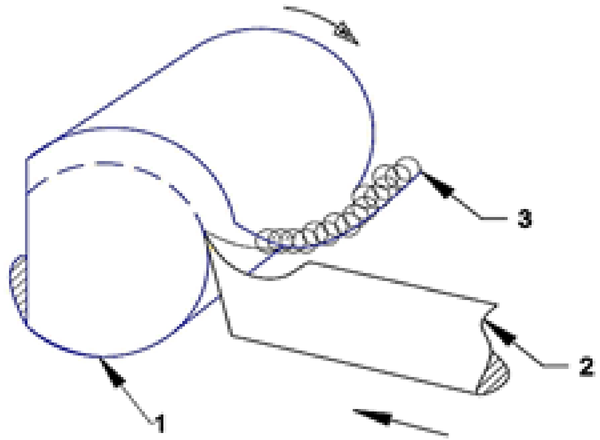
ABSTRACT
In this article, the physics fundamentals of the metal cutting process are discussed, particularly in the context of certain technological operations such as turning and milling. The mechanical work performed during metal cutting, the forces involved in metal cutting operations, and other related aspects are analyzed in detail. The conceptual basis of any technological process is demonstrated to be formed by the laws and principles of physics.

Introduction: Globally, there is a trend towards shaping the educational environment based on innovative approaches relying on physics laws, aimed at developing research activities of students in educational institutions beyond classroom and lesson activities. These research works are being conducted to shape the methodological system of teaching physics in technical directions, to develop students' conceptual understanding abilities, and to enhance their knowledge, skills, and competencies related to the working parts of modern equipment and tools. This, in turn, emphasizes the need to develop the methodological system of teaching physics in technical directions.

Literature Review and Methods: The research process utilized the principles of scientific objectivity, logic, analysis, and synthesis. The research uncovered objective issues in teaching physics at school and technical higher education institutions. The logical aspects of teaching physics in the educational field today were critically analyzed. The research drew on methodological sources such as V.D. Avagimov's "Processing Machine Materials", A.D. Ne'matjonov's "Reducing Friction in Metal Cutting", "Creating Tools in School Workshops", G.B. Volshin, and others' "Activities for Grades 6-7: Woodworking, Metalworking, and Other Tasks", C.I. Alai and others' "Practical Workshop in Mechanical Engineering".

Discussion and Results: Mechanical work carried out by the lathe during metal cutting. Understanding the physical nature of the mechanical work performed by the lathe during metal cutting reveals that it is essential for the resistance forces exerted by the metal being processed to be overcome by the lathe. The lack of clarity in this definition and what the resistance forces exerted by the metal being processed consist of, and how they are overcome by the lathe, necessitates a direct acquaintance with the cutting process to gain a deeper understanding.



1st Image: Chip Formation

The first image depicts the process of chip formation during metal cutting on a lathe. The external force applied through the working mechanism of the lathe causes the tool to cut into the metal as it rotates. As the tool moves towards the internal layers of the metal, it undergoes deformation due to the cutting action. In the cutting zone, a force is generated that opposes the free movement of the tool against the metal. This force applies pressure to the front surface of the tool. One of the primary mechanisms of mechanical work performed by the lathe during metal cutting is precisely the increase in this resistance force.

Apart from the cutting forces described above in metal cutting, there are also other forces at play, primarily: between the cutting edge of the tool and the front surface of the tool; between the chip and the front surface of the tool; and between the chip and the front surface of the tool as it separates. The separation of the chip during metal cutting indicates that mechanical work is being performed by the lathe. The physical nature of the mechanical work performed by the lathe is explained in more depth as follows.

In a lathe, a mass (**m**) of metal experiences a force (**F**) during cutting, resulting in it acquiring a velocity (**V**). After a certain period of time, the force causes the mass to travel a distance. The effectiveness of the mechanical work performed by the lathe increases with the velocity acquired by the mass under the force. After a certain period of time, the force causes the mass to travel a distance. The effectiveness of the mechanical work performed by the lathe increases with the velocity acquired by the mass under the force. $\boldsymbol{\mathcal{A}} = \boldsymbol{F_k \ell}$ We express it by the formula (1).

Here $\boldsymbol{F_k}$is the shear force, whose magnitude is not calculated in physics lessons. $\boldsymbol{\ell}$ the path of the cutter in relation to the processed metal (in mm). If we find the path of the cutter after a certain time has passed using the linear velocity formula $\boldsymbol{\vartheta = \pi D n}$ (2), it will be equal to ℓ=$\boldsymbol{\pi D n t}$ (3). If we put the value of ℓ in formula (3) into formula (1). $\boldsymbol{\mathcal{A}} = \boldsymbol{F_k \pi D n t}$ (4) appears. The last formula (4) represents $\boldsymbol{m}$ the amount of mechanical work done by the lathe when cutting Metal with a certain mass (D) diameter on a lathe. Thus, the physical essence of the mechanical work performed by the machine tool when cutting metal is to overcome the resistance of the processed metal to compression deformation, as well as the frictional forces that occur between the front and back surfaces of the cutter and the cutting surface and the processed surfaces. The physical nature of the mechanical work performed by the machine tool on the rotating part can be explained by the example of the grinding of metals with different surfaces on the grinding machines. It is known that the force of friction is equal to ishq $\boldsymbol{F}$=$\boldsymbol{\mathcal{RN}}$ (1), where - the coefficient of friction of the metal in the grinding circle $\boldsymbol{\mathcal{R}}$- the pressure force of the grinding stone against the processed metal $\boldsymbol{\mathcal{N}}$.

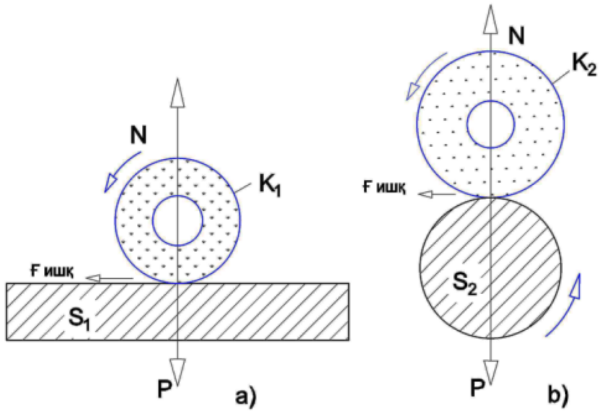


Figure 2 shows the grinding processes, in a) a flat surface (S1) and in b) a circular surface (S2). K1, K2 are grinding stones (circles). Knowing the magnitude of the thermal friction force in the formula $\boldsymbol{F}$ (1), it is possible to calculate the mechanical work performed by the grinding stone in one revolution. The mechanical work performed by the lathe during the grinding process can be calculated using the formula $\boldsymbol{\mathcal{A}} = \boldsymbol{\mathcal{RN}\ell}$ (1). Here $\boldsymbol{\ell}$ - is the year traveled by the grinding stone in one revolution, which can be written as $\boldsymbol{2\pi\mathcal{R}}$ because the grinding stone is circular, then the amount of mechanical work done by the lathe $\boldsymbol{\mathcal{A}} = \boldsymbol{\mathcal{R}2\pi\mathcal{RN}}$ (2) appears. **The power used by the machine when cutting metal.** The power of cutting metal on a machine tool We write in the form $\boldsymbol{\mathcal{N}} = \frac{\boldsymbol{\mathcal{A}}}{\boldsymbol{t}}$ (1). Here is the total work done by the engine. Machine engine power: $\boldsymbol{\mathcal{A}}$ - rotation of the engine shaft /primary/; $\boldsymbol{\mathcal{A}} = \boldsymbol{F_k\ell}$ circular movement of the leading and leading sheaves; $\boldsymbol{\mathcal{N}} = \frac{\boldsymbol{F_k\ell}}{\boldsymbol{t}}$ is used to drive the gears in the gearbox, as well as the part fixed to the spindle / metal being processed / rotating. Formula will be equal to (4) $\boldsymbol{\vartheta = \pi Dn}$.

We write the distance traveled by the cutter in relation to the metal being cut in the form of $\boldsymbol{\ell = \pi Dnt}$ (5). If we put the values of l in formula (5) instead of those in formula (1). $\mathcal{N} = \boldsymbol{F}$K s equal to $\boldsymbol{\pi Dn}$ (6). We can also write the formula (6) in the form $\boldsymbol{\mathcal{N}} = \boldsymbol{F}\theta$ (6). The physical essence of the formula (6) is as follows: with the cutting speed / V / increasing the value of the cutting force /Fk /, the number of revolutions of the spindle / n / decreases as the engine power remains unchanged. From this connection of physical quantities, it can be concluded that the power of the electric motor will be greater at a high cutting speed and high cutting force. In order to further strengthen the understanding of cutting force from physics, the following technical problem can be solved.

Rotational motion. Linear and angular velocity. When studying the topic of rotational motion in technical vocational education classes with materials covered in physics, it helps to have a solid understanding of the physical nature of the topic. This is because students in technical vocational classes directly encounter many examples of rotational motion, such as gears involved in mechanical processing of metals, toothed belts in dental equipment, and other components directly related to rotational motion.

When a machine operates in its working regime, the speed of its rotating parts is not constant because the values of resistance and driving forces vary periodically during the cutting process.

As a result of the influence of cutting forces and frictional forces, the cutting speed also varies, and **F_(k) ∞ ϑ_k** creates a correlation.

In the example of metal turning on a lathe, it's possible to illustrate the physical nature of the concept of linear and angular velocity of the rotating body undergoing rotational motion.

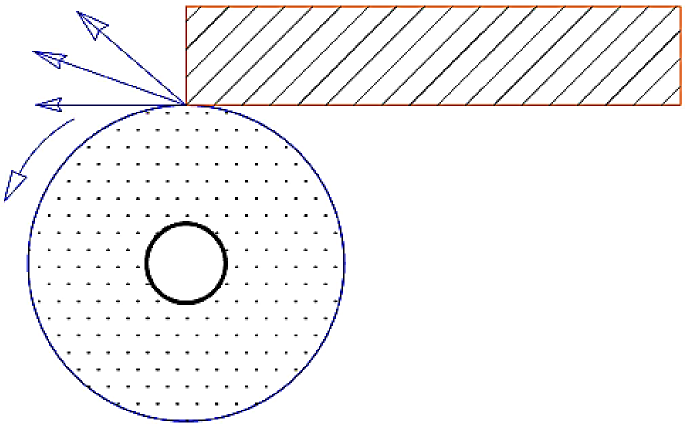
If we express the cutting speed or linear velocity of the rotating stone used in metal turning with the period of rotation /T/ and the number of rotations /π/, then **ϑ=2πR/T (1).**

From the equation I/T=n, we rewrite (1) in the form **ϑ=2πRn (**2).

Formula (3) expresses the linear velocity of the rotating stone undergoing rotational motion.

It's possible to depict the direction of the linear velocity of the rotating stone by the direction of its outgoing motion.

Due to the frictional heat generated by the interaction of the metal being machined with the rotating stone, the direction of the outgoing heat is always perpendicular to the surface of the rotating stone relative to the metal being machined.



Picture 3 Rotational motion

Rotating stone. 2-The metal being machined / the rotating/ metal. 3-Resulting frictional heat. The relationship between linear velocity or cutting speed and radius can be demonstrated in various ways on a rotating stone with different diameters when machining metal. For instance, on rotating stones with larger diameters, it's possible to achieve a relatively small cutting speed when metals are machined. This is because, considering the formula for cutting speed, if we focus on the cutting speed /ϑ_k/, its value varies inversely with the diameter, meaning this variation (ϑ∞D) is equal to the diameter; the larger the diameter, the smaller the cutting speed. This means that if the cutting speed is larger, there will be more resulting frictional heat, and the heat dissipation rate will also be higher.

To maintain a constant cutting speed, the number of rotations of the stone must increase **/ϑ_k/.** Therefore, to keep the cutting speed constant, the number of rotations of the stone must increase /ϑ_k/.

Thus, without changing the kinematic speed of the cutting, the angular velocity increases /ω∞n/. Through this example, we prove the dependency of constant angular velocity on the radius of the cutting speed**, /ω=I/R/.**

The linear velocities of intermediate links in a kinematic chain remain constant without changing. However, angular velocity changes.

On lathe machine 1K62, the rotating stone undergoes rotational motion from 12.5 to 2000 revolutions per minute, while the number of engine rotations is 1460 revolutions per minute.

To increase the angular velocity, small toothed gears with a smaller radius in the kinematic chain are used.

In rotational motion, as in translational motion, force N=F·V is found by the formula. Where ϑ is the linear velocity, F is the cutting force. If we substitute the expression for linear velocity into this formula (radius of the rotating body) N=F2πRn we get the formula. However, F R=M (torque). Therefore, expressing the cutting force as N=2πMn also works.

From the last formula, it is evident that the cutting force is directly proportional to the torque and the number of revolutions.

Frictional forces. Frictional coefficient. Many variables affect frictional force when machining metals. For example, between the machine tool and the metal being machined, between the teeth in the gear mechanism, between the belt and the gear in the toothed belt drive, between the rotating stone and the workpiece, etc.

Any metal cutting machine tool in operation not only works between the machine tool and the metal being machined but also experiences frictional forces between all interacting components. Therefore, understanding the physical nature of friction and its existing conditions is of great practical importance.

When metal is machined on a lathe machine, frictional phenomena can occur in the following cases: - During the machining process, friction occurs between the cutting tool and the machined surface. - During the mutual friction between the cutting tool and the machined surface. One of the conditions for the formation of friction is the increase in temperaments between the frictional surfaces. The increase in temperature affects the internal structure of the machined part, changing its mechanical properties (hardness, strength, thermal conductivity), and also affects the non-uniform rotation of the cutting tool.

The magnitude of the frictional forces depends not only on the surfaces in contact but also on the forces acting on the parts. This can be demonstrated by the following example:

In a rotating stone machine, it is possible to estimate the magnitude of the frictional force generated during the machining process by the speed of the resulting frictional heat. The speed of the resulting frictional heat is proportional to the pressure force / N / exerted on the rotating stone by the metal being machined.

SUMMARY

In summary, understanding the physics principles of metal machining: serves as a vital tool in sparking interest among students in specialties they will work in in the future in the engineering industry. This, in turn, helps students to grasp the role and significance of physics laws in technology, thereby providing close assistance, reducing the test conditions of the machine and the cutting tool, improving the quality of the workpiece, and reducing energy consumption in metal machining.

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