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IMPROVING THE DESIGN OF THE LOCATING SYSTEM OF PERIPHERAL-MILLING MACHINES

Based on the analysis of the designs of peripheral-milling machines, it was found that, according to the principle of operation, all the machines have a movable locating system, which is the dominant factor influencing the accuracy of machining and introduces an error of up to 60% of the total error of machining on these types of machine. As a result of theoretical studies on the influence of the structures of the locating systems, it was found that on a jointing machine, the greatest error is caused by the height of the rear plate placement, while on a thicknessing machine - the presence of rollers in the table plate. To improve the accuracy of machining on peripheral-milling machines, it is proposed to replace the movable locating system with the positional locating of workpieces on the feeding carriage. The design of a four-side peripheral-milling machine S20PK has been developed based on the principle of operation of a cyclo-through type with positional locating of blanks on a feeding carriage, which ensures the accuracy of machining a profiled bar measuring 4,000 x 200 x 200 mm within ±0.07–0.34, as well as the possibility of machine operation with the participation of one operator. As a result of experimental studies, a regression model of the dependence of machining accuracy on the S20PK machine on the feed rate and the thickness of the removed layer was obtained, which makes it possible to set rational milling modes to ensure machining accuracy in accordance with the requirements of current standards (± 0.1 mm).

Keywords: positional locating, feeding carriage, machining, error, regression model.

Relevance of the research topic. Today, each woodworking enterprise that manufactures products from solid wood requires the performance of technological operations for surface machining of blanks to give them the appropriate size and profile [1, 2]. To carry out these operations, peripheral-milling machines are used, designed to form longitudinal flat and profile surfaces on boards, bars and planks by the method of cut-up peripheral milling, to create base surfaces and machine them to size in thickness and width. At modern enterprises, three types of peripheral-milling machine are used: jointing machines, thicknessing machines, and four-side machines [3]. At small enterprises, operations of surface machining of blanks are carried out by machining each side of the bar blanks in turn on separate machines [4]: one or two base surfaces of the part are created on jointing machines; they are milled to size in thickness on thicknessing machines. At woodworking enterprises of Ukraine with a large volume of production,

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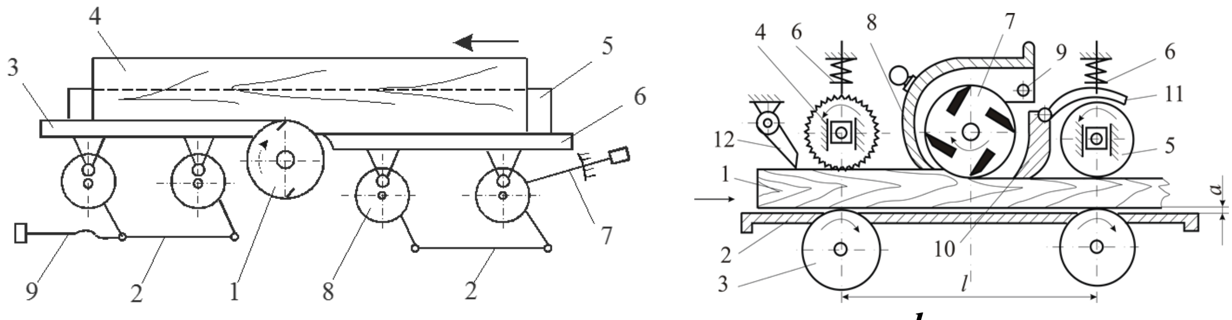
four-side machines of the world's leading manufacturers are used for plane and profile peripheral milling of blanks simultaneously on four sides [5-7].

Customer's demands on the market regarding the design capabilities of peripheral-milling machines are constantly increasing, including requirements on the accuracy of manufactured parts in accordance with the requirements of current standards [8–10], which are ± 0.1–0.2 mm depending on the size of the parts. As a result of experimental studies of operations [11] on jointing machines, thicknessing, and four-side machines of different manufacturers in the production conditions of woodworking enterprises in Ukraine, it was found that the actual machining errors exceed the allowable values of ± 0.2 mm by 1.8-6.3 times. One of the major causes of low accuracy is that all available machines [3–7, 11] are of the *passing-through-type*, that is, they have a movable workpiece locating system, which leads to a decrease in the dimensional accuracy of the manufactured parts. In addition, under the action of the pressure feed rollers, the surface of the workpieces is deformed and damaged by corrugated rollers, the traces of which remain on the machined surface. Thus, on the basis of previous studies on the actual technological accuracy of peripheral-milling machines, it can be argued that it is necessary to improve the accuracy of machining on such machines by conducting more thorough theoretical studies and developing practical solutions to improve the designs of locating systems. Therefore, the goal of research is to increase the technological accuracy of machining on peripheral-milling machines by developing effective ways to improve the system of locating the workpieces.

1. Analysis of known designs of locating systems. All the three types of peripheral-milling machines: jointing machines, thicknessing machines, and four-side machines [3] have a movable locating system. Schemes for locating workpieces on jointing machines and thicknessing machines are shown in Fig. 1 *a, b*. In the jointing machine, at the beginning of the cutting process, the workpiece *4* is based only on the front table *6.* After machining the workpiece with the cutter drum *1* to a length that is sufficient for locating it on the rear table *3*, the location of the workpiece is completely transferred to the rear table *3*, where the workpiece is pressed against the table with the machined surface.



a ***b***

Fig. 1. Schematic diagrams of jointing and thicknessing machines:
a – jointing machine; ***b*** – thicknessing machine

The main locating surface of the jointing machine consists of two plates - front and rear, which are located in front and behind the cutter drum. Each plate has a specific purpose. The front plate locates the workpiece at the beginning of the machining process. After the surface is machined to a length sufficient to locate the workpiece on the rear plate, the locating is completely transferred to the rear plate, on which the workpiece is pressed against the plate by the already machined surface. Thus, the initial error of the locating surface of the workpiece affects the accuracy of machining only in the initial period of milling, that is, before the transition of the workpiece location on the rear plate. On a thicknessing machine (see Fig. 1 *b*), the locating of the workpiece is carried out on the work table *2* by means of lower rollers *3*. The workpiece is pressed by rollers *4, 5*. The rollers protruding above the table surface affect the formation of the machined surface if the protrusion of the rollers is greater than the amount of their denting the workpiece surface. Rollers on locating surfaces are rare in finishing machines, more often they are found in machines for roughing operations, since rollers are an additional source of errors in the locating surface of the plate. Perhaps the only representative of machines that form the final dimensions of parts located on a plate with rollers is a thicknessing machine, therefore, this locating system must be investigated regarding the nature of impact of rollers on machining accuracy.

Modern designs of four-side machines [5–7] (Fig. 2) contain: four or more spindles on which knife blocks, cutters or saws are installed; front and rear tables with guide lines; top and side pressure rollers; feed cylindrical rollers which are placed distributed above the tables before and after each milling head.

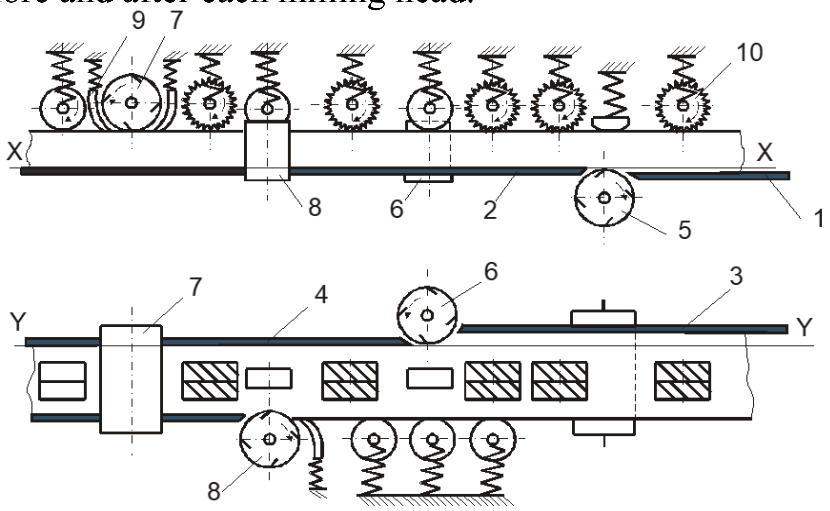


Fig. 2. Schematic diagram of four-side machine

Taking into account the fact that four-side machines contain the main functional units of thicknessing and jointing machines, their locating system also include several systems of these machines, therefore, further theoretical studies of the errors of the locating system are carried out according to the designs of systems of jointing and thicknessing machines.

2 Study of the effect of workpiece locating system errors on machining accuracy. The known designs of peripheral-milling machines are all of the 'passing-through' type with a movable locating system, the errors of which are systematic in nature and for machines with a higher accuracy class they should be no more than 10% of the total machining error [12].

In jointing machines, the rear plate of the table is the main factor influencing the magnitude and nature of the locating error, depending on the placement of its locating surface relative to the cutting circle of the knife shaft (Fig. 3 *a, b*).

The machining error, when installing the rear plate tangentially to the cutting circle and above (see Fig. 1, *a*), is $f = R_{z\ max}$, if $R_{z\ max}$ = 32-200 µm, then f = 0.032-0.2 mm, which is 5-30% total error tolerance for machined parts. In the case of forming the surface of the part when placing the locating surface of the rear table below the blades of the knives (see Fig. 3 *b*), the error will be determined by the dependence:

$$f_1 \approx \frac{a-y}{L_0}(R+0.5H) \approx \frac{a-y}{L_0}R \approx \frac{aR}{L_0}, \quad (1)$$

where: *a* is the amount of lowering of the rear plate in relation to the tangent of the circle describing the blades of the knives; *y* is the height of kinematic wave peaks.

On the basis of theoretical studies, it was determined that the level of the rear plate must be set below the tangent of the cutting circle by the height of the peak of the kinematic irregularities of the machined surface of the part.

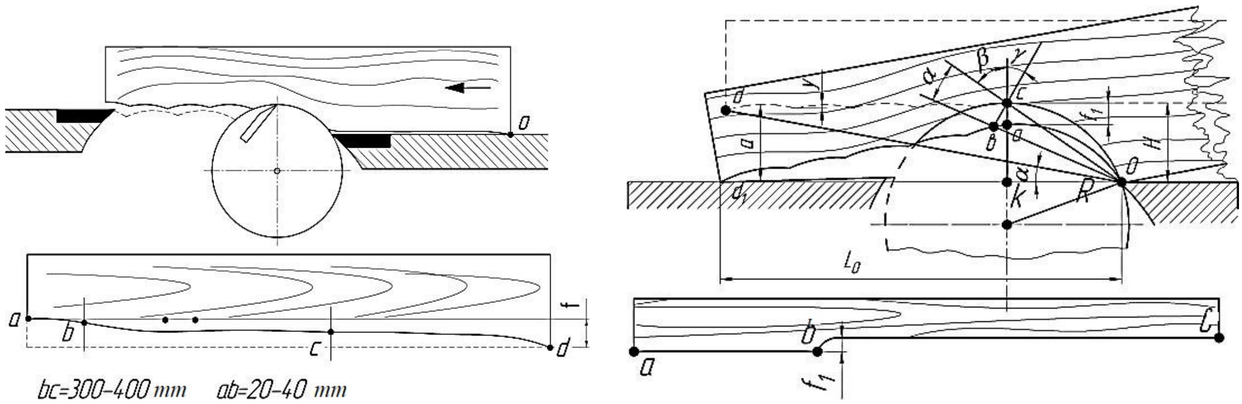
In thicknessing machines, the main factor influencing the error of the locating system is the main locating surface - a plate with rollers (Fig. 4 *a*). Depending on the protrusion of the rollers, the thickness of the workpiece and the radius of the rollers, the value of the machining error is determined by the following dependencies:

$$f = y_{max} - y_{min} = y_1 - y_3 = y_1 - (H - C), \quad (2)$$

where:

$$y_1 = \frac{R+H}{\cos\alpha} - R, \quad y_3 = H - C, \quad (3)$$

where: *H* – workpiece thickness*;* *C* – the amount of protrusion of the rollers*;* *r* – radius of rollers; *α* – workpiece rotation angle.



a ***b***

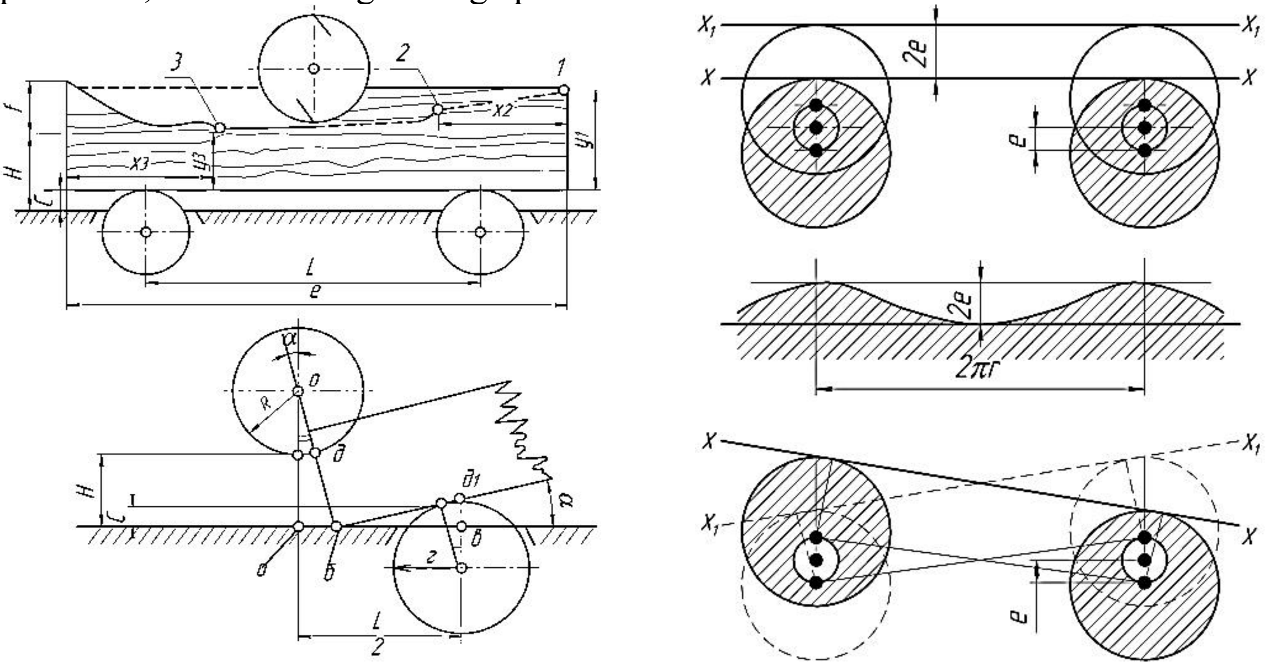
Fig. 3. Diagrams of machining errors depending on the placement of the locating surface of the rear table: a - tangential to the circle of the knife blades; ***b*** - below the circle of the knife blades

The radial runout of the rollers has a direct impact on the magnitude of the error in the machining of the parts (Fig. 4 *b*) and should not exceed 0.02 mm. The error from the radial runout of the locating rollers, if the phase angle *ξ=0*, will be maximum, i.e. *ΔH=2e* and equal to *ΔH* = 0.06...0.1 mm, which is 9-15% of the total error tolerance.

On the basis of theoretical studies, it was found that the optimal protrusion of rollers on a thicknessing machine should be within 0.1–0.2 mm.

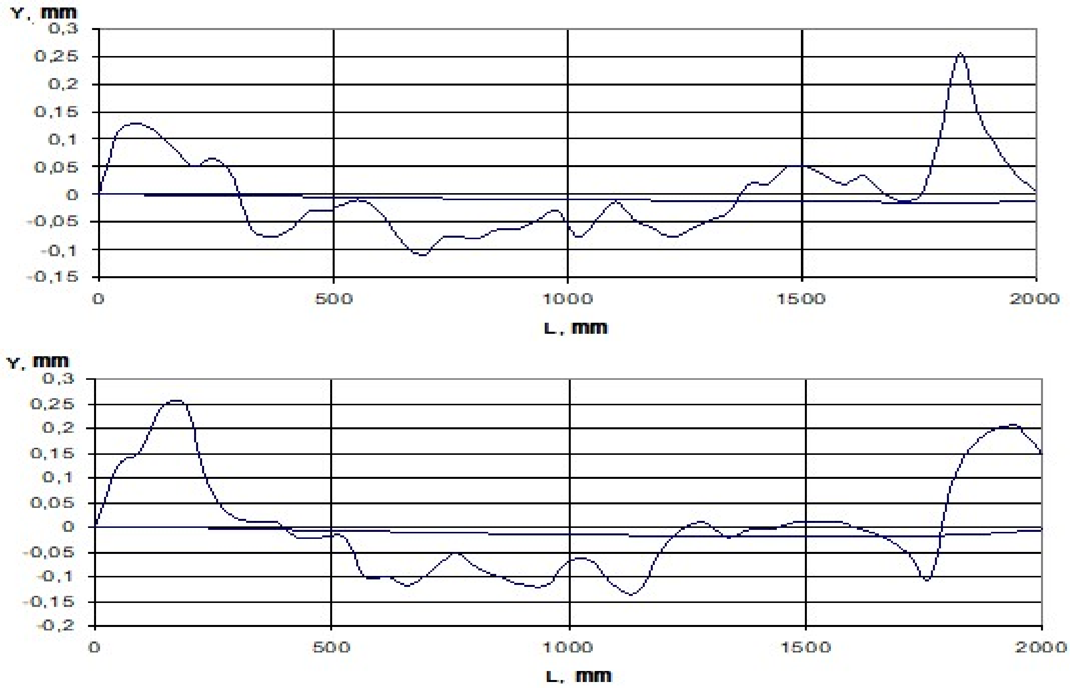
On the basis of experimental studies on the technological accuracy of peripheralmilling machines (jointing machine - SF-4 and thicknesser - SR6-9) and the distribution of the magnitude of the errors of the machined surface along the length of the part (Fig. 5 *a, b*), it was found that the accuracy of machining on both machines is lower than the permissible value (±0.1mm) almost by 2.5 times.

It should also be noted that the distribution of machining errors along the length of the part confirms the theoretically substantiated nature of the influence of the movable locating system, that is, this factor is dominant for these machines. Based on the analysis of the theoretical dependencies of the errors of the locating system on peripheral-milling machines and the results of experimental studies on the distribution of errors along the length of the parts, it was found that the movable system of locating the workpieces is the dominant factor affecting the accuracy of machining and makes up to 60% of the total error of machining on these machines tools. Reducing machining errors on peripheral-milling machines is possible by improving the design of the workpiece locating system by replacing the movable locating system with a fixed workpiece locating, in particular, on the feeding carriage plates.



a *b*

Fig. 4. Diagrams of errors of movable locating on a plate with rollers :
a *- locating on a plate with rollers;* ***b*** *- radial runout of the rollers*



a

b

Fig. 5. Graphs of the distribution of the magnitude of errors of the machined surfaces along the length of the part:
a *- machine tool SF-4;* ***b*** *– machine tool SR6-9*

3. Developing the design of machine with a feeding carriage. Improving the accuracy of machining on peripheral-milling machines is possible by replacing the movable workpiece locating system with a fixed one [13], in particular, equipping the machine with a feed mechanism in the form of a feeding carriage, which provides positional locating of workpieces, and also eliminates workpiece slippage and damage to their surfaces. On the basis of this method of increasing the accuracy of machining, *a new design of the S20PK machine [14, 15] was developed,* consisting (Fig. 6) of a vertical jointing head *1*, a horizontal profiling head *2*, a horizontal thicknessing head *3*, and a vertical profiling head *4*. To simplify and reduce the metal consumption for the machine, the frame is made in the form of a welded structure with a guide base *5* in the form of a calibrated rectangular profile. In order to eliminate the deformation of the workpieces by the feeding bodies and their relocation, the machine feeding mechanism is made in the form of a carriage *6*, which has a Π-shaped body with two working panels - the top one *7* and the side one *8*, on which the workpiece *9* is positionally located with the help of longitudinal *10* and limit *11* stops, and support rollers *12*. The carriage itself moves on rollers *13* on two guides *14* which are symmetrically placed on the ends of the side surfaces of the carriage body.

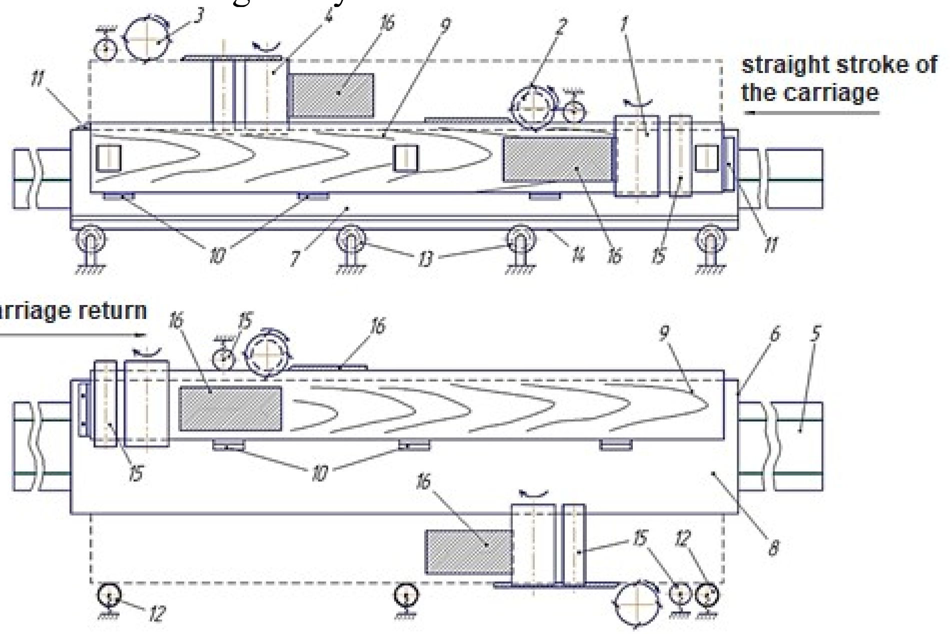


Fig. 6. Schematic diagram of a four-side peripheral-milling machine S20PK (patent for invention No. 110435) [14]

In front of each milling head, a pressure roller *15* is installed, and after the head - a receiving locating plate *16*. The feeding carriage of the machine (Fig. 7) is mounted on a welded structure of the frame *1*, the basis of which is a guide *2* of squared profile with two side guides *3* of a rectangular profile welded to it. The body of the carriage *4* has a Π-shape and consists of a metal framework *5* and wood sheathing *6*, which makes it possible to periodically calibrate its surfaces with milling heads, if necessary.

A prototype model of the S20PK machine was made (Fig. 8) with the presented technical specifications, which allows machining bars measuring 6.000 x 200 x 200 mm. The new design of peripheral-milling machine with a feeding carriage provides an increase in the dimensional accuracy of manufactured parts in accordance with the requirements of current standards [8–10], a reduction in the cost of machining, and maintenance of the machine by one operator.

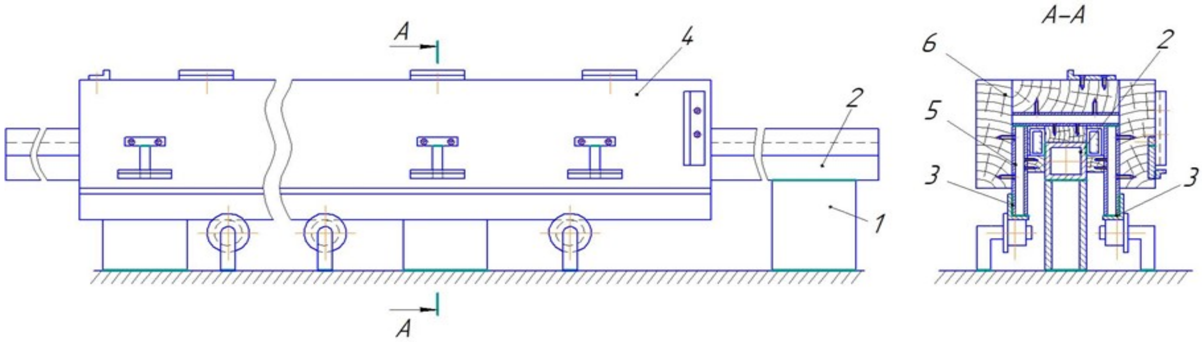


Fig. 7. The design of the feeding carriage of the S2OPK four-side peripheral -milling machine

Fig. 8. General view and technical specifications of the S20PK machine

Indicator name	Indicator value	Units
Blank dimensions: length:width:thickness	(200-6000) : (15-200)	mm
The number of milling heads	4	pcs
Milling cutter diameter	180	mm
Productivity: Profiled bar	4-5	m/shift
Lining board, lamella for window units	4-60	m/shift
Rotation speed of cutters	6000	rev/min
Carriage feed rate	1-12	m/min
The number of electric motors	7	pcs
Rated power of electric motors (overall)	5; 5; 4; 4; 7,5; 1; 1,4 (28)	kW
Overall dimensions: length:width:thickness	16000 : 1800 : 2100	mm
Weight	1100	kg

On the four-side peripheral-milling machine of a new design S20PK, experimental studies were carried out regarding the dependence of the accuracy of machining a profiled bar of pine species of size 4.000 x 200 x 200 mm on the feed rate *Vs* and the thickness of the removed layer *h*. As a result of the studies, a regression model was obtained, which takes the form:

$$\pm\omega = 0.344 - 0.111V_s - 0.02h + 0.009V_s h + 0.01V_s^2 \qquad (4)$$

Based on the analysis of graphical dependencies (Fig. 9), it should be noted that with an increase in the feed rate within 4–8 m/min and the removal of a layer of 1.0 to

5.0 mm in thickness, the scattering field of the size of the produced parts also increases within ± 0.07–0.34 mm.

When milling a bar at a minimum feed rate of 4 m/min and removing a layer of 1.0 mm thick, it is possible to achieve maximum machining accuracy, ± 0.07 mm.

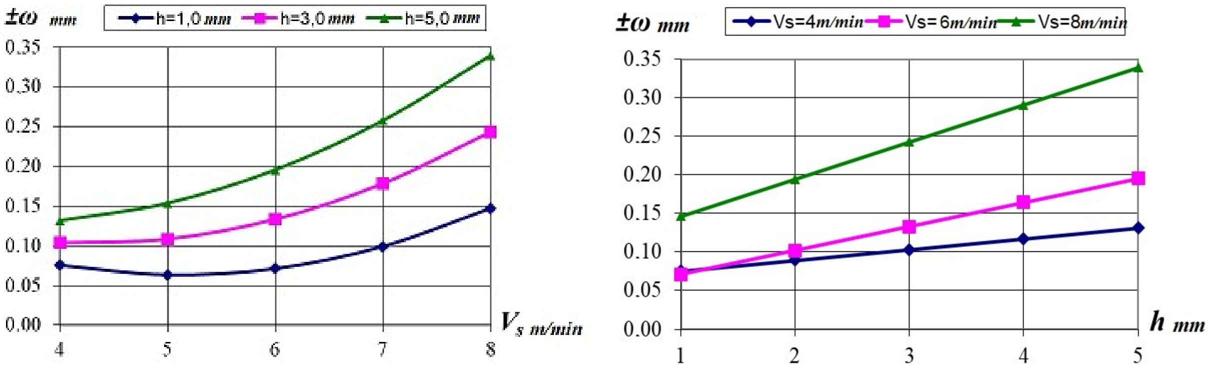


Fig. 9. Dependencies of milling accuracy on feed rate and the thickness of the removed layer.

The resulting regression model of accuracy makes it possible to establish rational milling modes to ensure the required milling accuracy. Thus, for machining accuracy within ±0.2 mm, the following milling modes will be rational:

$$Vs = 4\text{–}7 \text{ m/min}; \; h = 1.0\text{–}3.0 \text{ mm}.$$

Conclusions

1. Based on the analysis of modern designs of peripheral-milling machines, it was found that by the principle of operation, all machines are of the passing-through type, that is, they have a movable locating system, which is the dominant factor affecting the accuracy of machining and introduces an error of up to 60% of the total error of machining on these machine tools.

2. As a result of theoretical studies on the influence of the structures of the locating systems, it was found that on a jointing machine, the greatest error is caused by the height of the rear plate placement, while on a thicknessing machine - the presence of rollers in the table plate. To reduce machining errors on peripheral-milling machines, it is proposed to replace the movable locating system with the positional locating of workpieces on the feeding carriage.

3. The design of the four-side peripheral-milling machine S20PK was developed according to the principle of operation of the cyclo-pass type with positional locating of the workpieces on the feeding carriage, which ensures the accuracy of machining within ± 0.07–0.34 mm of the profiled bar measuring 4000 x200 x 200 mm, as well as the possibility of operation of the machine with the participation of one operator.

4. As a result of experimental studies, a regression model of the dependence of machining accuracy on the S20PK machine on the feed rate and the thickness of the removed layer was obtained, which makes it possible to set rational milling modes to ensure machining accuracy in accordance with the requirements of current standards (± 0.1 mm).

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Удосконалення конструкції системи базування поздовжньо-фрезувальних верстатів

На основі аналізу конструкцій поздовжньо-фрезувальних верстатів встановлено, що за принципом роботи всі верстати мають рухому систему базування, яка є домінуючим чинником впливу на точність обробляння і вносить похибку, що складає до 60% від сумарної похибки обробляння на цих верстатах. У результаті теоретичних досліджень впливу конструкцій систем базування встановлено, що на фугувальному верстаті найбільшу похибку вносить величина виставлення задньої плити, а на рейсмусовому – наявність роликів у плиті стола. Для підвищення точності оброблення на поздовжньо-фрезувальних верстатах запропоновано замінити рухому систему базування позиційним базуванням заготовок на подавальній каретці. Розроблено конструкцію чотирибічного поздовжньо-фрезувального верстата С20ПК за принципом роботи цикло-прохідного типу із позиційним базуванням заготовок на подавальній каретці, що забезпечує точність обробляння профільованого бруса розміром 4000x200x200 мм у межах ±0,07–0,34мм, а також можливість роботи верстата за участі одного робітника. У результаті експериментальних досліджень отримано регресійну модель залежності точності обробляння на верстаті С20ПК від швидкості подавання та товщини шару, що знімається, яка дає змогу встановлювати раціональні режими фрезування для забезпечування точності обробляння відповідно вимогам чинних стандартів (± 0,1мм).

Ключові слова: позиційне базування, подавальна каретка, обробляння, похибка, регресійна модель.