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Gulrukhsor Sobirjonovna Zakiriyayeva
Navoi State Mining and Technological University
Master student of the Department of Mechanical Engineering Technology, Navoi, Uzbekistan

Rashid Olimovich Muminov
Navoi State Mining and Technological University
Docent of the department Mechanical Engineering, Navoi, Uzbekistan
rashid_81@mail.ru

RESEARCH METHODS OF EFFICIENCY OF REPAIR AND OPERATION OF SCREW-CUTTING MACHINE

Abstract: *The article considers the analysis and proposes methods for the effectiveness of the use of screw-cutting lathes. And also, the research of screw-cutting lathes was carried out on the basis of an analysis of operation. Existing methods for evaluating the effectiveness of the use of metal-cutting machines are considered, methods for calculating the return on assets, as the most important indicator, are analyzed.*

Key words: *efficiency, organizational and technical indicator, load factor, equipment productivity, cutting forces, cutting speed, cutting coefficient, tensile strength, tension, area, cross section, cut layer.*

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Introduction

Efficiency measurement is based on a comparison of costs (time, money) and results. At present, following the established tradition, the effectiveness of the use of screw-cutting lathes is evaluated by well-known indicators, such as reducing the cost of products, payback period, and others, they also use an organizational and technical indicator - the equipment load factor. But the assessment of efficiency is not reliable, since there is no accounting for the use of the technological capabilities of a screw-cutting lathe. With a high load factor of a screw-cutting lathe, there are no guarantees about the efficiency of using the machine, since this may be the result of a high-speed machine operated at low cutting conditions, limited by the durability of the tool available at the enterprise. As a result, screw-cutting lathes, which allow the manufacture of very complex parts, are often used to process fairly simple parts. Return on assets is one of the performance indicators, which can be assessed using the complexity theory [2,5].

Complexity theory Sharina Yu.S. offers a formula for evaluating the effectiveness of use - the formula

$$T = \frac{C}{B \cdot \alpha}.$$

Formula for finding the complexity of a part - formula

$$C = 0.02_n \cdot К_P \cdot K_M \cdot K_{исп} \cdot К_т \cdot К_В$$

According to Yu.S. Sharin, α can only be equal to 0 (when the part is erroneously correlated with the machine) or 1 (when the processing method and the machine correspond to each other). It should be taken into account that the coefficient α can also be in the interval between them, while it can be defined in more detail than originally, namely, as the coefficient of realization of the technological capabilities of the machine [3,8].

Technological capabilities B is the performance of the equipment for a given quality of product processing, expressed in units of complexity per minute. More productive equipment has a value of B higher than less productive. In this case, the technological possibilities, i.e. performance, act as the most important qualimetric characteristics of CNC machines [4,10].

The value of B according to the presented formula by Yu.S. Sharin is an integral indicator that can characterize the machine, taking into account its various technical characteristics. Consider obtaining an estimate of the magnitude of complexity, using the same method we will try to determine the productivity of the machine according to Yu.S. Sharin [6,11].

Let's start from the Granovsky criterion - the formula $V = v \cdot s \cdot t \frac{mm^3}{min}$ parameter B can be estimated as the maximum volume of metal cut on the machine per unit time - the formula

$$B = v_{max} \cdot S_{max} \cdot t_{max}, \quad (1):$$

where v_{max} is the maximum cutting speed for this machine, m/min;

S_{max} is the maximum feed value for this machine, mm/rev;

t_{max} is the maximum depth of cut for this machine, mm.

As you know, cutting power is formula (2):

$$N_{cut} = \frac{P_{z \cdot v}}{1020 \cdot 60} \quad (2)$$

where N_{cut} is the tangential component of the cutting force P, N; $(Pz = (0.96 \div 0.99)P)$;

v – cutting speed, m/min.

In turn, according to - formula (3):

$$Pz = k \cdot \sigma \cdot f, \quad (3)$$

where k is the cutting factor, depending on the structural state and other properties of the metal being processed;

σ is the tensile strength of the treated metal, Mpa;

f is the cross-sectional area of the cut layer, m:

$$f = s \cdot t, \quad (4)$$

where s is the feed, mm/rev;

t is the depth of cut, mm.

Based on formulas (1) - (4) we can deduce:

$$N = \frac{k \cdot \sigma \cdot s \cdot t \cdot v}{1020 \cdot 60} \quad (5)$$

$$t = \frac{1020 \cdot 60 \cdot N}{k \cdot \sigma \cdot s \cdot t} \quad (6)$$

Since the maximum cutting power Nmax is – formula (7):

$$Nmax = Nst \cdot \eta, \quad (7)$$

where Nst – power, W;

η – efficiency of the main drive of the machine.

Then – formula (8):

$$t_{max} = \frac{1020 \cdot 60 \cdot N_{ст} \cdot \eta}{k \cdot \sigma \cdot s^{\rho}_{min} \cdot v^{\rho}_{min}} \sim \frac{N_{ст}}{s^{\rho}_{min} \cdot v^{\rho}_{min}} \quad (9)$$

where – s^{ρ}_{min} the smallest calculated feed rate, mm/min;

v^{ρ}_{min}– the lowest calculated value of cutting speed, m/min.

But it is necessary to take into account formulas (10) and (11), that:

$$v^{\rho}_{min} = \frac{\pi \cdot D_{min} \cdot n^{\rho}_{min}}{1000} \quad (10)$$

$$v_{max} = \frac{\pi \cdot D_{max} \cdot n_{max}}{1000} \quad 11)$$

where D_{min} is the smallest diameter of parts processed on the machine, mm;

D_{max} – the largest diameter of parts processed on the machine, mm;

n^{ρ}_{min}– the lowest calculated speed of the machine spindle, rpm;

n_{max} – the highest passport speed of the machine spindle, rpm. Formula (11) follows from the above:

$$B = \frac{D_{max} \cdot n_{max} \cdot s_{max} \cdot N_{ст}}{D_{min} \cdot n_{min} \cdot s_{min}} \quad (11)$$

Based on it can be assumed that formulas (12) and (13):

$$n^{\rho}_{min} = n_{min} \sqrt[4]{\frac{n_{max}}{n_{min}}} \quad (12)$$

$$s^{\rho}_{min} = s_{min} \sqrt[4]{\frac{s_{max}}{s_{min}}} \quad (13)$$

where n_{min} – the lowest spindle speed indicated in the machine passport, rpm;

s_{min} – the smallest feed indicated in the passport of the machine, mm / min.

In accordance with formula (14):

$$\frac{D_{max}}{D_{min}} \approx 8.5 \quad (14)$$

Considering the latter, we can summarize – formula (15)

$$B \sim 8.5 \frac{n_{max} \cdot s_{max} \cdot N_{ст}}{n^{\rho}_{min} \cdot s^{\rho}_{min}} \quad (15)$$

The technological capabilities of the machine are also affected by the type of CNC system, the dimensions of the machine, the presence of a monitoring and diagnostic system, automatic changeover systems for the lathe chuck and other devices available on the machine, the ability to carry out roughing and finishing on the machine, the number of tools simultaneously installed on the machine, the availability driven tools. Therefore, it is necessary to supplement the obtained formula (15) with coefficients that take into account the influence of these factors. Formula (16) [1,2,3,4,5,7,12]:

$$B = M \frac{n_{max} \cdot s_{max} \cdot N_{ст}}{n^{\rho}_{min} \cdot s^{\rho}_{min}} \cdot К_{СУ} \cdot К_{ИН} \cdot К_{АК} \cdot К_{РС} \cdot К_{ВС} \cdot К_{ПИ} \cdot К_{ПП} \quad (16)$$

where M – proportionality factor;

$К_{СУ}$ – coefficient characterizing the type of machine control system;

$К_{ин}$ – coefficient linking the technological capabilities of the machine. B with the number of tools z installed on the machine at the same time;

$К_{АК}$ – coefficient characterizing the presence on the machine of a system of automatic control of the dimensions of parts and diagnostics of the state of the tool;

$К_{РС}$ – coefficient characterizing the dimensions of the machine;

$К_{ВС}$ – coefficient characterizing the type of processing;

$К_{ПИ}$ – coefficient characterizing the presence of driven tools;

$К_{ПП}$ – coefficient characterizing the availability of means for automatic changeover of the cartridge and other devices.

For coefficients $K_{СУ}$, $K_{АК}$, $K_{ПИ}$, $K_{ПП}$ using calculations, the data given below in table 1 were obtained.

When finding the coefficients K_{PC} and K_{BC} an analogy was made with the coefficients K_P and K_B in the formula for determining the complexity, then we get the formula (17)

$$K_{PC} = \frac{D_{max}+L_{max}}{1200} \quad (17)$$

where D_{max} – maximum diameter of the part processed on the machine, mm:

L_{max} – the greatest length of the detail processed on the machine, mm.

Table 1 – Dependence of the coefficient on the conditions that determine the value

Condition that determines the value of the coefficient				The numerical value of the coefficient
$К_{СУ}$	$К_{АК}$	$К_{ПИ}$	$К_{ПП}$	
The machine is equipped with a contour control system	Availability of automatic control and diagnostics system	Availability of driven tools on the machine	Availability of automatic changeover devices	1,3
The machine is equipped with a positioning system	Lack of automatic control and diagnostics system	Lack of driven tools on the machine	Lack of automatic changeover devices	1

For coefficient K_{BC} the condition:

• K_{BC} = 0,6, if the machine is designed for roughing only;

• K_{BC} = 0,4, if the machine is intended for finishing only;

• K_{BC} = 1, if the machine is designed for roughing and finishing.

To calculate the oil recovery factor in the course of the work carried out, the formula was derived (18):

$$К_{ИН} = 2{,}43 - \frac{1{,}944}{z - 264}$$

Thus, in the formula for finding the technological capabilities of the machine, one unknown remains – M. The search for the indicator M was carried out together with the study of the parameter α. Studies have been carried out on a number of NMMC plants that have many years of positive experience in operating CNC machines. During the survey, an analysis was made of the processing of parts of two hundred names on machines of twenty models. For each machine and the part processed on it, the program time Ti was measured, the complexity was calculated using the formula and

$$C = 0{,}02n \cdot Kр \cdot Kм \cdot Kисп \cdot Kт \cdot Кв$$

Formula

$$B = M\frac{n_{max} \cdot s_{max} \cdot N_{ст}}{n_{min}^{\rho} \cdot s_{min}^{\rho}} \cdot K_{СУ} \cdot K_{ИН} \cdot K_{АК} \cdot K_{PC} \cdot K_{ВС} \cdot K_{ПИ} \cdot K_{ПП}$$

magnitude B ′ - formula (19):

$$B' = \frac{B}{M} \quad (19)$$

After according to the formula (20):

$$T = \frac{C}{\alpha \cdot M \cdot B'} \quad (20)$$

and the same parts processed on different machines were considered as different. As we considered above, the value of the parameter α can be from 0 to 1, it was assumed that in the largest α M the factor α is equal to 1. Then the product α · M can be considered equal to M . Thus, M = 1.895 · 10−8 was obtained. Dividing all values of α · M by M, we get all the values of α.

When testing statistical hypotheses about the law of the probability distribution of the values of the parameter α, it showed that the specified distribution obeys the Rayleigh law with a confidence of 0.95 – the formula (21):

$$\varphi(\alpha) = \frac{\alpha}{0.0736}\exp\left(-\frac{\alpha^2}{0.1472}\right) \quad (21)$$

The most probable value α = 0.26, and the arithmetic mean α = 0.34. These values correspond to the implementation of the technological capabilities of machine tools in enterprises, that is, they are most often implemented by 26%, and on average by 34%. It should be noted and taken into account that the data were obtained at factories with extensive experience in operating CNC machines, which means that they are able to use them more rationally than new enterprises.

Using Internet resources, a sample of 15 was made to calculate and analyze indicators of technological capabilities and return on assets.

Let’s consider their technical characteristics below – table 2, after each table, the calculation of technological capabilities – parameter B will be made.

Table 2 – Technical characteristics of the screw-cutting lathe

Screw-cutting lathe	
Parameter	Parameter
1	2
Machine price	
Machine type	cartridge center
Max RPM, n_{max}	2500 rpm
Minimum speed, n_{min}	20 rpm
Maximum feed, s_{max}	5000 mm/min
Minimum feed, s_{min}	0,04 mm/rev 0.8 mm/min

We find the lowest calculated frequency by the formula (22):

$$n^p_{min}=20\sqrt[4]{\frac{2500}{20}} = 66{,}874\,\frac{\text{об}}{\text{мин}} \quad (22)$$

We find the smallest calculated feed using the formula (23):

$$s^p_{min}=0{,}8\sqrt[4]{\frac{5000}{0{,}8}} = 7{,}113\,\frac{\text{об}}{\text{мин}} \quad (23)$$

We will find the coefficient of the control system according to table 1: $К_{СУ}$ = 1,3 – contour control system.

The coefficient of the simultaneously installed tool $К_{ин}$ is found by the formula (24):

$$К_{ИН} = 2{,}43 - \frac{1{,}944}{z-2{,}64} \quad (24)$$

We find the coefficient of availability of automatic control according to table 1: $К_{АК}$ = 1,3 – availability of an automatic control system.

Coefficient of machined dimensions on the machine $К_{РС}$ find by formula (17):

$$К_{РС} = \frac{1000\ +\ 360}{1200} = 1{,}133.$$

The coefficient of the type of processing on the machine $К_{ВС}$ = 1 – for roughing and finishing. The coefficient of the presence of driven tools can be found from table 1: $К_{ПИ}$ = 1 – lack of driven tools on the machine.

We find the coefficient of availability of automatic changeover of the cartridge according to table 1: $К_{ПП}$ = 1,3 – the presence of automatic readjustment of devices. Calculate the value of B by the formula (19): The coefficient of the type of processing on the machine $К_{ВС}$ = 1 – for roughing and finishing. The coefficient of the presence of driven tools can be found from table 1: $К_{ПИ}$ = 1 – lack of driven tools on the machine [5,6,7,8,9,10,11,12].

We find the coefficient of availability of automatic changeover of the cartridge according to table 1: $К_{ПП}$ = 1,3 – the presence of automatic readjustment of devices.

We calculate the value of B by the formula (16):

$B = 1{,}895 \cdot 10^{-8} \cdot \frac{2500 \cdot 5000 \cdot 5{,}5}{66{,}874 \cdot 7{,}113} \cdot 1{,}3 \cdot 1{,}851 \cdot 1{,}3 \cdot 0{,}667 \cdot 1 \cdot 1 \cdot 1{,}3 = 1261{,}934 \cdot 10^{-5}$ units sl/min

Table 3 - Technical characteristics of turning. Similarly to the previous calculations, we find by the formulas (12) - $n^p_{min}$and (13) s^p_{min}:

$$n^p_{min}=40\sqrt[4]{\frac{2200}{40}} = 108{,}93\,\frac{\text{об}}{\text{мин}};$$

$$s^p_{min}=1{,}6\sqrt[4]{\frac{11000}{1{,}6}} = 14{,}569\,\frac{\text{об}}{\text{мин}};$$

Coefficient of the control system according to table 1: $К_{СУ}$ = 1,3 – contour control system. Coefficient of the simultaneously installed tool Кин – formula (24):

$$К_{ин} = 2{,}43 - \frac{1{,}944}{4\ -\ 2{,}64} = 1.$$

Coefficient of availability of automatic control according to table 1: $К_{АК}$ = 1,3 – availability of an automatic control system.

Coefficient of machined dimensions on the machine $К_{РС}$ – formula (23):

The coefficient of the type of processing on the machine $К_{ВС}$ = 1 – for roughing and finishing. Coefficient of the presence of driven tools according to table 1: $К_{ПИ}$ = 1 – lack of driven tools on the machine.

Coefficient of availability of automatic changeover of the cartridge according to the table 1: $К_{ПП}$ = 1,3 – the presence of automatic readjustment of devices;

Let us calculate the value of B by formula (22):

$B = 1{,}895 \cdot 10^{-8} \cdot \frac{2200 \cdot 11000 \cdot 11}{108{,}93 \cdot 14{,}569} \cdot 1{,}3 \cdot 1 \cdot 1{,}3 \cdot 3{,}167 \cdot 1 \cdot 1 \cdot 1{,}3 = 2211{,}7 \cdot 10^{-5}$ units sl/min

Table 3 - Technical characteristics of the machine NT-250

Screw-cutting lathe NT-250	
Parameter	Meaning
Цена станка	Sum
Machine type	cartridge center

Max RPM, n_{max}	2000 rpm
Minimum speed, n_{min}	20 rpm
Maximum feed, s_{max}	12 mm/rev 24000 mm/min
Minimum feed, s_{min}	0.039 mm/rev = 0.78 mm/min
Power, $N_{ст}$	7,5 kW
Max Machinable Length, L_{max}	1500 mm
Maximum machined diameter, D_{max}	500 mm
Number of simultaneously installed tools, z	4
Control System Coefficient, $K_{СУ}$	1.3
Tool ratio, Кин	1
Coefficient of availability of automatic control, $K_{АК}$	1.3
Coefficient of machined dimensions on the machine, $K_{РС}$	1.667
Processing type factor, $K_{ВС}$	1
Driven Tool Availability Factor, $K_{ПИ}$	1
The coefficient of availability of automatic changeover of the cartridge, $K_{ПП}$	1.3

Similarly to the previous calculations, we find by the formulas (12) - n^p_{min} and (13) -s^p_{min}:

$$n^p_{min}=20\sqrt[4]{\frac{2000}{20}} = 63{,}246rpm;$$

$$s^p_{min}=0{,}78\sqrt[4]{\frac{24000}{0{,}78}} = 10{,}331rpm;$$

Table Control Coefficient 1: $К_{СУ}$ = 1,3 – contour control system. Coefficient of the simultaneously installed tool Кин – formula (24):

$$К_{ин} = 2{,}43 - \frac{1{,}944}{4 - 2{,}64} = 1.$$

The coefficient of the presence of automatic control according to Table 1: $К_{АК}$ = 1,3 – the presence of an automatic control system.

The coefficient of processed dimensions on the machine – $К_{РС}$ formula (23):

$$К_{РС} = \frac{3000 + 800}{1200}=3{,}167.$$

The coefficient of the type of processing on the machine $К_{ВС}$ = 1 – for roughing and finishing. Factor of availability of driven tools according to table 1: $К_{ПИ}$ = 1 – lack of driven tools on the machine.

Coefficient of availability of automatic changeover of the cartridge according to the table 1: $К_{ПП}$ = 1,3 – the presence of automatic readjustment of devices;

Let us calculate the value of B by formula (22):

$$B = 1{,}895 \cdot 10^{-8} \cdot \frac{2000 \cdot 24000 \cdot 11}{63{,}246 \cdot 10{,}331} \cdot 1{,}3 \cdot 1 \cdot 1{,}3 \cdot 1{,}667 \cdot 1 \cdot 1 \cdot 1{,}3 = 2941{,}431 \cdot 10^{-5} \text{ units sl/min}$$

Let's turn to our sample of machines that we will use to calculate and analyze the indicator of technological capabilities and the indicator of capital productivity

According to the analysis and calculation in the course of the research work, we see that the price of the machine is not directly proportional to its technological capabilities - Table 5, in contrast to a direct relationship.

Table 4 - Calculation of technological capabilities for a sample of machines

Machine brand	B·105	$Ц_c$
Screw-cutting lathe	1261,93	176413055.76
Screw-cutting lathe 16K20	2211,66	453629135,16
Screw-cutting lathe NT-250	2941,43	189436311,36

Therefore, we cannot calculate the pricing coefficient and we will carry out the calculation without deducting depreciation charges, that is, using the original price.

Conclusions.

In the article, an analysis was carried out and methods for the effectiveness of the use of screw-cutting lathes were proposed. The study of screw-cutting lathes was carried out on the basis of an analysis of operation over the past 17 years. Existing methods for evaluating the effectiveness of the use of metal-cutting machines are considered, methods for calculating the return on assets, as the most important indicator, are analyzed. In turn, productivity is a factor that determines the value of capital productivity. Efficiency indicators for the use of machine tools were developed based on the theory of Yu.S. Sharina. The assessment takes place according to the indicator of the technological capabilities of the machine - the value of v, which characterizes the machine, taking into account its various technical parameters. According to the studies, it was revealed that the implementation of the technological capabilities of machine tools at enterprises is carried out on average by 34%.

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