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STUDY ON REDUCING ENERGY CONSUMPTION IN ROUGH TURNING OPERATIONS

I. T. Abbasov[1], S. Simon[1], P. D. Fritzsche[1], N. D. Yusubov[2]

[1]*Brandenburg University of Technology Cottbus-Senftenberg, Cottbus-Senftenberg, Germany;*

[2]*Azerbaijan Technical University, Baku, Azerbaijan*

ABSTRACT

Optimizing energy consumption is one of the key issues in the engineering industry, as in other advanced manufacturing industries. Models for cutting parameters, material extraction and other influencing parameters have been developed until now. Most of these models are subject to one principle. The higher the rate of material extraction, the lower the specific energy consumption. In this article, a number of tasks have been implemented to increase energy efficiency. First, the cutting speed, feed rate, cut of depth are investigated to optimize energy in the machining process. Then the processing is carried out with dry, coolant lubricants and idle machining, and the optimal cutting parameters are selected. These processes are carried out during rough turning. In addition, the energy effects of coolants and lubricants have been studied. For this purpose, heat capacities and dynamic viscosity studies of coolant lubricants were conducted.

KEYWORDS

Turning;
Surface roughness;
Energy efficiency;
Cutting parameter;
Coolant lubricants;
Heat capacity;
Dynamic viscosity.

1. Introduction

Sustainability is a claim, that is increasingly being used as an opportunity to design production processes with a different approach. As a result of the political changes, the topic of energy efficiency is receiving increased attention in society. The combination of social attention and cost-cutting programs makes it necessary to address this issue. Sustainable manufacturing is based on resource-efficient actions that ensure the opportunity for long-term profitability. Research projects such as the Fraunhofer Company's E -production are working on the transition of a novel concept for the future of industrial production in Germany [1]. Reducing costs is a motivation for manufacturing companies to strive for energy efficiency in times of rising energy prices. However, the cost-driven incentive for short-term measures decreases in times of falling energy prices. Due to the dynamics of energy prices, efficiency considerations, since the oil crisis in the 1970s, are driven more strongly in times of rising energy prices than when energy prices are falling. Because of the correlation of world energy consumption with world population growth and the finite nature of fossil primary energy sources, consideration is not only useful during periods of rising prices. Worldwide energy demand continues to rise, making a global view necessary [2,3]. Modelling energy consumption to reduce costs is a topical issue in various advanced industries. This can be achieved by optimizing the cutting parameters, especially during the preparation of parts in the machining process. The basis of the cutting manufacturing processes are the cutting manufacturing processes, which are classified in the main group Cutting of DIN 8580 [4]. Machining processes are used in a variety of ways in industrial manufacturing, as the range of parts that can be produced is almost unlimited. Turning, milling and drilling are the most frequently used processes. In a market study of the years 2004-2013, the worldwide market for cutting tools has been considered. The market volume of 2004 for turning, milling, drilling and other cutting tools is 11.22 billion US$ and was increased to 18.59 billion US$ in 2018 [5]. The consideration of the machining process refers to the workpiece, the tool and the resulting interactions. In a black-box view, the machining process can be represented as an effective system with input and output variables. In the process, the input variables are converted into output variables. The output variables can be divided into process variables such as cutting forces, power, temperatures and vibrations, which can be recorded during the process, and effective variables such as dimensions, shapes and roughnesses of the workpiece, tool wear and machine changes, which are present after the process has been completed. In many scientific studies, cutting forces are used as a process variable and tool wear and workpiece geometry are used as an effective variable to study and evaluate processes [6-8]. Due to the friction between the tool and the workpiece during machining, a high temperature occurs and affects the tool. This heat affects the life and cutting performance of the cutting tool and causes wear, cracking, breakage and various deformations in the cutting tools. This has a direct effect on the quality of the machined surface. In addition, several factors influence the quality of the surface: these are the material of the workpiece, the type of cutting tool, cutting speed, feed rate, depth of cut, cooling lubricants and machine design. If ones of these factors changes, the surface quality also changes. In addition, wear of cutting tools, especially during turning or the wrong

**E-mail:* Ilgar.Abbasov@b-tu.de
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selection of optimal cutting tool and cutting parameters reduces energy efficiency in the machining process [9, 13]. Energy optimisation in mechanical machining is carried out separately for roughing and finishing operations. In roughing, it is less important than surface quality. Therefore, other aspects such as machining time and tool life should be considered. This allows process parameters to be optimised by alternating between power consumption and tool service life. An exemplary consideration of the unit costs in machining production processes is contained in the market study on cutting tools published by Dedalus Consulting in 2011: The unit cost of a component produced by machining is divided into 20% variable costs (tool and material costs) and 80% fixed costs (machine, labor, building and administration costs). A 30% reduction in tooling costs changes the unit cost by 1%. A 50% increase in tool life reduces unit costs by 1%. A 20% increase in cutting speed and an improved process reduces unit costs by 15% or more [10]. The machining production process has an influence on the energy requirements of a machine tool. In the machining process, value is added to the product. The aim of the legislation is to ensure that, in addition to the classic aspects of quality, costs and time, the energy requirement has an influence on the design of the machining process. The question of the optimum input variables, both for the system variables machines, tools and materials, and for the control variables cutting speed, feed rate, work engagement and cooling to achieve the required output variables with minimum energy requirements, must be researched.

The aim of this research work is to determine the influence of cutting parameters on the energy, to understand the influence of the cooling lubricants used during turning on the energy requirement of the process and thus to examine their physical and chemical properties in order to improve energy efficiency in the future. Another goal is to reduce energy consumption by optimizing the cutting parameters when turning. New materials, new tool cutting edge shapes, new coolants and new machining technologies have a high potential to increase the. For these reasons, these investigations take place to determine the latest state of the technologies.

2. Design of experiment

A test workpiece with a simple geometry was developed in the laboratory of the Brandenburg Technical University Cottbus-Senftenberg to investigate the processes that take place on a lathe. In fifteen machining steps, the workpiece made of S355JR steel material is turned from 50 mm diameter to 41.5 mm diameter table 1. Figure 1 a) and b) shows the workpiece above before and below after the turning operation. Tungaloy CCMT09T308-24NS9530 short carbide insert was used for all machining tests in this study.

The number of auxiliary axes, tool change, tool holder, driven axes and other peripheral components must be considered for the test period. The machine tools consist of various peripheral components and these peripheral components affect the design of the workpiece. Here, the workpiece is attached to the main spindle and the machining process is performed. The blue areas before and after machining the workpiece correspond to the locating surfaces for the jaw chuck. The pink areas represent the machining areas.

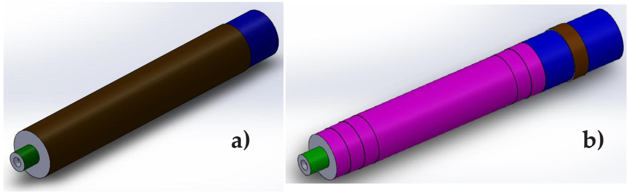

Fig.1. Workpiece before (a) and after turning (b)

Longitudinal machining of the test workpiece with a turning tool was performed in different machining steps with different machining parameters. These parameters are cutting depth a_p (mm), cutting speed V_c (m/min) and feed rate f (mm/U or mm/rev). The depth of cut is the thickness of the metal that is removed when the tool makes a cut. It is the perpendicular distance between the machined surface and the uncut surface of the workpiece. The depth of cut is usually given in the third perpendicular direction (speed, feed and depth of cut usually act in mutually perpendicular directions). Mathematically, it is half the difference of the diameters. In machining, the terms «speed,» «cutting speed,» and «surface speed» all refer to the relative linear velocity between the tip of the cutting edge and the workpiece. The definition is the same for all machining operations such as turning, milling, etc. (unlike feed rate, which is defined differently for different applications). The feed rate (often referred to as feed speed) is the relative speed at which the tool moves along the workpiece; its vector is perpendicular to the vector of the cutting speed. During each machining step, two of the cutting parameters were kept constant and one was changed (table 1). The material removal rate Q is calculated for external longitudinal turning according to equation 1 [11].

Material removal rate during turning Q:

$$Q = A \cdot v_c \tag{1}$$

Table 1

Machining parameters turning test workpiece

Stage	Cut of depth, a_p in mm	Feed rate, f in mm/rev	Cutting speed, v_c in m min^{-1}	Material removal rate, Q in mm^3 s^{-1}
1	3.25	0.2	200	130
2	2.75	0.2	200	110
3	2.25	0.2	200	90
4	2	0.2	150	60
5	2	0.2	180	72
6	2	0.2	210	84
7	2	0.2	240	96
8	2	0.2	270	108
9	2	0.13	200	52
10	2	0.19	200	76
11	2	0.25	200	100
12	2	0.31	200	124
13	2	0.37	200	148
14	1.75	0.2	200	70
15	1.25	0.2	200	50

The chip cross-section *A* for 1 is calculated with equation 2 [11].

$$A = f \cdot a_p \quad (2)$$

In our research, we used tools from Sandvik Coromant and Tungaloy. The corner radius of each of the applied tools is 0.8 mm. Cooling lubricants were not used in the processing of workpieces. These experiments were carried out on the CTX 310 ecoline lathe from DMG Mori-Seiki. The total power consumed by the machine during processing was measured using the Fluke 434 energy analyser [12].

3. Investigation of heat capacity and dynamic viscosity of cooling lubricants used

It should be noted that for the study of the energy influence on the machining, the machining was done with dry machining, cooling lubricants and idle machining and these processes were performed with the cutting parameters listed in the table 1.

During machining, 4 different types of cooling lubricants and emulsions from the Jokisch company were used. The technical data of these cooling lubricants are listed in table 2.

Table 2

Technical data of cooling lubricants

Nr.	Cooling Lubricants	Kinematic viscosity in 20 °C [mm²/s]	Density in 20 °C [g/sm³]	Mineral oil content, %	Concent-ration, %
1	Jokisch RS 200	59	1.0	18	8-10
2	Jokisch HZ 22	14	1.1	0	5-15
3	Jokisch OZ 33 CBF	41	0.97	22	5-12
4	Jokisch TCF 60	93	0.91	60	6-10

The use of cooling lubricants in machining is widespread today, but little knowledge is available about the crucial properties of cooling lubricants. Mixed friction occurs mainly during machining and forming operations. Cooling lubricants reduce this friction by lubrication and thus reduce tool wear. Cooling lubricants also reduce the heating of the workpiece and the energy required. Cooling lubricants also have the task of dissipating heat from the effective point as quickly as possible. This is because if the temperature is too high, the structure in the surface layers of the tool and material can change. This must be prevented by the use of cooling lubricants. In addition, good cooling also improves machining accuracy. The cooling effect depends on various factors: the amount of cooling lubricant used per minute, the pressure, the shape and direction of the cooling lubricant jet, the viscosity, the type and temperature of the cooling lubricant. In the case of water-miscible cooling lubricants, in addition to water evaporation, the high heat capacity of the water component is also an important factor for cooling. For this reason, investigations have been carried out into the heat capacity of cooling lubricants in order to be able to assess them in terms of their cooling effect. This research is being carried out at the Faculty of Mechanical Engineering, Electrical and Energy Systems at the Brandenburg University of Technology Cottbus-Senftenberg (fig. 2). The heat capacity of the cooling lubricant was determined with a calorimeter in a physics laboratory. Casy-LAB software was used here. The aim of the program is to investigate the temperature rise of the cooling lubricant as a function of the given energy. As shown in figure 2, the heat capacity of cooling lubricants increases with increasing electrical power.

On the other hand, the viscosity of lubricants used in mechanical engineering determines the course of the lubrication process. Viscosity is closely related to the structure of the material and indicates its physical and chemical properties obtained on the eve of the technological process. For many chemical compounds, viscosity increases with increasing molecular weight. The high viscosity of oils is explained by the fact that they contain molecular circuits. Due to the lubricating effect, a thin film is formed between the tool and the workpiece, which reduces friction. This prevents wear of the tool and improves the surface quality. For this purpose, the dynamic viscosity of cooling lubricants and emulsions was determined from 20 °C to 80 °C degrees in the capillary viscosity device of Rheotest Medingen of the Brandenburg Technical University. Figure 3 a) and b) shows dynamic viscosity of cooling lubricants and emulsions.

Tests have shown that the dynamic viscosity of cooling lubricants decreases with increasing temperature. As can be seen from the graph, only the dynamic viscosity of the cooling lubricant OZ 33 CBF from Jokisch increases with rising temperatures. Here, the dynamic viscosity of the coolant at 40 °C degrees is 58 mPas. At 60°C and 80 °C degrees, the dynamic viscosity decreases further (60 °C – 21.3 mPas, 80 °C – 8.3 mPas). These are due to the chemical composition of the coolant and a rare condition. Figure 3.b) shows the temperature dependence of the dynamic viscosity of emulsions. Here, when the temperature varies between 20 °C and 80°C degrees, the dynamic viscosity of emulsions varies between 1.1 and 0.37 mPas. From this it is clear that the dynamic viscosity of each cooling lubricant is close to each other when mixed with water. This is because most of the emulsion is water and the amount of water determines the viscosity. In addition, the lubricity of these cooling lubricants was investigated in various ways.

The lubricant tests were carried out on a four-ball apparatus at the University of Zielona-Gora. In this test, the HZ 22 cooling lubricant from the Jokisch company was used.

The balls are loaded with an initial load of 63 kg and tested for 10 s at 1500 rpm. The wear marks on the stationary

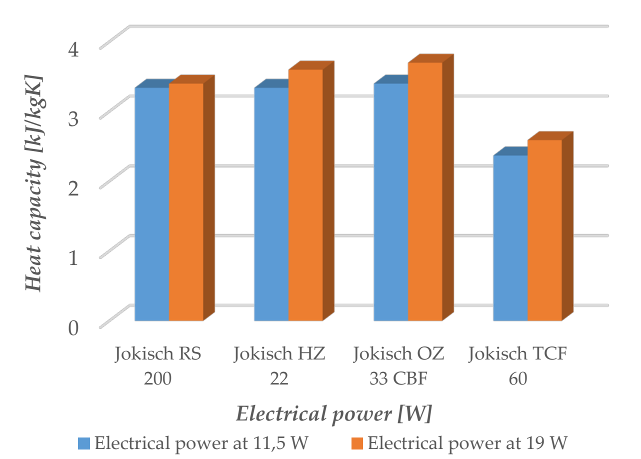

Fig.2. The influence of electrical power on the heat capacity of cooling lubricants

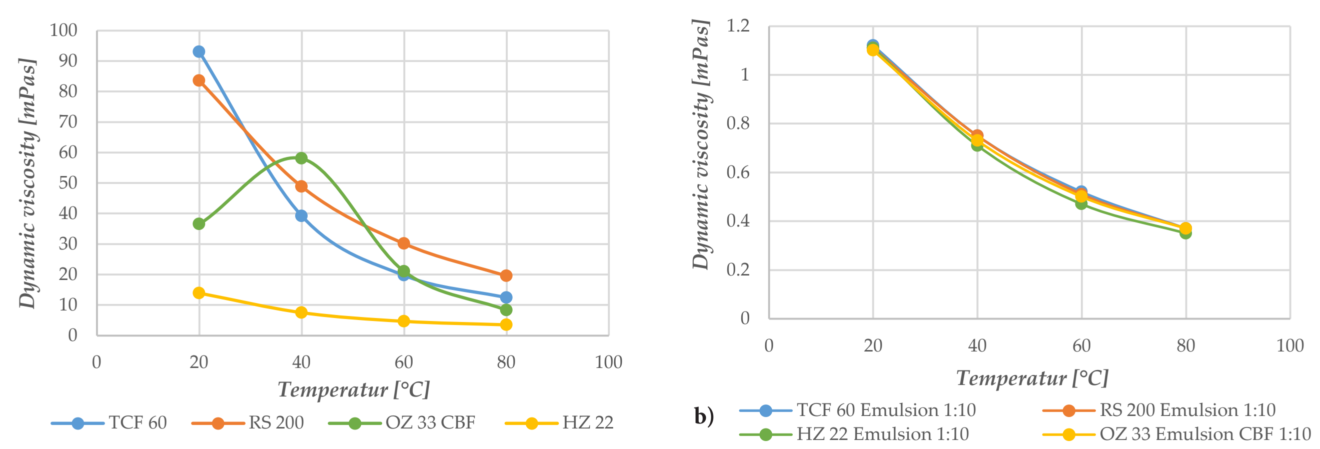

Fig.3. The influence of temperature on the dynamic viscosity of cooling lubricants (a) and emulsions (b)

balls are then measured and entered in the measurement report. The procedure is then repeated with reduced loads until no wear marks are visible on the stationary balls. The load is then increased until the balls weld. If the balls weld, the welding force has been reached. The force that just fails to weld is called the good force. After the test, the balls are examined for wear and, if necessary, measured with a measuring magnifier. The measuring accuracy is 0.1 mm. The values are entered into the program and later used for evaluation.

In the test performed, a welding force of 1000 N (approx. 100 kg) was determined. The yield force is 800 N. The development of the friction force over the measurement time is shown in figure 4. In the first 5 seconds, the friction force decreases. The lubricant is in its working window. After the drop, there is an increase in the frictional force. The fluid is no longer able to form a sufficiently strong lubricating film under the load. This results in wear and an increase in the lubricant temperature. The resulting wear surfaces could absorb lubricant again due to their roughness, so that a lubricant film is formed, which leads to a drop in the frictional force. A cutting force estimate would provide information on the actual force range. However, it should be borne in mind that the lubricants only act on the cutting edge for a very short time.

4. Determination of the energy consumption of rough turning.

Performance measurements are performed and evaluated

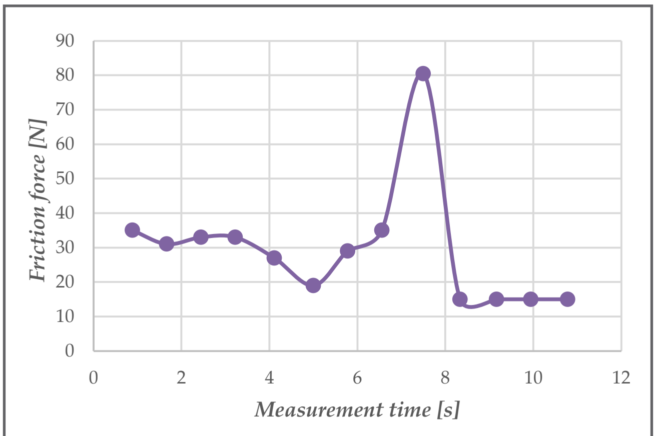

Fig.4. Determination of the lubricity of cooling lubricants

with the workpiece and process parameters shown in figure 1 and table 1. Machining is performed with dry machining, idle and cooling lubricants. Figure 5 shows the dependence of the material removal rate implemented in these machining processes on the total power consumed in the machining process. It can be seen that there are slight differences between dry machining and the use of cooling lubricants. In addition, there are also very small differences between cooling lubricants. Looking at these differences, the best results were obtained with the TCF 60 cooling lubricant. One of the main reasons for this is that this coolant consists of 60% mineral oil. About 0.1 kW of efficiency is achieved with dry machining and other cooling lubricants.

Figure 6 shows the power curve during workpiece machining of the DMG Mori Seiki CTX 310 ecoline lathe. At the beginning, the machine tool is regulated into the Operational Mode. Here, the machine-controlled components such as feed drives, pumps and spindles are supplied with energy. Approximately 1.4 kW of standby power and regular, periodic fluctuations by the hydraulics are a matter of course. The hydraulics supply the jaw chuck and the hydrostatic bearings of the spindle.

At the beginning of the program of machining, the side of the workpiece is longitudinal turned at a constant cutting speed. During longitudinal turning, cooling is performed with a cooling lubricant. In this test, the HZ 22 cooling lubricant from the Jokisch company and Tungaloy CCMT09T308-24NS9530 short carbide insert was used. Pressure on the machine 1 bar. The fifteen steps described here are longitudinal cuts with different metal removal rates (see table 1.).

The active power is calculated from the recorded currents and voltages, and by integration over the duration of the individual process stages, the total energy requirement Etotal is obtained for each stage during longitudinal turning. As expected, the energy demand decreases with decreasing metal removal rate. In addition, the energy consumption decreases with increasing feed rate and cutting speed. We can clearly see this in figure 7. Figure 7 shows the dependence of the energy consumption per volume on the material removal rate. It seems that the machining energy accounts for a large part of the total energy consumption. In the diagram, we can see at the 13th level that the cutting parameters v_c = 200 m/min, a_p = 2 mm, and the highest value of the feed f = 0.37 mm/rev have the least energy consumption (see table 1).

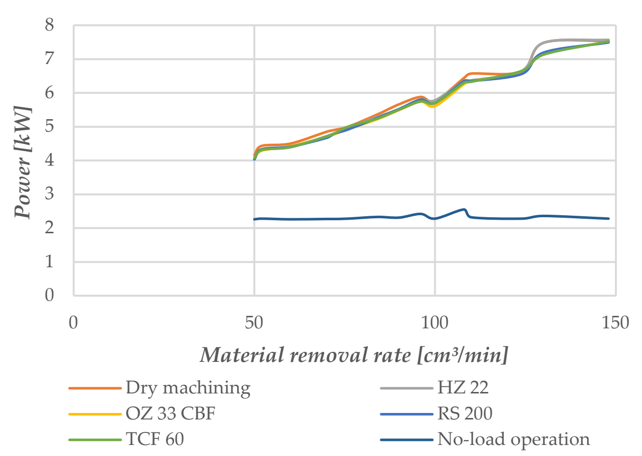

Fig.5. The influence of material removal rate on the overall performance in dry machining, cooling lubricants and idle machining or no-load operation (Cutting parameter: depth of cut mm, cutting speed m/min, feed rate *f* – mm/U or mm/rev)

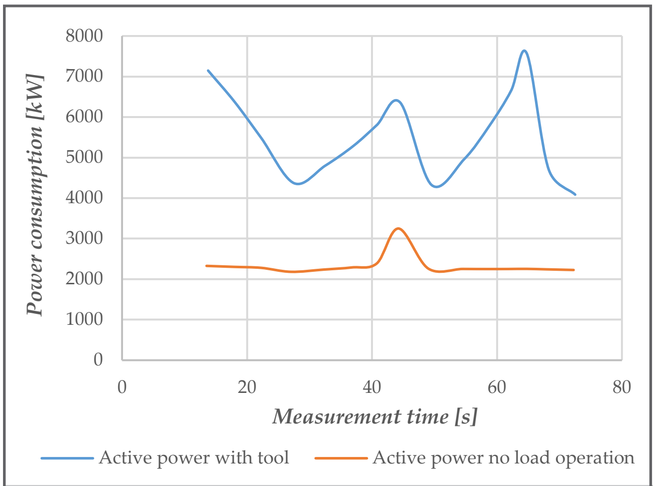

Fig.6. Total power consumption DMG Mori Seiki CTX 310 ecoline workpiece machining with cooling lubricants and idle operation (active power no-load operation)

The cutting parameters should thus be selected as high as possible. High cutting parameters also generate high mechanical loads in the machine tool. Dynamic and rigid machines are needed for effective and cost-efficient machining. Reading errors in the software, measurement inaccuracies of the current transformers, for example, can be mentioned as sources of error. These sources of error have a natural influence on the measurement results.

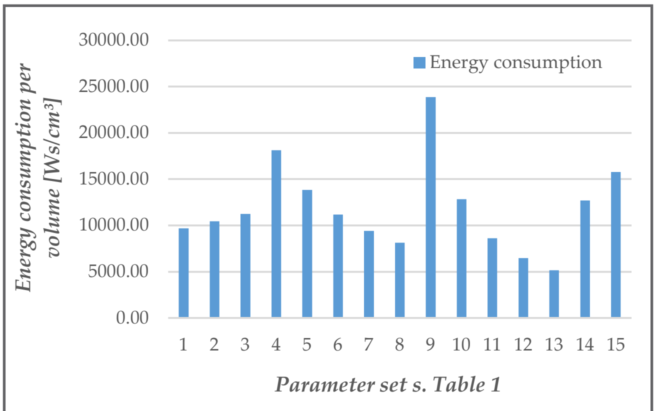

Fig.7. The influence of metal removal rates on energy consumption per volume

Conclusion

By selecting the optimum cutting parameters, coolant lubricant and tools in the machining process, it is possible to increase energy efficiency in the machining process. Cutting tools from different companies were used during the experiments. Since depth of cut, feed rate and cutting speed have a greater influence on the cutting performance in the machining process, two of these parameters were kept constant and one was changed and tests were carried out. According to the results of the experiment, the feed rate has the greatest influence on energy consumption. With increasing feed rates, the energy consumption for processing and the time spent on cutting decrease, despite the increase in the power of the machine used for processing and the metal removal rates produced.

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Исследование по снижению энергопотребления при черновой токарной обработке

И. Т. Аббасов[1], З. Зимон[1], П. Д. Фрицше[1], Н.Д. Юсубов[2]

[1]Бранденбургский технический университет Котбус Зенфтенберг, Котбус- Зенфтенберг, Германия; [2]Азербайджанский технический университет, Баку, Азербайджан

Реферат

Оптимизация энергопотребления является одним из ключевых вопросов в машиностроении, как и в других передовых производственных отраслях. До настоящего времени были разработаны модели для параметров резания, извлечения материала и других влияющих параметров. Большинство этих моделей подчиняются одному принципу. Чем выше скорость извлечения материала, тем ниже удельный расход энергии. В данной статье реализован ряд задач для повышения энергоэффективности. Сначала исследуются скорость резания, скорость подачи, глубина среза для оптимизации энергии в процессе обработки. Затем проводится обработка на сухую, с охлаждающей жидкостью и на холостом ходу, и выбираются оптимальные параметры резания. Эти процессы выполняются при черновом точении. Кроме того, было изучено энергетическое воздействие охлаждающих и смазочных жидкостей. Для этого были проведены исследования теплоемкости и динамической вязкости смазочно-охлаждающих жидкостей.

Ключевые слова: точение; шероховатость поверхности; энергоэффективность; параметр резания; смазочно-охлаждающие жидкости; теплоемкость; динамическая вязкость.

Kobud torna emalında enerji istehlakının azaldılmasının araşdırılması

İ. T. Abbasov[1], S.Simon[1], P. D. Fritzsche[1], N. D. Yusubov[2]

[1]Brandenburq Texniki Universiteti Kotbus-Senftenberq, Kotbus-Senftenberq, Almaniya; [2]Azərbaycan Texniki Univesiteti, Bakı, Azərbaycan

Xülasə

Enerji istehlakının optimallaşdırılması digər qabaqcıl istehsal sahələrində olduğu kimi maşınqayırma sənayesində də əsas məsələlərdən biridir. Indiyə kimi kəsmə parametrləri, material çıxarılması və digər təsir göstərən parametrlər üçün modellər hazırlanmışdır. Bu modellərin əksəriyyəti bir prinsipə tabedir. Materialın çıxarılması sürəti nə qədər yüksək olarsa, xüsusi enerji sərfiyyatı bir o qədər az olar. Bu məqalədə enerji səmərəliliyinin artırılması üçün bir sıra tapşırıqlar həyata keçirilmişdir. Əvvəlcə emal prosesində enerjini optimallaşdırmaq üçün kəsmə sürəti, veriş, kəsmə dərinliyi araşdırılır. Sonra emal quru, soyuducu yağlayıcı mayelərlə və boş gedişlərlə aparılır və optimal kəsmə parametrləri seçilir. Bu proseslər kobud torna emalı zamanı həyata keçirilir. Bundan əlavə, soyuducu yağlayıcı mayelərin enerji təsirləri öyrənilmişdir. Bu məqsədlə soyuducu yağlayıcı mayelərin istilik tutumları və dinamik özlülükləri üçün tədqiqatlar aparılmışdır.

Açar sözlər: torna emalı; səthin kələ-kötürlüyü; enerji səmərəliliyi; kəsmə rejimi paramterləri; soyuducu yağlayıcı mayelər; istilik tutumu; dinamik özlülük.