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Modernization of the KarPLAZ Plasma Cutting Machine Design in Classic-B LLP

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***Abstract.** The study aims to increase the efficiency of the plasma cutting machine by optimizing the technological parameters of plasma cutting equipment, improving quality (precision cutting of shaped parts, cutting quality), reducing the number of locksmith work (removal of deburring, cauterization), and reducing the percentage of defects in production. Inaccuracies were revealed when cutting parts on the KarPLAZ plasma machine in Classic-B LLP. The design and operation features of machine parts and assemblies have been studied. After analyzing the experimental data and the design of the machine, design and technological decisions were made. The drive was calculated, working drawings were developed, the kinematic pair "gear-rack" was replaced, and a full-scale experiment was carried out. The results of the research work confirmed the correctness of the technical decisions made.*

***Keywords:** modernization, plasma cutting machine, CNC machines, plasma cutting, grate, drive, rack, working drawings, cutting speed.*

Introduction. Due to the cutting accuracy of 0.001 mm, and positioning of 0.01mm, CNC plasma machines are widely used in industry for cutting precise shapes in steel sheets with a thickness from 0.1 mm to 100 mm, dimensions 1500x6000mm, 2000x12000mm.

Classic-B LLP successfully uses a plasma cutting machine "KarPLAZ" of its design, which consists of a power source, a device for supplying gas (argon), a plasma distributor, a distribution system, a horizontal beam along the X-axis, longitudinal rail guides along the Y axis, an electric height regulator along the Z axis, toothed rails and the cutter (Figure 1). Guides and drives are part of the playback system. She is responsible for moving the cutter when performing work operations.

The principle of operation of the machine is as follows: the workpieces are installed on the table, the machine is set up and the processing program is started. According to the trajectory set by the program, the plasma head cuts out shapes. The cutting speed (movement of the working body along the rail guides) is carried out using a pair of gear – racks.

When cutting on the KarPLAZ machine, the formation of a grate is observed (Figure 2, b, c). The grate is a cooled metal or metal oxide that adheres to the lower edge during operation on a plasma cutting machine. Deburring may occur at inappropriate cutting speeds if the cutting speed is too high or too low [1].

Figure 1 – Assembly of the KarPLAZ plasma cutting machine

Research methods. The research methods were a comparative analysis; the study

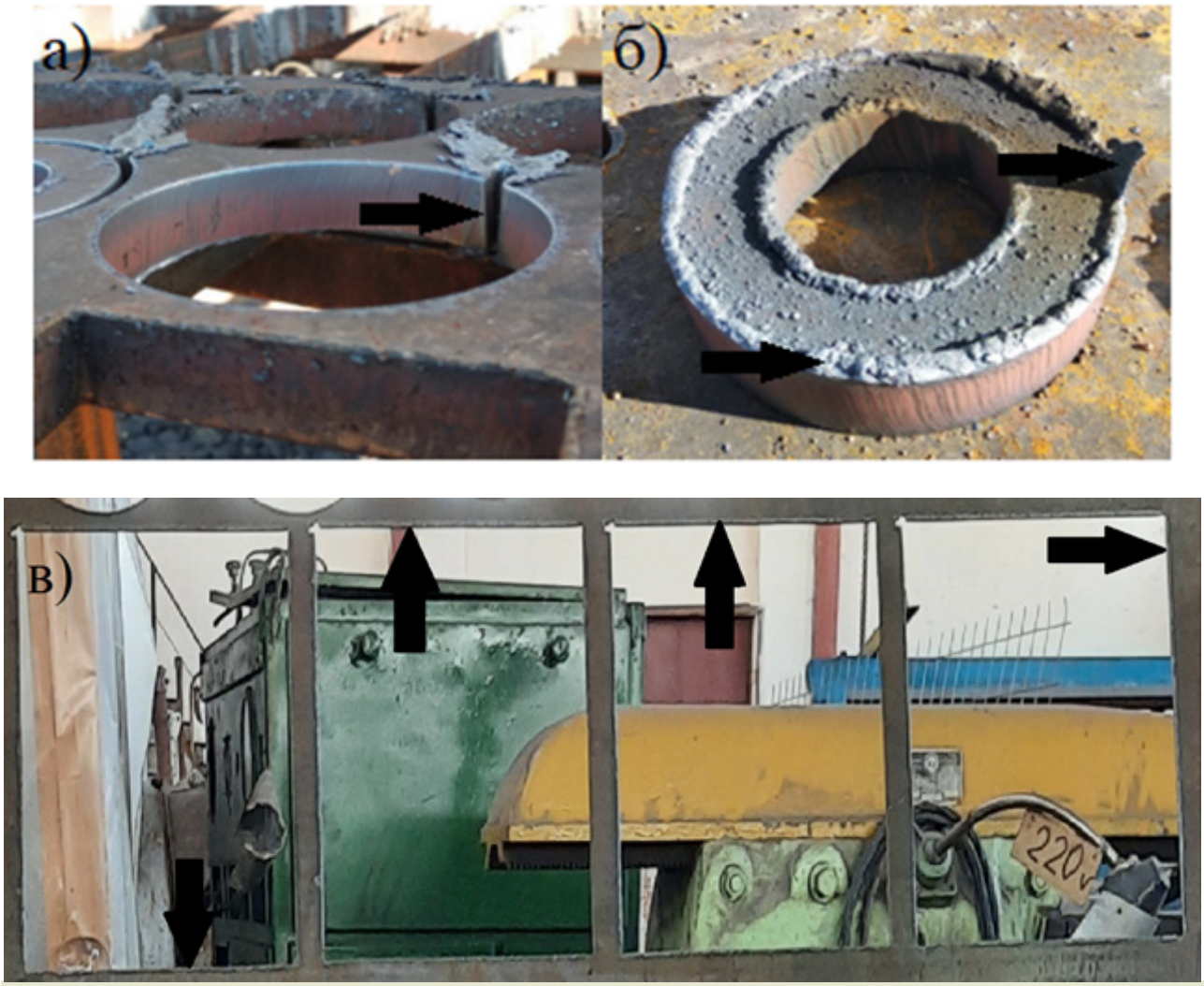


Figure 2 – Inaccuracies in plasma cutting machine "KarPLAZ":
a) the end point of the cut does not coincide with the starting point of the cut; b) the formation of a grate when cutting from a circle c) the formation of a grate from a rectangular cutting

of foreign experience in using plasma cutting; and a field experiment in the conditions of Classic-B LLP.

To determine the cause of the inaccuracy, we study the statistical data of the enterprise for the period January-May 2022 (Table 1), the total amount of work performed is shown in Table 2.

Based on statistical data, we conclude that accuracy is not ensured when cutting shapes. To solve these problems, we conduct a review of theoretical and experimental studies.

In [2], the authors conducted a comprehensive review of developments in the field of plasma cutting for steel alloys. There are many cutting problems such as electrode erosion, metal oxide, tilt angle, double arc, surface properties and thermal effects. It is noted that the feed rate and edge roughness have a significant effect on the processing characteristics.

An experiment was conducted to study AISI 304 stainless steel by plasma arc cutting, taking into account three process parameters and three levels of factors for each parameter [3]. The gas pressure, the speed of movement and the thickness of the material are taken as input parameters of the process. A full-factor experiment consisting of 27 experiments is set. After the experiments, recommendations were given for high-quality stainless steel cutting at travel speeds of 1.6 to 4.7 m/min.

Experimental studies of plasma cutting on 15 mm thick steel sheet samples for cutting 17 shaped parts have shown [4] that too high a speed negatively affects both the workpiece and the tool and leads to a disorderly scattering of sparks with incomplete cutting of the metal; the appearance of an inclined strip on the surface and solution spots on the cut from below. Low speed contributes to the appearance of the unevenness of the cut and its melt-

Table 1 – Percentage of usable parts from the total amount of work performed on the plasma machine "KarPLAZ" in LLP "Classic-B" LLP

Months	Percentage of precisely cut shape parts, %			
	rectangular	round	triangular	shaped
1	92.3	91	88.1	86.4
2	88.3	89.3	85.8	83.2
3	85.4	87.7	84.7	79.4
4	83.2	83.1	81.4	76.7
5	82.2	76.8	78.4	72.7

Table 2 – Scope of work performed on the KarPLAZ plasma machine in Classic-B LLP

Months	The number of parts when cutting the mold, pcs			
	rectangular	round	triangular	shaped
1	10500	10800	9500	9000
2	10500	10800	9500	9000
3	10500	10800	9500	9000
4	10500	10800	9500	9000
5	10500	10800	9500	9000

ing, leads to the formation of deburring, and reduces the efficiency of the process. The optimal speed is set from 25 to 55 m/min with a thickness of 15 mm of carbon steel.

With the help of experimental planning, the surface quality is evaluated during CNC plasma cutting of mild steel sheets with a thickness of 10 mm [5]. The input parameters selected are cutting speed, height, and arc voltage. The analysis of the average values (ANOM) and the analysis of deviations (ANOVA) showed a significant effect of the cutting speed on the surface quality, and the deviation of the other parameters is low so that they can be ignored.

Mathematical modeling of the effect of cutting speed, gas pressure, and voltage on the cutting characteristics during the processing of steel alloys [6] showed direct dependencies of cutting accuracy on cutting speed. The resulting sections were examined, and their macroscopic and microscopic parameters were evaluated.

Optimization of plasma arc cutting parameters such as cutting speed, arc current, and distance between burners when processing a sheet of mild steel with a thickness of 12 mm is considered in [7]. All data is analyzed using the orthogonal matrix "Taguchi's L9". The experiment results showed that to obtain the maximum cutting speed of steel with a thickness of 12 mm, the cutting arc current should be 65 A, the cutting speed should be 2000 mm/min, and the tap distance should be 2.0 mm. The results of the experimental studies have shown that the feed rate, surface roughness, plasma gas pressure, gas composition, cutting current, arc voltage, and cutting speed are the main parameters affecting the cutting quality; at the same time, the speed of movement of the working body significantly affects the cutting quality.

Scientific results and discussion. Having familiarized myself with the design of the machine made by employees of Classic-B LLP, I know that to perform cutting, the cutter adjusts to the desired height using an electric height controller. The regulator is mounted on a beam along which horizontal movement is performed. With the help of toothed rails (Figure 3) mounted on longitudinal rail guides, vertical movement along the Y-axis is performed. Rack and pinion transmission is used to convert rotational motion into translational motion. Rack and pinion parameters: module m = 4 mm, length l1 = 500 mm, width b = 22 mm, pitch s = 12.5 mm, number of teeth z = 40.

The kinematic pair "gear-rack" has an important feature: the unevenness of the gear ratio due to the considerable influence of gearing errors on the speed of movement of the rack. It is tough to ensure the uniformity of slow movements in the feed drive of high-pre-

Figure 3 – Gear rack of the KarPLAZ plasma machine

cision machine tools, such as plasma cutting machines, with the "gear-rack" pair [8].

One of the important indicators of a gear transmission is the module. The modulus is the primary indicator of gearing, linking the essential transmission parameters, such as pitch, height, number of teeth, the diameter of the circle of tooth protrusions, etc. A decrease in the module and a corresponding increase in the number of teeth in a pair helps reduce the specific slip, increasing the transmission's efficiency and reliability against jamming [8].

The module in the "gear-rack" pair is associated with such a parameter as pitch. Changing the pitch value affects the smoothness of the ride. The smaller the stroke, the smoother the linear movement [8].

In the KarPLAZ plasma machine, the rack module is m = 4 mm. Using the formula (1), we calculate the pitch of the rack:

$$p_n = \pi \cdot m_n, \qquad (1)$$

$$p_n = 3,14 \cdot 4 = 12,56,$$

$$p_n = 3,14 \cdot 2,5 = 7,85.$$

Next, a gear rack with module m = 2.5 mm, small pitch s = 7.85 mm, length l1 = 1000 mm, width b = 25 mm, and number of teeth z = 128 from the standard range is selected [9]. We are developing working drawings of the elements of the "gear-rack" pair (Figures 4, 5).

The cutting speed is approximately determined by the expression [1]:

$$V = \frac{150 \cdot K \cdot I}{\delta}, \qquad (2)$$

where, V – cutting speed, mm/min;

I – cutting current, A;

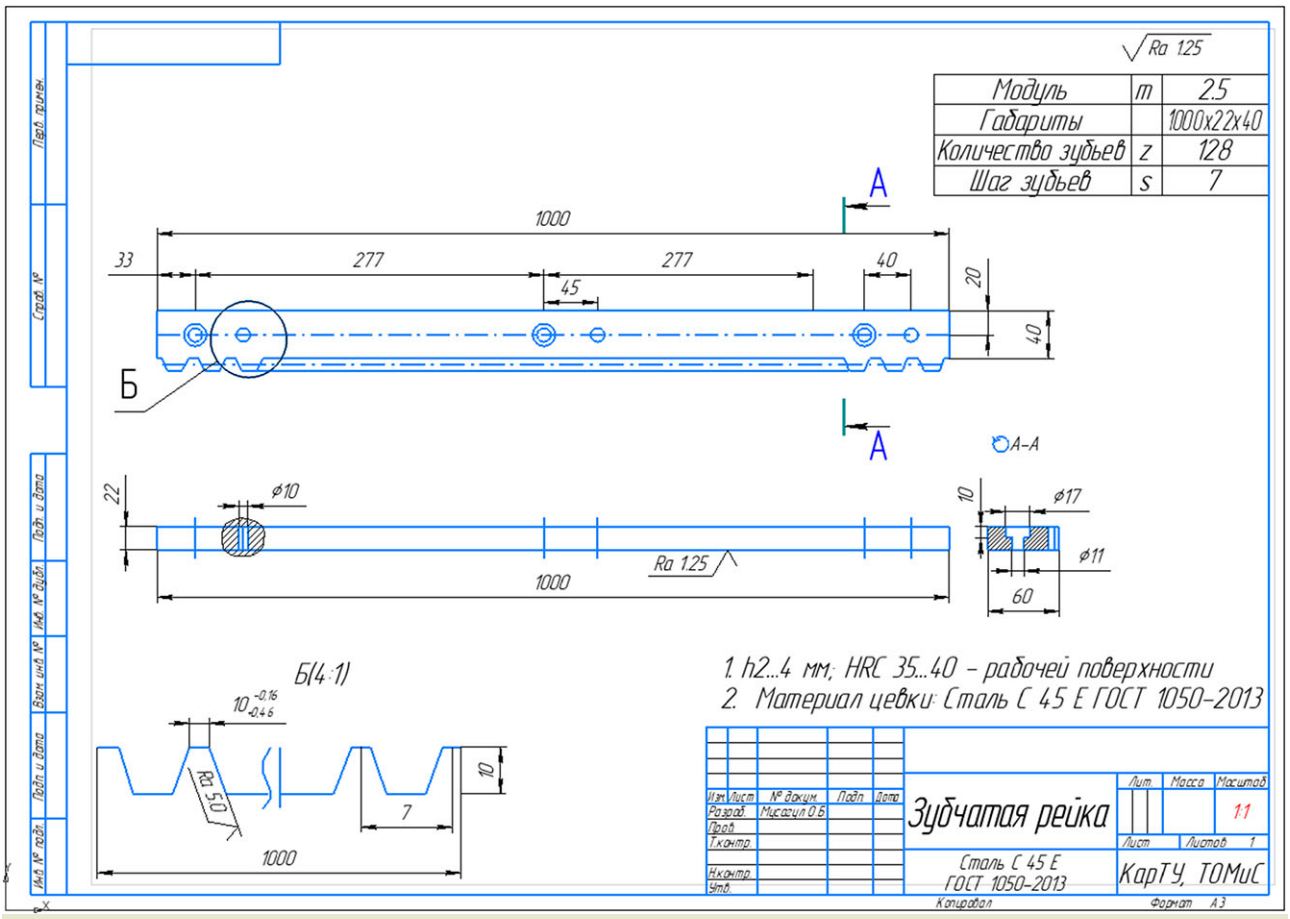


Figure 4 – Gear-rack with module m = 2.5 mm

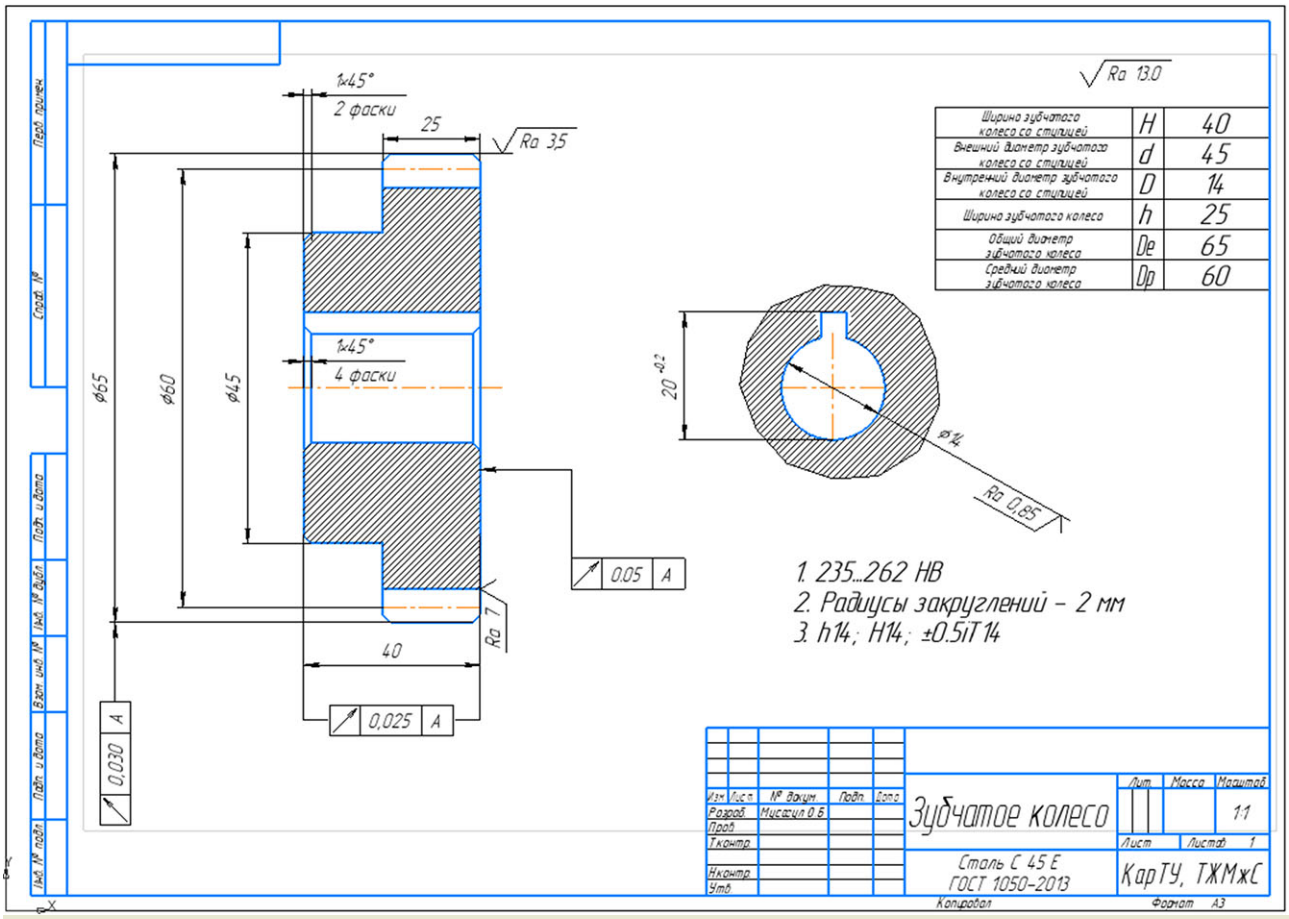


Figure 5 – Gear

δ – thickness of the metal being cut, mm;

K – coefficient taking into account the type of metal being cut: for carbon steels K = 1; for aluminum alloys K = 0.6; for copper alloys K = 0.4; for corrosion-resistant steels K = 0.8.

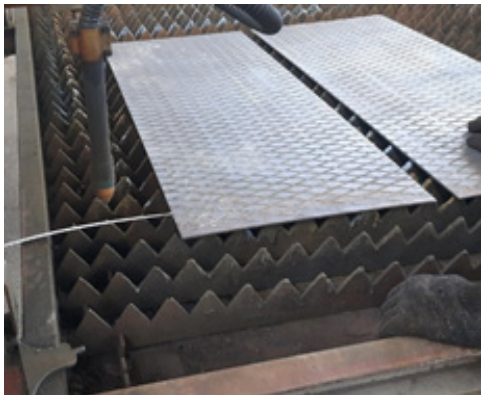
Using the formula (2), we calculate the theoretical cutting speed:

$$V = \frac{150 \cdot 1 \cdot 150}{5} = 4500\text{mm}/\min\,(4{,}5\text{m}/\min).$$

The design of the machine was changed by replacing the "gear-rack" pair with a module m = 4 mm with a pair with a module m = 2.5 mm (Figure 6), and then full-scale tests were carried out, during which batches of sheets N = 5 pieces were cut, made of steel 40, with a thickness of 5 mm. A straight cut of a part measuring 400x600mm (n = 10 pcs) was carried out, as well as a shaped cut (n = 50 pcs) (Figure 7) at a speed of V = 5 m/min.

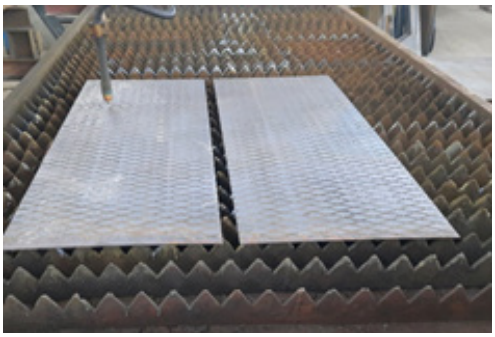
The test showed that the modernized design of the KarPLAZ machine with a module m = 2.5 mm at a speed of V = 5 m/min when cutting structural steel with a thickness of 5 mm satisfies the needs of Classic-B LLP, ensures accurate cutting of the figure, high contour accuracy at sharp corners and edges, narrow tolerance for unevenness of cutting surfaces, the ability to make holes with a diameter of Ø10mm and Ø25mm.

Figure 6 – Gear m=2,5 mm

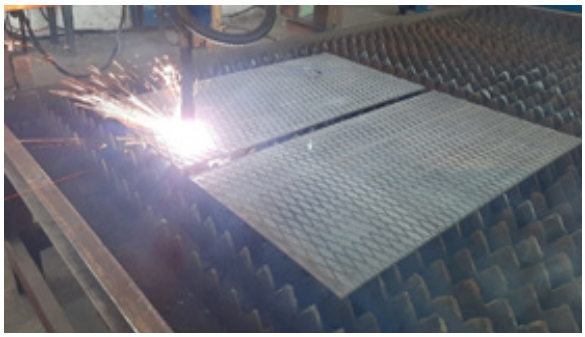


a)

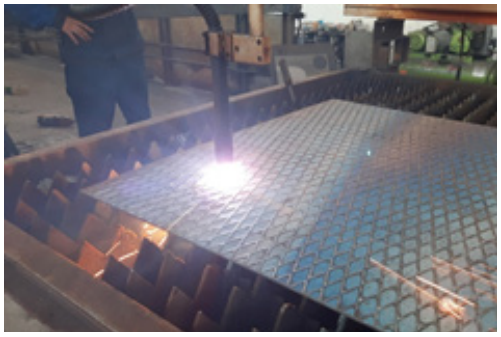
b)



c)

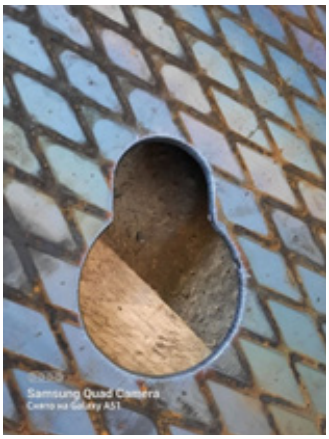


d)



e)

f)



g)

h)

Figure 7 – Tests of the modernized machine:
a) measuring the parallelism between the metal plate and the edge of the table; b) determination of the starting point; c) cutting; d – e) cutting process; f) completed cutting process; g – h) cut out profiles of parts

Conclusions:

1. As a result of the studies conducted on the plasma cutting machine "KarPLAZ", inaccurately cut parts were revealed.

2. When studying the design of the machine and statistical data, we revealed the shortcomings of the existing structures.

3. Based on the analysis of the machine mechanism designs, a node affecting the cutting quality has been identified.

4. The design of the drive unit has been improved by optimizing the gearing parameters.

5. The result of the full-scale experiment confirmed the design and technological solutions adopted during the study.

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«Классик-Б» ЖШС шартындағы «КарПЛАЗ» плазмалық кесу машинасының конструкциясын жетілдіру

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Аңдатпа. *Зерттеудің мақсаты – плазмалық кесу машинасының технологиялық параметрлерін оңтайландыру, кесу сапасын жақсарту (пішінді бөлшектердің кесу дәлдігі, кесу сапасы) арқылы шеберханалық жұмыстардың көлемін азайту (қабыршақтарды, күйіктерді жою), және өндірістегі ақаулардың пайызын азайту. «Классик-Б» ЖШС өндірісіндегі «КарПЛАЗ» плазмалық машинасында кесу кезінде ақаулар анықталды. Станоктың конструкциясы және тетіктермен түйіндердің жұмыс істеу ерекшеліктері анықталды. Тәжірибелік мәліметтерді және машинаның конструкциясын сараптай келе конструкторлық және технологиялық шешімдер қабылданды. Жетек есептелді, жұмысшы сызбалар әзірленді, «тісті дөңгелек-рейка» кинематикалық жұбы алмастырылды және өндірісте эксперимент жүргізілді. Зерттеу жұмыстарының нәтижесінде қабылданған шешімдердің дұрыстығы расталды.*

Кілт сөздер: *жетілдіру, плазмалық кесу машинасы, СББ білдек, плазмамен кесу, қабыршақтар, жетек, тісті рейка, жұмысшы сызбалар, кесу жылдамдығы.*

Модернизация конструкций машины плазменной резки «КарПЛАЗ» в ТОО «Классик-Б»

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Аннотация. *Целью исследования является повышение эффективности машины плазменной резки за счет оптимизации технологических параметров оборудования плазменной резки, повышения качества (точность резки фасонных деталей, качество реза), снижения количества слесарных работ (удаление грата, прижогов) и снижения процента брака при производстве. При резке деталей на плазменной машине «КарПЛАЗ» в ТОО «Классик-Б» были выявлены неточности. Изучена конструкция и особенности работы деталей и узлов станка. Анализируя экспериментальные данные и конструкцию машины, были приняты конструкторские и технологические решения. Проведен расчет привода, разработаны рабочие чертежи, произведена замена кинематической пары «зубчатое колесо – рейка», и натурный эксперимент. Результаты исследовательской работы подтвердили правильность принятых технических решений.*

Ключевые слова: *модернизация, машина плазменной резки, станки с ЧПУ, плазменная резка, грат, привод, зубчатая рейка, рабочие чертежи, скорость резки.*

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