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Development of the Manufacturing Technology of the "Bolt Internal Component" of the "Sight Assembly" for Firearms

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Abstract. *This article investigates the manufacturing technology and quality assessment of an internal locking component used as a precision mechanical element. The study focuses on the structural and technological features of the component, material and blank selection, machining route development, quality control stages, and mathematical calculation of machining parameters. The main objective is to justify a systematic manufacturing approach that ensures dimensional accuracy, surface quality, functional reliability, and production efficiency. The research evaluates key indicators such as dimensional deviation, tolerance range, surface roughness, machining allowance, material utilization coefficient, cutting speed, feed rate, and machining time. The results show that the correct selection of structural steel, the use of a rolled blank, and the sequential organization of rough machining, precision machining, inspection, heat treatment, and final control contribute to improved component quality. The calculated values demonstrate that optimized machining parameters can reduce material and time consumption while improving dimensional stability and surface integrity. The proposed approach may be applied to the production of similar small-sized precision mechanical components.*

Keywords: *internal locking component, precision mechanical component, manufacturing technology, machining parameters, dimensional accuracy, surface roughness, quality control, material utilization coefficient*

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Odlu silahlar üçün "Görmə Quraşdırmasının" "Bolt Daxili Komponentinin" istehsal texnologiyasının inkişafı

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Xülasə. *Bu məqalə dəqiq mexaniki element kimi istifadə olunan daxili kilidləmə komponentinin istehsal texnologiyası və keyfiyyət qiymətləndirilməsini araşdırır. Tədqiqat komponentin struktur və texnoloji xüsusiyyətlərinə, material və ilkin blank seçiminə, emal marşrutunun hazırlanmasına, keyfiyyətə nəzarət mərhələlərinə və emal parametrlərinin riyazi hesablanmasına yönəlib. Əsas məqsəd ölçü dəqiqliyini, səth keyfiyyətini, funksional etibarlılığı və istehsal səmərəliliyini təmin edən sistemli istehsal yanaşmasını əsaslandırmaqdır.*

Tədqiqat ölçü sapması, tolerantlıq aralığı, səth nahamarlığı, emal ehtiyatı, materialdan istifadə əmsalı, kəsmə sürəti, verilmə sürəti və emal vaxtı kimi əsas göstəriciləri qiymətləndirir. Nəticələr göstərir ki, struktur poladın düzgün seçilməsi, prokat blankdan istifadə və kobud emal, dəqiq emal, yoxlama, istilik emalı və son nəzarət mərhələlərinin ardıcıl təşkili komponentin keyfiyyətini artırır. Hesablanmış göstəricilər sübut edir ki, optimallaşdırılmış emal parametrləri material və vaxt sərfini azaldaraq ölçü sabitliyini və səth bütövlüyünü yaxşılaşdıra bilər. Təklif olunan yanaşma oxşar kiçik ölçülü dəqiq mexaniki komponentlərin istehsalında tətbiq oluna bilər.

Açar sözlər: *daxili kilidləmə komponenti, dəqiq mexaniki komponent, istehsal texnologiyası, emal parametrləri, ölçü dəqiqliyi, səth nahamarlığı, keyfiyyətə nəzarət, materialdan istifadə əmsalı*

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Introduction

In modern manufacturing technology, the production of small-sized precision mechanical components is a key factor affecting functional reliability, service life, and product quality. The manufacturing of an internal locking component is therefore not limited to conventional machining; it requires the coordinated selection of material, blank type, machining sequence, dimensional accuracy, surface quality, and quality control procedures (Groover, 2020; Kalpakjian & Schmid, 2014). Since the internal locking component works in mechanical contact with adjacent elements, its dimensional stability, surface quality, and geometrical accuracy are particularly important. Dimensional deviations, excessive surface roughness, and improper machining sequences may reduce assembly compatibility, increase friction and wear, and negatively affect operational reliability. Therefore, the development of a scientifically justified manufacturing technology for such components is a relevant issue in precision engineering (Klocke, 2011; Özdemir & Kaya, 2021).

Efficient manufacturing requires proper blank selection, a systematic machining route, suitable machine tools and cutting instruments, and staged inspection procedures. This approach helps achieve the required technical characteristics while reducing material consumption, machining time, and production costs (Davim, 2013; Sharma, 2014). The aim of this study is to analyze the manufacturing technology of the internal locking component, justify the material and blank selection, determine the machining sequence, and evaluate the main quality indicators. Dimensional accuracy, tolerance range, surface roughness, machining allowance, quality control, and process efficiency are used as the main evaluation criteria.

Research

Structural and Technological Characteristics of the Component. The internal locking component is a small-sized precision mechanical element that requires high dimensional accuracy and structural stability. It ensures proper positioning and interaction of adjacent parts within the mechanism, thereby supporting functional compatibility and structural integrity (Groover, 2020; Boothroyd et al., 2011). Structurally, the component may include reference surfaces, joining zones, threaded or seating surfaces, radius transitions, and contact regions. These surfaces directly affect operational accuracy; therefore, machining sequence and inspection methods must be planned systematically. Excessive dimensional deviations or surface roughness in contact areas may increase friction, accelerate wear, and reduce reliability (Kalpakjian & Schmid, 2014; Özdemir & Kaya, 2021). The main technological objective is to ensure dimensional accuracy, geometrical stability, and required surface quality. For this reason, machining should proceed from reference surface formation to main dimensional processing and final precision finishing, which helps reduce accumulated machining errors (Klocke, 2011; Davim, 2013).

The dimensional deviation of the component may be expressed as:

$$\Delta = \mid D_n - D_f \mid \qquad (1)$$

where D_n is the nominal dimension and D_f is the actual measured dimension of the component.

The dimensional accuracy condition is satisfied when the deviation remains within the allowable tolerance range:

$$\Delta \leq T \qquad (2)$$

where T represents the permissible tolerance value.

Surface quality, which significantly affects friction and wear characteristics, may be approximately evaluated by the arithmetic surface roughness parameter:

$$R_a = \frac{1}{n}\sum_{i=1}^{n} \mid y_i \mid \qquad (3)$$

where R_a is the average surface roughness value and y_i represents the profile deviation measured along the surface.

Justification of Material and Blank Selection. Material and blank selection is essential for ensuring the reliability, dimensional stability, and service life of the internal locking component. Since the component is exposed to mechanical loads, friction, vibration, and wear, the selected material should provide strength, hardness, wear resistance, machinability, and operational stability (Kalpakjian & Schmid, 2014; Groover, 2020). Structural steel is suitable for this type of precision component due to its balanced mechanical properties, good machinability, and heat-treatment capability. For the blank, a rolled steel form is considered appropriate because the component has a compact and relatively simple geometry. This choice reduces material loss and simplifies subsequent machining operations (Boothroyd et al., 2011; Klocke, 2011).

The strength condition of the selected material may be expressed as:

$$\sigma = \frac{F}{A} \leq [\sigma] \qquad (4)$$

where σ is the working stress, F is the applied force, A is the cross-sectional area, and $[\sigma]$ is the allowable stress of the material.

The efficiency of material utilization can be evaluated by the material utilization coefficient:

$$\eta = \frac{m_f}{m_b} \cdot 100\% \qquad (5)$$

where η is the material utilization coefficient, m_f is the mass of the finished component, and m_b is the mass of the initial blank.

Thus, the material and blank selection should be based not only on mechanical strength requirements, but also on machinability, heat-treatment suitability, material utilization, and overall production efficiency.

Development of the Machining Route. The machining route for the internal locking component is developed according to its structural features, selected material, blank type, and required dimensional accuracy. Its main purpose is to organize the transition from blank to finished component in a systematic and quality-oriented manner (Groover, 2020; Kalpakjian & Schmid, 2014). The process begins with initial inspection of the material grade, blank dimensions, and technical documentation. Then, rough machining is performed to remove excess material and form reference surfaces. In the next stage, semi-finishing and precision machining are applied to achieve the required dimensions, improve surface quality, and form functional surfaces with minimum machining allowance (Klocke, 2011; Davim, 2013).

Additional operations may include bench work, thread machining, radius formation, heat treatment, calibration, and protective coating. Bench work prepares surfaces for further processing, while heat treatment and protective coating improve mechanical properties, corrosion resistance, and operational reliability (Smith, 2016; Çernışov, 2016).

The total machining allowance can be expressed as:

$$Z = Z_r + Z_s + Z_f \tag{6}$$

where Z is the total machining allowance, Z_r is the rough machining allowance, Z_s is the semi-finishing allowance, and Z_f is the finishing allowance.

The total technological error accumulated during machining may be estimated as:

$$\Delta_\Sigma = \Delta_1 + \Delta_2 + \Delta_3 + \cdots + \Delta_n \tag{7}$$

where Δ_Σ is the total machining error and $\Delta_1, \Delta_2, \dots, \Delta_n$ are the errors formed at individual machining stages. In general, the machining route may be organized as follows: initial inspection, blank fixing, rough milling, intermediate inspection, precision milling, bench work, hole and thread machining, heat treatment, calibration, protective coating, and final inspection. This sequence ensures technological continuity and enables the component to meet the required technical specifications (Tlusty, 2000; Məmmədov, 2020).

Evaluation of Quality Indicators. The evaluation of quality indicators is a key stage in determining whether the manufactured internal locking component meets the specified technical requirements. Quality control should not be limited only to final inspection; rather, it must be applied systematically throughout all stages of the manufacturing process. This approach enables the timely detection of dimensional errors, surface defects, and technological inconsistencies (Groover, 2020; Kalpakjian & Schmid, 2014). The main quality indicators include dimensional accuracy, tolerance range, surface roughness, geometrical and positional accuracy, thread conformity, visual surface condition, and functional compatibility. Dimensional accuracy characterizes the conformity of the actual dimensions of the component with the nominal values specified in the technical drawing. Maintaining the required tolerance range ensures reliable assembly and proper interaction with other structural elements (Pahl et al., 2007; Həsənov, 2019).

The tolerance range may be expressed as:

$$T = D_{\max} - D_{\min} \tag{8}$$

where T is the tolerance range, $D_{\max}$ is the upper dimensional limit, and $D_{\min}$ is the lower dimensional limit.

Surface quality is one of the most important indicators affecting the operational reliability of the component. In particular, maintaining surface roughness within the permissible range in contact zones reduces friction and wear intensity. Therefore, surface conditions should be inspected after milling, precision machining, and bench work operations (Özdemir & Kaya, 2021; Smith, 2016).

The dimensional deviation may be determined as:

$$\Delta = | D_n - D_a | \quad (9)$$

where $\Delta$is the dimensional deviation, $D_n$is the nominal dimension, and $D_a$is the actual measured dimension.

During quality control, calipers, micrometers, radius gauges, threaded plug gauges, and visual inspection methods may be used. Initial, intermediate, and final inspections ensure blank conformity, dimensional stability, and compliance of the finished component with technical drawing requirements (Zeynalov, 2022; Aslanov, 2018). In evaluating the technological process, both component quality and manufacturing efficiency are considered. Machining time, material consumption, operation sequence, equipment utilization, and defect probability are accepted as the primary assessment criteria (Rao, 2018; Əliyev, 2021).

Table 1
Summary of Evaluation Results

No.	Evaluation area	Main indicator	Expected result
1	Material selection	Strength and machinability	Increased component durability
2	Blank selection	Material utilization coefficient	Reduced material loss
3	Machining process	Sequence of rough and precision machining	Ensured dimensional accuracy
4	Surface quality	Surface roughness	Reduced friction and wear
5	Quality control system	Initial, intermediate, and final inspection	Timely detection of defects
6	Technological efficiency	Time and labor consumption	Optimized manufacturing process

Mathematical Calculation of Machining Parameters. The proper selection of machining parameters plays an important role in ensuring dimensional accuracy, surface quality, and manufacturing efficiency of the internal locking component. For this purpose, the main technological parameters were calculated for the milling operation (Groover, 2020; Klocke, 2011).

The cutting speed is determined as follows:

$$V = \frac{\pi D n}{1000} \quad (10)$$

where $D = 80$mm is the milling cutter diameter and $n = 400$rpm is the spindle rotational speed.

The feed rate per minute is calculated using the following equation:

$$S_{\min} = S_z \cdot z \cdot n \quad (11)$$

where $S_z = 0.08$mm is the feed per tooth and $z = 8$is the number of cutter teeth.

The machining time is determined by:

$$T = \frac{L}{S_{\min}} \qquad (12)$$

where $L = 120$mm is the machining length.

The material utilization coefficient is calculated as:

$$\eta = \frac{m_f}{m_b} \cdot 100\% \qquad (13)$$

where m_f is the mass of the finished component and m_b is the mass of the initial blank.

The approximate surface roughness may be evaluated by:

$$R_a \approx \frac{f^2}{32r} \qquad (14)$$

where f is the feed and r is the tool nose radius.
The calculated machining parameters are presented in Table 2.

Table 2
Calculated machining parameters

Parameter	Symbol	Value
Milling cutter diameter	D	80 mm
Spindle speed	n	400 rpm
Cutting speed	V	100.5 m/min
Number of cutter teeth	z	8
Feed per tooth	S_z	0.08 mm
Feed rate per minute	$S_{\min}$	256 mm/min
Machining length	L	120 mm
Machining time	T	0.47 min

The obtained results indicate that the selected machining conditions are suitable for achieving the required dimensional accuracy and surface quality of the component.
The comparative assessment of surface quality and dimensional accuracy is presented in Table 3.

Table 3
Comparative evaluation of quality indicators

Indicator	Rough machining	Precision machining
Tolerance	±0.20 mm	±0.02 mm
Surface roughness, R_a	6.3 μm	1.6 μm
Dimensional deviation	High	Low
Surface quality	Medium	High

The technological efficiency indicators of the process are summarized in Table 4.

Table 4
Technological efficiency indicators

Indicator	Value
Material utilization coefficient	82%
Machining time	0.47 min
Number of operations	7
Number of inspection stages	3
Defect probability	Low

The calculations show that the proper selection of technological operations and optimization of machining parameters improve dimensional accuracy and surface quality while reducing material and time consumption (Singh, 2017; Rao, 2018). The obtained results indicate that the optimization of machining parameters improves dimensional accuracy and surface quality while reducing material and time consumption. The graphical representation of the calculated machining parameters and the comparative quality indicators is presented in Figures 1 and 2.

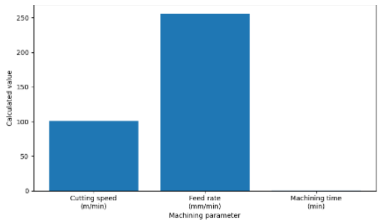

Figure 1
Calculated Machining Parameters

Figure 1 presents the calculated machining parameters used in the milling process of the internal locking component. The graph shows the cutting speed, feed rate, and machining time obtained from the mathematical calculations.

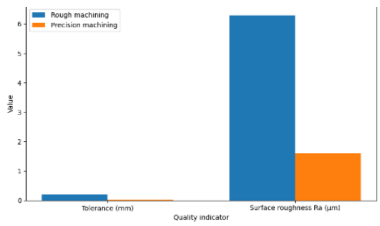

Figure 2
Comparison of Quality Indicators

Figure 2 illustrates the comparison of quality indicators between rough machining and precision machining. The results show that precision machining significantly reduces tolerance deviation and surface roughness, thereby improving dimensional accuracy and surface quality.

Conclusion

The study confirms that the manufacturing quality of an internal locking component depends on the coordinated selection of material, blank type, machining sequence, and quality control methods. Structural steel and rolled blank preparation were found to be suitable for ensuring machinability, strength, dimensional stability, and production efficiency. The developed machining route, including initial inspection, rough milling, precision machining, intermediate control, calibration, and final inspection, provides a systematic basis for achieving the required technical characteristics. The mathematical calculations of cutting speed, feed rate, machining time, material utilization, and surface roughness show that optimized machining parameters positively affect both quality and efficiency. The comparison between rough and precision machining demonstrates a significant improvement in tolerance and surface roughness values after precision processing. Overall, the proposed technological approach reduces machining errors, improves surface quality, increases functional reliability, and can be recommended for similar precision mechanical parts requiring stable dimensional and operational performance.

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