E3S Web of Conferences **390**, 06013 (2023) https://doi.org/10.1051/e3sconf/202339006013
AGRITECH-VIII 2023

Algorithm for the analysis of the electrical parameters of the electric motor in energy-intensive technological processes

Mukhabbat Saidova, and *Nodir* Urinov*

Bukhara Engineering-Technological Institute, Bukhara, Uzbekistan

Abstract. Implementation of technological processes of shaping is one of the main components of energy intensity of mechanical engineering enterprises. One of the methods for reducing energy intensity in implementation of technological processes of mechanical engineering is the method of compensating the reactive component of the power consumed during their operation. It is advisable to implement this method by means of automation, which allows not only considering the actual parameters of the technological process and equipment, but also increasing the efficiency of compensation and, as a result, reduce the energy intensity of technological processes and increase the competitiveness of products. The relationship between the parameters of technological process, the rated power of electrical equipment and the energy consumed in the implementation of these processes are determined in the article. Their peculiarity is that the main reason for the increase in the energy intensity of technological processes of mechanical engineering is the difference between the real cutting power and the rated power of the equipment. The article proposes a method for controlling the energy intensity of technological processes of mechanical engineering by means of automatic compensation of reactive component of the current consumed during the implementation of these technological processes.

1 Introduction

The economic stability of modern Uzbekistan is one of the most important conditions for the development of the country, which largely depends on the achievement of energy saving.

Government of Uzbekistan has declared the improvement of energy efficiency and the introduction of energy saving measures at industrial enterprises as one of the key priorities for the development of the economy. This will increase the competitiveness of the industry of Uzbekistan as a whole and release some of the limited gas resources, as well as reduce emissions of carbon dioxide.

The most important component of energy saving is the energy intensity of technological processes of cutting in mechanical engineering. At present, the energy intensity of

* Corresponding author: urinov1960@mail.ru

https://doi.org/10.1051/e3sconf/202339006013

technological processes in Uzbekistan significantly exceeds the energy intensity of similar processes in industrialized countries. This is especially important for the reason that the high-energy intensity of technological processes leads to energy consumption during their implementation, reaching up to 70% of the total energy consumption of mechanical engineering enterprise.

The purpose of the research was reducing the energy intensity of technological processes of the mechanical engineering by means of an automated system for compensatory minimization of energy consumption during their implementation. In order to achieve this goal, the following tasks have been solved: establishing the relationship between the parameters of cutting technological processes of the mechanical engineering, the nominal power of the electrical equipment of the machine and the electrical energy consumed in the implementation of these processes, and developing algorithms for automating the control of the energy intensity of technological processes of mechanical engineering based on the established relationships.

One of the methods for reducing energy intensity in the implementation of technological processes of mechanical engineering is the method of compensating the reactive component of the power consumed during their implementation. It is advisable to implement this method by means of automation, which allows not only considering the actual parameters of the technological process and equipment, but also increasing the efficiency of compensation and, as a result, reduce the energy intensity of technological processes and increase the competitiveness of products.

The works of scientists as A.S. Vereshchak, I.V. Jejelenko, M.G. Kosov, V.I. Kochkin, O.P. Nechaev, Yu.M. Pavlov, V.V. Solomentsev, V.K. Starkov, I.V. Schwarzburg and others, which studied the automation of technological processes, increasing the level of technological equipment, the quality of technological processes, as well as automated reduction of energy consumption have been analyzed [1- 6].

The automation of energy management in the implementation of technological processes is the most important direction of automation of these processes. The low energy efficiency of technological processes depends on a number of their characteristic features [7-9].

The main characteristic is the fact that technological operations occupies a significant place, the implementation of which requires power that is significantly less than the rated power of electric motors, for example, chamfering, finishing, etc. the presence of idle strokes should also be noted, which are depend on the supply or replacement of a tool, workpiece reversal, etc. All this leads to the fact that the values of the cutting power required for the implementation of the technological process are significantly lower than the rated power of the electric motor of machining facilities, resulting in a significant increase in the energy intensity of these processes. During the research, the main provisions of the theory of automatic control, mechanical engineering technology, the theoretical foundations of electrical engineering, and the theory of experiment have been used. Modern information technologies have been used in processing the results of experimental studies.

The main reason for the need to minimize the energy intensity of technological processes of mechanical engineering is the underloading of the electric motor, which is characteristic of machine tools that implement technological processes. This is because the power required for the implementation of the engineering process and determined by the cutting forces, in most cases, is significantly less than the rated power of the machine.

In order to study this issue, the load characteristics of various engineering technological processes have been theoretically studied. For this study, typical products for mechanical engineering, i.e. parts of the “shaft” type have been selected. By calculating the processing modes in accordance with the technology of their manufacture, the cutting power was determined for the corresponding operations. Based on the data obtained, load characteristics have been built, and in accordance with the methods, the equivalent power of these processes have been determined.

The results obtained, which are correlated with the parameters of the equipment on which these technological processes are implemented, allow drawing conclusions regarding the degree of loading of the electric motor of the machine tool.

2 Research methods

Analysis of the load characteristics showed that in real conditions, the power on the electric motor shaft during the implementation of technological processes of cutting is 3–5 times less than the rated power of the complete electric drive motor of the machine tool.

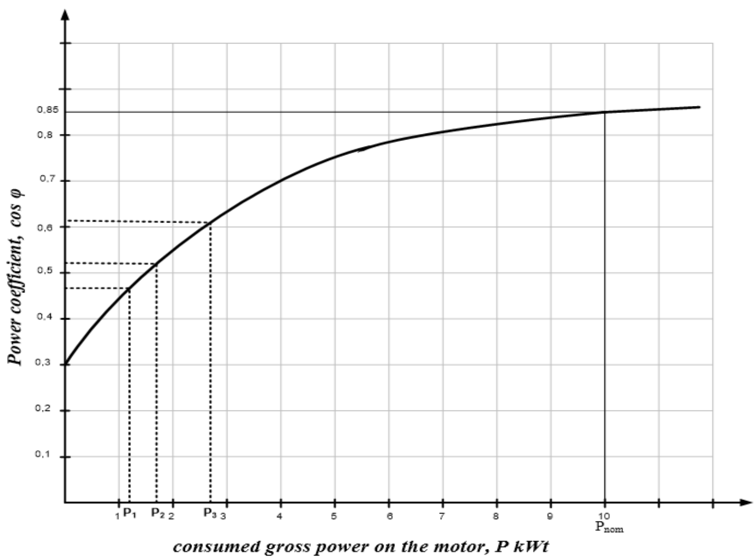


Fig. 1. Values of the power coefficient for the studied technological processes.

The underloading of the electric motor leads to a significant decrease in the power coefficient of the electrical equipment of the machine. Reference data on the value of the power coefficient of the electric motor of the machine 16K20 when the load changes relative to its nominal value P_H, is given as an example in Table 1 [10]. As follows from Table 6, the decrease in the power coefficient during underloading of the electric motor reaches more than 1.5 times and is the reason for a significant increase in relative units of the reactive component of the power consumption during the implementation of technological processes

Table 1. The value of power coefficients during the changes of load.

Power on the motor shaft	0.25 P_H	0.50P_H	0.75P_H	P_H	1.25P_H
Power coefficient of the electric motor	0.55	1.75	0.84	0.87	0.88

In this case, underloading of electric motors leads to an increase in the energy intensity of technological processes. Indeed, underloading of electric motors leads, on the one hand, to a decrease in the values of power consumption, but, on the other hand, to an increase in its reactive component, i.e. the implementation of the technological process is carried out with capacities that are significantly larger than necessary for their implementation

Analysis of the electrical parameters of electric motor, in the first place, the values of power consumption in the implementation of technological processes of mechanical engineering, the currents consumed and power coefficients, was carried out on an L-shaped equivalent circuit for one phase of the electric motor (Figure 2), considering the electromagnetic processes occurring in the motor (x_0,x_1,x_2'), thermal processes in the core and its windings (r_0,r_1,r_2') and the load on its shaft (S) [11].

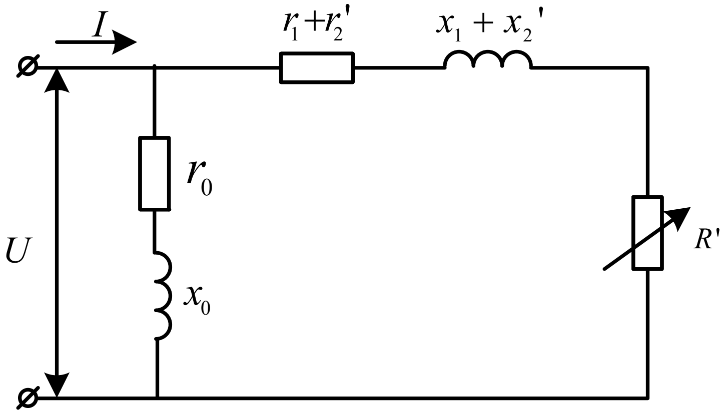


Fig. 2. L-shaped equivalent circuit of asynchronous electric motor. Where: $R'=r_2'\cdot(1\text{-}s)/s$, $s=(n_0\text{- }n)/\ n_0$ is slip, $n_0= 60\cdot f/p$ is synchronous speed, f is supply voltage frequency, p is number of pole pairs, n is motor rotation speed, U is phase voltage, I is phase current. (Compiled by the authors).

To simulate the process, we determine the active and inductive resistance of the magnetization circuit of asynchronous motor.

$$q_0 = \frac{r_0}{r_0^2 + x_0^2},$$

$$b_0 = \frac{x_0}{r_0^2 + x_0^2}.$$

Then, we determine the total active resistance of the stator phase and the rotor resistance reduced to the stator winding, as well as the total inductive phase resistance of the stator winding and the inductive resistance of the rotor reduced to the stator winding.

$$q_1 = \frac{r_{1+}r_2' + R'}{(r_{1+}r_2' + R')^2 + (x_1 + x_2')^2},$$

$$b_1 = \frac{x_1 + x_2'}{(r_{1+}r_2' + R')^2 + (x_1 + x_2')^2}.$$

After that, we determine the total active and inductive resistances of the L-shaped equivalent circuit of asynchronous motor.

$$q_\Sigma = q_0 + q_1 = \frac{r_0}{r_0^2 + x_0^2} + \frac{x_1 + x_2'}{(r_{1+}r_2' + R')^2 + (x_1 + x_2')^2},$$

$$b_\Sigma = b_0 + b_1 = \frac{x_0}{r_0^2 + x_0^2} + \frac{x_1 + x_2'}{(r_{1+}r_2' + R')^2 + (x_1 + x_2')^2}.$$

After that, we can obtain the equivalent values of active and reactive reactance of this circuit, determined by the following dependencies

$$R_э = \frac{q_\Sigma}{{q_\Sigma}^2 + {b_\Sigma}^2},$$

$$X_э = \frac{b_\Sigma}{{q_\Sigma}^2 + {b_\Sigma}^2}.$$

After the conversion, the values of the equivalent active ($R_э$) and reactive ($X_э$) resistances of this circuit were obtained.

$$R_э = \frac{r_0[(r_1 + r_2{}' + R')^2 + (x_1 + x_2{}')^2] + (r_1 + r_2{}' + R')(r_0^2 + x_0^2)}{(r_1 + r_2{}' + R')^2 + (x_1 + x_2{}')^2 + r_0^2 + x_0^2 + 2r_0(r_1 + r_2{}' + R') + 4x_0x_1},$$

$$X_э = \frac{x_0[(r_1 + r_2{}' + R')^2 + (x_1 + x_2{}')^2] + 2x_0(r_0^2 + x_0^2)}{(r_1 + r_2{}' + R')^2 + (x_1 + x_2{}')^2 + r_0^2 + x_0^2 + 2r_0(r_1 + r_2{}' + R') + 4x_0x_1}.$$

Further, based on simplified dependences of the values of energy consumption parameters, which are given below, the analysis of impact of reducing the load on these parameters can be done.

$$I = \frac{U}{\sqrt{R_э{}^2 + X_э{}^2}},$$

$$cos\varphi = \frac{R_э}{\sqrt{R_э{}^2 + X_э{}^2}},$$

$$S = \sqrt{3} \times I \times U,$$

$$P = \sqrt{3} \times I \times U \times cos\varphi.$$

where: S is power consumed during the implementation of the technological process;
P is power required for the implementation of the technological process;
$Cos\varphi$ is the power coefficient.

3 Research results

These values allowed analyzing the electrical parameters of electric motor, assuming that the working section of the mechanical characteristic was assumed to be rectilinear [12].

The analysis was carried out using the Mathcad program and showed that when the load was reduced relative to the rated load by 2 times, with a general decrease in the current consumed for the implementation of the technological process from 20.20A to 12.17A, its excess relative to the required value was 23% (the excess at the rated load was 13 %). At the same time, the energy intensity of the technological process increased by 29%. Therefore, with a general decrease in the currents consumed for the implementation of technological processes, relative to the nominal values, the energy intensity of technological processes increases, because the relative value of the reactive component of these currents increases.

The article proposes a method for controlling the energy intensity of technological processes of mechanical engineering by means of automatic compensation of the reactive component of the current consumed during the implementation of these technological processes.

When developing an algorithm for the functioning of an automated control system for energy saving of technological processes of shaping, the power coefficient was chosen as the control parameter due to the most objective indicator characterizing the energy efficiency of these processes. To determine the values of the power coefficient, it is necessary to determine the values of the consumed current and voltage in the network, and it is necessary to know the value of the phase shift angle between these parameters. The latter can be obtained by simple calculations.

To implement the algorithm for automated control of energy saving of technological processes of shaping, it is necessary to determine the specified power coefficients:

- Required value, at which the implementation of the technological process will take place in the mode of maximum energy efficiency.
- Critical value, i.e. the value that the power coefficient must not exceed.

The latter is necessary to avoid the effect of overcompensation, which in turn leads to a decrease in the energy efficiency of the process and an increase in losses.

 https://doi.org/10.1051/e3sconf/202339006013

Condensers were chosen as devices that create a compensation current. The number of control steps is set based on the nomenclature of these compensators, the control range, the characteristics of the load characteristics of the technological process and the requirements for the speed of the system. The control range is determined by the minimum value of the power coefficient (at idle running of the electric motor of the machine) and the required value. This range is divided into n steps of regulation, each of which is assigned the corresponding capacitance of the condensers [13].

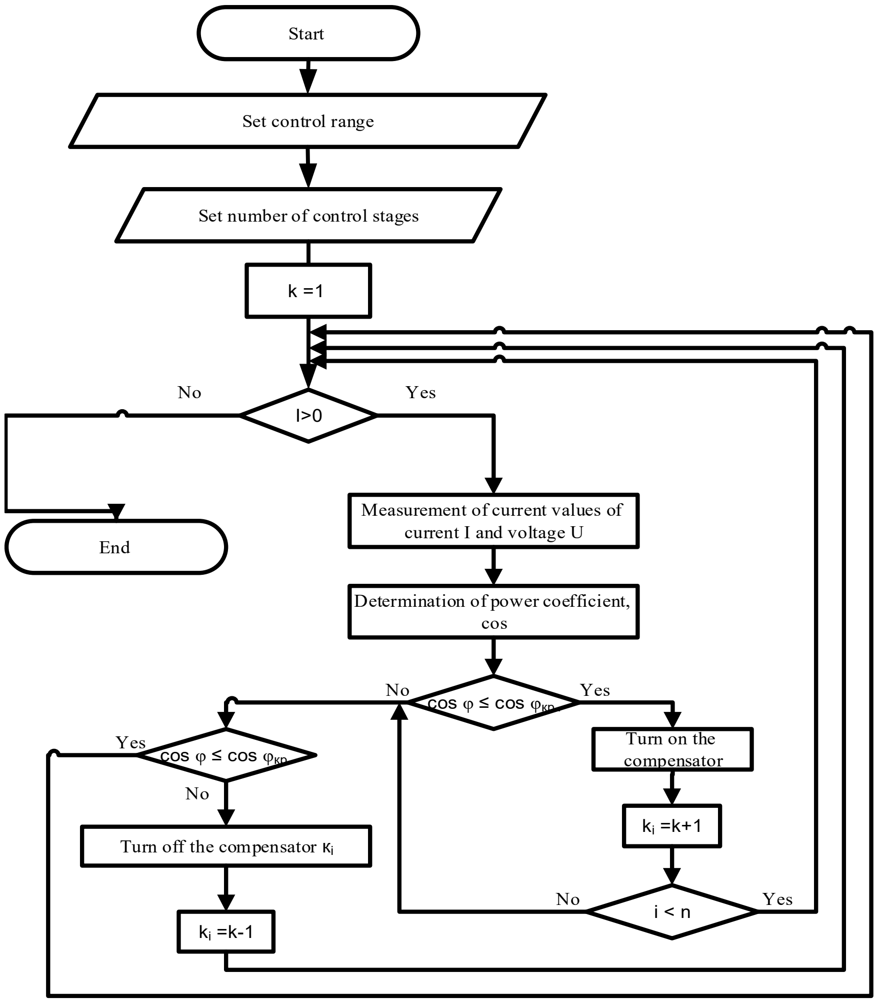


Fig. 3. Algorithm for automatic control of energy intensity of technological processes of mechanical engineering. (Compiled by the authors).

After the input of the required values, the power supply of the machining facilities that implements the technological process is checked. Next, the current values of the consumed current and mains voltage are read and the phase shift angle and power coefficient are determined. The obtained value of the power coefficient is compared with the required value and, if it is lower, a condenser is connected. Next, the new values of the power coefficient are read and, if necessary, additional condensers are connected [14]. In cases where the current value of the power coefficient is greater than or equal to the required value, as well as in cases where all the condensers are already connected, it is necessary to check for

 https://doi.org/10.1051/e3sconf/202339006013

exceeding its critical value. If the critical value is exceeded, the condenser must be disconnected. This is necessary in order to avoid the effect of overcompensation, which leads to a decrease in the energy efficiency of the process.

With the correct selection of the capacitance of condensers and the number of control steps, the efficiency of the proposed scheme should tend to 100%, i.e. the power coefficient of the shaping process should tend to 1.

4 Discussion

Analysis of the results of experimental studies showed that when the motors are underloaded, despite the fact that the current consumed decreases, its reactive component changes and its relative value increases, which determines the increase in the energy intensity of technological cutting processes with underloading.

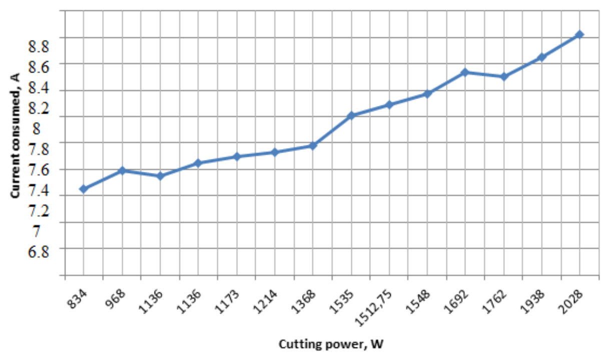


Fig. 4. Dependence of current consumption on cutting power.

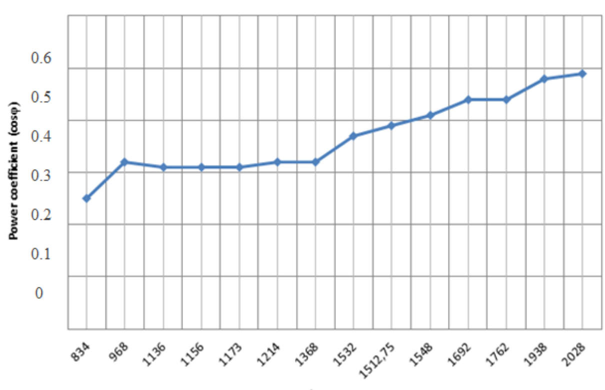
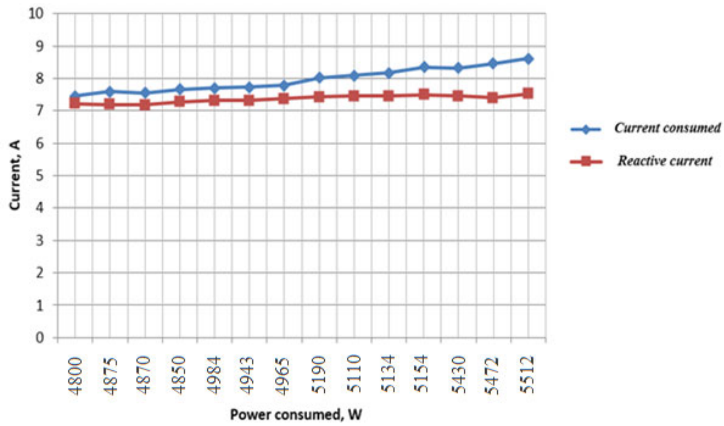


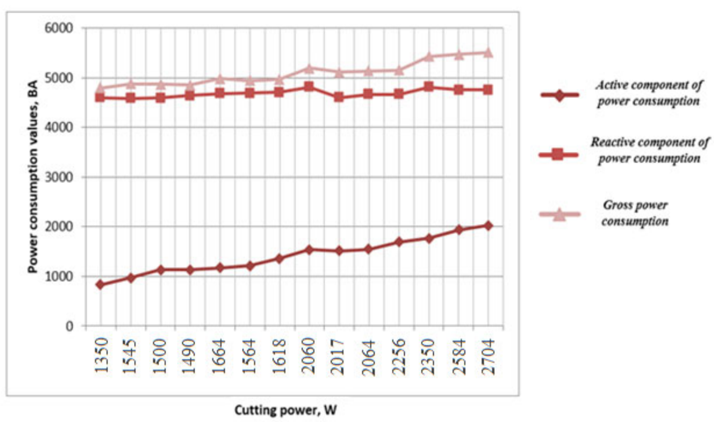
Fig. 5. Dependence of power coefficient on cutting power.



Current consumed // reactive current

Fig. 6. Dependences of consumed currents on power consumption.

A similar situation is obtained when analyzing the power consumption in the implementation of technological processes of cutting and its active and reactive components.



Active component of power consumption // reactive component of power consumption // gross power consumption

Fig. 7. Dependence of power consumption, its active and reactive components on cutting power.

From the data obtained, it can be concluded that the parameters of the technological processes of shaping have a significant impact on the energy characteristics of these processes [15]

As can be seen from the graphs presented, such quantities as the current consumption and the active component of the power consumption and the total power consumption increase with increasing spindle speed and cutting depth. This is because with an increase in the values of these parameters, an increase in speed and, as a result, cutting power occurs. This leads to an increase in the load on the motor shaft, which in turn causes an increase in the energy efficiency characteristics of the turning process. The result of this is the increasing values of the consumed current.

We observe another situation when analyzing the obtained data on the reactive component of the consumed power. We can see that the value of the reactive component of the power consumption does not depend on the cutting conditions. In the first averaging, it can be observed that the reactive component is a conditionally constant value. This may be because this component of the power consumption is necessary for magnetic transformations in induction consumers of electrical energy and its value depends on the characteristics of the consumer itself, and not on its operating conditions.

From the data obtained, it can be seen that the power factor also increases with increasing load on the motor shaft. However, with a more detailed analysis, it can be concluded that the increase in the power factor with an increase in the load on the shaft of the electric motor is caused by an increase in the active component, and not a decrease in the reactive component of the power consumption.

Based on the results of theoretical and experimental studies, it is possible to determine recommendations for the creation of automated control systems for the energy intensity of technological processes of the mechanical engineering based on a decrease in the reactive component of power consumption. [16]

As follows from the results of the analysis, the obtained experimental data almost completely coincide with the results of the theoretical analysis.

5 Conclusions

Analysis of consumed energy components from the standpoint of possibility of its minimization without changing the parameters of technological process showed that it is advisable to reduce the energy intensity of technological processes of mechanical engineering by the method of compensating the reactive component of the consumed power. It is important to note that this also reduces the consumed current and, as a result, the impact of these processes on the environment and humans is reduced.

Proposed algorithm allows significantly increasing the energy efficiency of technological processes of shaping, by reducing the reactive component of power consumption, and as a result, increasing the power coefficient. This algorithm allows considering such a feature of technological processes as a wide spread of load characteristics during their implementation and avoid the effect of overcompensation. Moreover, this algorithm can be used by local automated energy management systems, i.e. in relation to specific pieces of machining facilities. This will allow managing energy consumption as accurately and efficiently as possible. Additionally, it should be noted the versatility of this algorithm and the possibility of its use in relation to a wide range of machining facilities.

The practical significance of the work is the methods of adapting automated energy intensity control systems to real technological processes and equipment of the mechanical engineering; creation of automated control system for the energy intensity of technological processes of the mechanical engineering through compensatory minimization of energy consumption during their implementation.

References

1. A. S. Vereshchaka, A. K. Kirillov, O. Yu. Khaustova, *Environmentally friendly and resource-saving processing technologies: Manual for the implementation of course work* (M., 2004)
2. E. A. Kulikova, A. B. Chuvakov, A. N. Petrovsky, *Automation of production processes in mechanical engineering: Textbook for universities* (Yurayt Publishing House, Moscow, 2022)

3. V. I. Kochkin, O. P. Nechaev, *Application of static compensators of reactive power in electrical networks of energy systems and enterprises* (Publishing house of ENAS scientific center, M., 2000)
4. V. V. Pavlov, Yu. M. Solomentsev, A. A. Gusev, *Mechanical engineering: Encyclopedia: in 40 vol.: Section III: Technology of production machines* **III-5**: *Assembly technology in mechanical engineering* (Mashinostroenie, M., 2002)
5. E. V. Tuev, M. Kozlova, O. Olshevskaya, Modern Innovations, Systems and Technologies **1(2)**, 34-45 (2021)
6. L. E. Schwarzburg, K. A. Zmieva, A. V. Markin, *Reducing the energy load on the environment during processing by cutting. Collection of articles and monographs "Ecological aspects of production and environment" Opole (Poland)*, 139-145 (2008)
7. G. Ishankhodjayev, M. Sultanov, B. Nurmamedov, Modern Innovations, Systems and Technologies **2(2)**, 0251-0263 (2022). https://doi.org/10.47813/2782-2818-2022-2-2-0251-0263
8. Ch. Brecher, M. Weck, *Machine Tools Production Systems 3. Mechatronic Systems, Control and Automation. Lecture Notes in Production Engineering (LNPE)* (Springer Wiesbaden, 2021)
9. M. Saidova, N. Urinov, L. Schwarzburg, IOP Conf. Series: Earth and Environmental Science **839**, 052031 (2021)
10. A. E. Kravchik, M. M. Schlaf, V. I. Afonin, E. A. Sobolenskaya, *Asynchronous motors of 4A series*: Handbook (Energoizdat, M., 1982)
11. V. A. Kuzovkin, V. V. Filatov, *Modeling of processes in electrical circuits. Textbook on discipline "Electrical engineering and electronics"* (Information center of "Stankin" MSTU, M., 2006)
12. K. K Kim, Theoretical foundations of electrical engineering. IPR MEDIA (2017). Available at: https://www.perlego.com/book/2681095/theoretical-foundations-of-electrical-engineering-textbook-pdf (Accessed: 15 October 2022)
13. V. V. Filatov, D. A. Chumaev, Bulletin of the "Stankin" Moscow State Technical University. Scientific peer-reviewed journal (M.: "Stankin" MSTU, 2008), **4(4)**, 93-101
14. L. E. Schwarzburg, *Information-measuring systems of drives of metal-cutting machines* (Stankin Publishing house, M., 1991)
15. L. E. Schwarzburg, I. N. Mikhailov, Bulletin of "Stankin" MSTU. Scientific peer-reviewed journal **3(15)** (2011)
16. K. A. Zmieva, Questions of modern science and practice **9**, 162-166 (2009)