Selection of tools and cutting modes for turning small-sized high-precision parts of micro-wave electronics from beryllium bronze

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Abstract. Beryllium bronze has the property of plasticity after heat treatment, which is a decisive factor when choosing the material of conductors in unpressurized coaxial connectors. The presence of burrs on these parts according to technical requirements is not allowed. When turning details of beryllium bronze, difficult to remove burrs appear. The aim of the study is to select a tool and cutting modes for turning small-sized high-precision parts of microwave electronics from beryllium bronze, in which there are no burrs or their size and quantity are minimal. In this study, empirical methods are used in the form of experimental selection of cutting modes and tools for the purpose of combating burrs, and analytical methods in the form of analysis of the character of burrs using the provisions of the theory of metal cutting, analysis of factors affecting the formation of burrs during machining surface parts. On CNC lathes CITIZEN CINCOM studied typical of this type of production tools ten leading manufacturers of precision cutting tools for turning. As a result of the study, it was not possible to completely exclude the appearance of burrs during machining. The smallest size and the number of burrs were obtained when machining with carbide tools manufactured by Swiss companies Fraisa, Utilis, IFANGER, Applitec. TiAlN coating is well suited for beryllium bronze treatment. When turning with a new tool at low speeds, the number of burrs decreases, their character changes, they become small drop-shaped. The processing modes recommended by the tool manufacturer differ from those selected experimentally. For further use of the selection results, it is necessary to create a database of regulatory and reference information on the types of processing for specific materials, tools, machine tools according to the accuracy criteria, taking into account the minimization of the number and size of burrs.

1.  Introduction
Parts for coaxial radio components, which are external and internal conductors in coaxial transmission lines, are made of certain materials and have strict requirements for surface quality. So, the inner and outer conductors of leaky connectors are made mainly of BrB2 beryllium bronze, since this material has the property of plasticity after heat treatment, which is necessary to obtain a tight connection of parts during assembly. Beryllium bronze case lamellas are easily cramped to connector assemblies. The signal
is transmitted in coaxial radio components over the surface of the parts, in order to create a highly conductive surface layer, a galvanic coating of 2-3 “skin layers” or about 2-3 microns is applied to the parts [1]. The coating can be two-layer or even three-layer, depending on the possibility of direct application of the coating material to the material of the part. The highly conductive layer should be uniform, and the surface of the parts should not have defects that would impair the conductivity of the surface layer during assembly. Therefore, according to technical requirements, sinks, burrs, sharp edges, and the presence of contaminants are not allowed on the surface of these.

When choosing a machining strategy, selecting a tool, and choosing machining modes, the most important factor is minimizing the number and size of burrs. Since removing them is a difficult task and requires considerable time and labor. This study is devoted to the selection of tools and cutting modes for the manufacturing of small-sized high-precision parts of electronic equipment made of beryllium bronze and the creation of the efference guide on the recommended processing modes, tools depending on the material and size of details to meet the requirements of minimizing the number and size of burrs.

2. Materials and research methods
When studying the problem of burrs on parts for microwave electronics, processed on CNC machines, in the framework of this study, from the entire nomenclature of parts processed on CNC machines, we selected parts manufactured on lathes of longitudinal turning with CNC CITI-ZEN CINCOM K16E-VII, CITIZEN CINCOM K16-VI, CITIZEN CINCOM R07-VI (body of rotation) from materials beryllium bronze Wire Brb2 GOST 15834-77, Bar Brb2 GOST 15835-2013.

In this study, analytical and experimental research methods are applied. The experimental methods were carried out in the form of full-scale experiments - this is an experimental selection of cutting modes and tools in which no burrs appear, or the number of burrs and their size are minimal. Analytical studies were performed in the form of analysis of the character of burrs using the provisions of the theory of metal cutting, analysis of factors affecting the formation of burrs during machining of the surface of parts.

The selection of cutting modes and tools in which the number of burrs was minimally carried out on cutting tools from Fraisa (Switzerland), IFANGER (Switzerland), Utilis (Switzerland), Applitec (Switzerland), Seco (Sweden), Sandvik (Sweden), Schunk (Germany), Guhring (Germany), Mitsubishi (Japan), WhizCut (Taiwan), Sharp Tool (China).

The list of tools used in machining on longitudinal turning machines for the manufacture of parts having hard-to-reach internal surfaces of the type Housing made of BrB2 beryllium bronze material for which processing modes were selected:

1. Cutting plate 731R (L) -1.5 H1.5 (right and left direction).
2. Plate for cross turning 744x-1.5-R.
3. Frontal passage plate CCGT 09T301FN-F23.
4. Plate for reverse turning Back turn 743x-1.2.
5. Cutter boring frontal SDG 435 192-R Ø1.92.
6. Grooving boring tool SDS 440 292-R Ø2, 92.
7. Drill centering DRP 442 090 R-C Ø4.
8. Twist drill B570140220 Ø2.2.
9. Mill disk cutting 1101-0.35 40z (80z).
10. End mill E124F-Dc5 0 Ø5.
11. End mill E102F-Dc1 0 Ø1.
12. End mill E102F-Dc1 5 Ø1.5.
13. Twist drill B570140160 Ø1.6.
14. Twist drill 2023-1.05 Ø1.05.

Quality control of parts was carried out under the Instrument Microscope IMC-150x50 and the Microscope stereoscopic pancreatic Altami SM0745, and using a measuring tool:
1. Micrometer MK25-1 GOST 6507-90.
2. The indicator ICh-10 GOST 577-68.
3. A support for the PA9370570 indicator.
4. Tip indicator PA9372294.
5. Gauge plug Ø2.67 H10 (+0.04) RA9600745.
6. Gauge plug Ø2.52 N9 (+0.025) RA9600745.
7. Gauge plug Ø1.7 (+ 0.02 / + 0.07) RA9600745.
8. Gauge plug Ø2.25 ((+ 0.02 / + 0.07) RA9600745.
9. Gauge plug Ø1.6 (+ 0.02 / + 0.07) RA9600745.
10. Gauge plug Ø1.1 (+ 0.02 / + 0.07) RA9600745.
11. Gauge plug Ø1.25 (+ 0.02 / + 0.07) RA9600745.
12. Gauge plug Ø2.8 (+ 0.02 / + 0.04) RA9600745.
13. Gauge plug Ø2.37 H9 RA9600745.
14. Caliber bracket Ø2.9 h9 (-0.025) RA9600751.
15. Caliber bracket Ø0.35 (+0.06) RA9600750.
16. Watch GOST 23350-98.
17. Samples of roughness parameters for ISO TESA turning.
18. Magnifier LPZ-6x TUZ-3 1809-84.

An analysis of the nature and size of the burrs was carried out under the scanning electron microscope SEM Multi Beam System JEOL JIB-Z4500.

3. Research results and discussion
Beryllium bronze BrB2 according to GOST 18175-78 has characteristic properties - high strength and wear resistance, high spring properties, good anti-friction properties, average electrical conductivity and thermal conductivity, very good deformability in the hardened state, and is intended for the manufacture of springs, spring parts for critical purposes, wear-resistant parts of all kinds, non-sparking tools [2]. It is the property of very good deformability in the hardened state that is decisive when choosing a material for the manufacture of external conductors, since during assembly it is necessary to ensure tight compression of the lamellas of the case.

Thermally hardened BrB2 copper-beryllium alloy becomes more durable, elastic and ductile. Initially, it is brought into a soft state by heating to 760-780 °C, and then subjected to aging in water at a temperature of 310-330 °C for 3 hours. Upon heating and subsequent cooling of the alloy to room temperature, beryllium dissolves in copper to form a saturated solid solution. Subsequent hardening leads to its deposition, as a result of which BrB2 bronze acquires high hardness up to 350 - 400 HB.

Due to their high strength and hardness, BrB2 beryllium bronze is a hard-to-work material: when cutting along the entire surface, there are solid burrs that are firmly mated to the surface, and when removed by a scraper, there is a high probability of gouging, and other mechanical removal methods are also more complicated and take longer. This leads to an increase in the complexity and production time of parts. In this regard, the selection of tools and cutting modes in order to minimize the size and number of burrs is relevant.

CAM-system CAMWorks allows you to produce:
- selection of processing strategies and setting parameters of selected strategies;
- selection of machined and bounding surfaces on the model of the product (details) [3];
- formation of the tool path taking into account machining strategies, selected surfaces, cutting tool, automatic control of notches and optimization of the tool path taking into account the current state of the workpiece;
- automatic tracking of changes made to the model of the product (details) [3];
- the use of standard technological templates for processing and forming the tool path with a partial change of parameters to obtain similar parts [3-6].

So, at the stage of creating a control program for processing a part on CNC longitudinal turning machines, the problem arises of the need to select the types and parameters of processing depending on the material being processed, the tool used, the required surface quality, of the volume of material being
removed. When choosing a sequence and the number of passes, choosing the selection of cutting modes, such as feed, the number of spindle revolutions, depth of cut must be considered:

- shavings should not be clogged into the tool;
- it is necessary as quickly as possible to ensure exit to the specified design dimensions and to control the size of the allowances obtained at each stage of processing;
- the quality of the treated surface must meet the requirements of the drawing;
- it is necessary to ensure the planned wear resistance of the tool.

If chips quickly become clogged, then it is necessary to reduce the feed, or increase the number of passes, or use intermittent turning. The new CITIZEN machines have a wave turning function, due to which chips are less clogged and less burrs occur.

The surface roughness is provided by the selection of cutting speed and allowances. At low speeds and small allowances, the surface quality is higher, the number and size of burrs are reduced. However, at low loads, swift and crushing occur, which negatively affects the dimensional stability and wear resistance of the tool.

Tool manufacturers attach tables to it with recommended ranges or specific values of processing modes for various materials on different equipment, however they are focused only on ensuring tool wear resistance and the ranges of recommended modes can be quite wide, and the selection of real processing modes for a particular part is multifactorial, requires the establishment of specific parameter values that differ from those recommended. In this regard, the information from these tables is not applicable in practice and is refined by conducting field experiments. Figure 1 shows a fragment of the Cutting specification table from the Utilis Multidec Swiss Type Tools catalog with recommended processing parameters for various materials, in particular for bronze when using a tool with UHM 20 HX cutting material. The recommended cutting speed range \( V_c \) is from 5000 to 18000 mm / s. Figure 2 shows that for machining bronze with a tool for drilling and longitudinal turning SDG in diameter of 2.9 mm, the recommended feed values \( f \) is in the range from 0.015 mm / rev to 0.035 mm / rev. It has been experimentally established that when setting the cutting speed \( V_c = 904 \) mm / s, feed \( f = 0.012 \) mm / rev, using the material of the cutting part UHM 20 HX of the tool for drilling and longitudinal turning SDG, the requirements of stability of dimension and ensuring tool wear resistance, and surface quality requirements for subsequent processing are fulfilled. As you can see, the feed value is below the minimum recommended, and the cutting speed is in the middle of the recommended range.

![Figure 1](image)

**Figure 1.** Recommended processing parameters for various materials from the Utilis Multidec Swiss Type Tools catalog, Cutting specification table [7].
Figure 2. Recommended processing parameters for various materials from Utilis Multidec Swiss Type Tools catalog, Feed and depth of cut table for SDG tools for drilling and longitudinal turning [7].

Figure 3 shows that for bronze processing with a 2.9 mm diameter SDS tool, the recommended feed values \( f \) is in the range from 0.007 mm / rev to 0.020 mm / rev. It was experimentally established that when setting the cutting speed \( V_c = 5501 \text{ mm / s} \), feed \( f = 0.010 \text{ mm / rev} \) using the material of the cutting part UHM 20 HX of the tool for boring the SDS groove, the requirements for dimensional stability, ensuring tool wear and surface quality requirements are fulfilled. The number, size and size of burrs are minimal. As you can see, the feed and speed values are in the middle of the recommended range.

Figure 3. Recommended processing parameters for various materials from Utilis Multidec Swiss Type Tools catalog, Feed and depth of cut table for SDS tools [7].

Figure 4 shows that for bronze processing with a B57014 spiral drill with a diameter of 1.6 mm, the recommended feed \( f \) is 0.025 mm / rev, the cutting speed \( V_c \) is 3000 mm / min, the number of revolutions \( n \) is 5970 min\(^{-1}\). And for processing with a drill with a diameter of 2.2 mm, recommended feed \( f = 0.034 \text{ mm / rev} \) with a cutting speed \( V_c \) equal to 4000 mm / min. The number of revolutions \( n \) is equal to 5785 min\(^{-1}\). It was established experimentally that when setting the cut-ting speed \( V_c = 3044 \text{ mm / min} \), feed \( f = 0.020 \text{ mm / rev} \). The number of revolutions \( n = 6000 \text{ min}^{-1} \) for drilling with a drill bit B57014 with a diameter of 1.6 mm. The requirements for dimensional stability, ensuring tool wear and surface quality requirements are fulfilled, the number and the size of burrs are minimal. For drilling with a twist drill B57014 with a diameter of 2.2 mm, feed values \( f = 0.027 \text{ mm / rev} \) were selected with a cutting speed \( V_c \) equal to 3454 mm / min, the number of revolutions \( n \) equal to 5000 min\(^{-1}\). As can be seen, the feed and speed values are close to recommended, but small reducing these parameters reduces the size and number of burrs while maintaining the remaining requirements.
When selecting cutting tools, the best quality of surface treatment, proceeding from the requirements of ensuring dimensional stability, tool wear and surface quality, minimum number and size of burrs, showed carbide tools manufactured by Swiss companies Fraisa, Utilis, IFANGER, Applitec. The TiAlN titanium-aluminum-nitride coating, which is characterized by high heat resistance (up to 900 degrees) and corrosion resistance, is well suited for drilling durable BrB2 materials with or without cooling. The results of selecting a cutting tool and cutting conditions for a small-sized part from BrB2 material with the aim of combating burrs are presented in table 1.

In a number of cases, when establishing the boundary values of the ranges recommended by the manufacturer, it was noted that when setting the minimum feed and maximum cutting speed, the cutters overheat. When setting the minimum feed and speed, the necessary chip-breaking space and chip removal are not provided, and at maximum feed and speed large shavings form and the tool burns. Combustion occurs due to overheating, which can be caused by increased friction due to tool wear, poor chip heat dissipation due to thinning, operation with low feeds or with the feed turned off [9].

An analysis of the change in the nature and the number of burrs on beryllium bronze parts during the selection of cutting tools showed that when the speed and depth of cut are reduced to values acceptable to satisfy the above requirements and the use of a new cutting tool manufactured by Swiss companies Utilis, Fraisa, IFANGER, Applitec the number and the size of burrs are minimal. At higher cutting speeds with a small feed, burrs randomly occur over the entire surface and become long, stretching, with a reinforced base. Their number increases and the base area reaches 0.1 mm. This indicates that the material heats up, its fluidity increases and it splashes onto the surface in the form of burrs. Tool wear increases friction, and as a result, material heating increases. When turning with a new tool at low speeds, the number of burrs decreases, their character changes, they become small drop-shaped. It was not possible to completely eliminate the appearance of burrs on parts made of BrB2 material by selecting a cutting tool and cutting modes.

To solve the problem of selecting the processing regimes by experimental methods, it is proposed to use standard technological templates for processing and forming a tool path with a partial change in parameters to obtain similar details. To create standard technological templates for processing and forming the tool path with a partial change in the parameters for obtaining such parts, it is necessary to create a database of normative and reference information on the types of processing for specific materials, tools, machines for accuracy standards taking into account the minimization of the number and size of burrs.

| $d_1$ [mm] | $v_c$ [m/min] | $f$ [mm] | $n$ [min$^{-1}$] | $v_f$ [mm/min] | $Q$ [cm$^2$/min] | $T$ [sek] |
|------------|---------------|----------|-----------------|-----------------|-----------------|--------|
| 1.10       | 30            | 0.017    | 8680            | 150             | 0.0             | 2.2    |
| 1.20       | 30            | 0.018    | 7960            | 145             | 0.0             | 2.5    |
| 1.30       | 30            | 0.020    | 7345            | 145             | 0.0             | 2.7    |
| 1.40       | 30            | 0.022    | 6820            | 150             | 0.0             | 2.8    |
| 1.50       | 30            | 0.023    | 6365            | 145             | 0.5             | 3.1    |
| 1.60       | 30            | 0.025    | 5970            | 150             | 0.5             | 3.2    |
| 1.70       | 30            | 0.026    | 5615            | 145             | 0.5             | 3.6    |
| 1.80       | 30            | 0.028    | 5305            | 150             | 0.5             | 4.0    |
| 1.90       | 30            | 0.029    | 5025            | 145             | 0.5             |        |

**Figure 4.** Recommended processing parameters for solid materials from Fraisa catalog for twist drills B57014 [8].
Table 1. Cutting tools and machining modes for KAPD.724212.030 housing (-01, -02)

| Name | F - feed, mm/min | n – number of spindle revolution | Cutting depth, mm | Number of moves | Comment |
|------|------------------|---------------------------------|-------------------|----------------|---------|
| 1. Cutting plate 731R-1.5 TIALN | 0.01 | 8000 | 1.5 | 1 | Cut Ø5 |
| 2. Frontal passage plate CCGT 09T301FIN-F23 CTR2120 | 0.02 | 8000 | 0.25 | 2 | Butt trimming Ø5. Groove Ø5 → Ø4.9 |
| 3. Plate for cross turning 744-1.0-R TIALN | 0.03 | 6000 | 0.5 | 2 | Ø5 → Ø3 |
| 4. Cutter boring frontal SDG 435 192-R Ø1,92 UHM 20 HX | 0.012 | 1500 | 0.3 | 1 | Groove width Ø1.92 |
| 5. Grooving boring tool SDS 440 292-R Ø2, 92 UHM 20 HX | 0.01 | 6000 | 0.3 | 2 | 0.5 to Ø3.5 0.3 to Ø2.2 Ø2.92 |
| 6. Drill centering DRP 442 090 R-C Ø4 UHM 20 HX | 0.017 | 5500 | 1.25 | 1 | Deep centering 1.25 Ø4 |
| 7. Twist drill B570140220 Ø2, 2 TIALN | 0.027 | 5000 | 0.5 | 12 / 2 Intermittent turning | Ø2.2 0.2 The number of interruptions 12 is due to the need for chip removal |
| 8. Mill disk cutting 1101-0.35 x 40z | 0.4 | 5000 | 0.4 | 1 | Lamella cross cutting |
| 9. End mill E124F-Dc5 0 Ø5 TIALN | 0.083 | 6000 | 0.3 | 1 | Ø5 → Ø4.7 |
| 10. End mill E102F-Dc1 0 Ø1 TIALN | 0.012 | 5000 | 0.1 | 1 | Ø1 → 1.1 ÷ Ø 1.7 |
| 11. End mill E102F-Dc1 5 Ø1.5 TIALN | 0.003 | 6000 | 0.2 | 3 | Ø1 → Ø1.25 Ø1.6 → Ø2.25 |
| 12. Twist drill B570140160 Ø1.6 MG10 | 0.003 | 6000 | 1 | Ø1.6 |
| 13. Twist drill 2023-1.05 Ø1.05 TIALN | 0.003 | 6000 | 1 | Ø1.05 |
| 14. Plate for reverse turning Back turn 743x-1.2 TIALN | 0.005 | 5000 | 0.1 | 1 | Ø2.9 ÷ Ø3.25 |

4. Conclusion
The selection of tools and cutting modes for turning small-sized high-precision parts of radio electronic equipment made of beryllium bronze, manufactured on CNC lathes, showed that beryllium bronze is a difficult to process material. And it was not possible to completely exclude the appearance of burrs during machining.

The best quality of surface treatment, based on the requirements of ensuring dimensional stability, tool wear and surface quality, minimum number and size of burrs, was shown by carbide tools manufactured by Swiss companies Fraisa, Utilis, IFANGER, Applitec. TiAlN titanium-aluminum-nitrite coating, characterized by high heat resistance (up to 900 degrees) and corrosion resistance, is well suited for drilling durable materials like BrB2. When turning with a new tool at low speeds, the number of burrs decreases, their character changes, they become small drop-shaped. The processing modes recommended by the tool manufacturer differ from those selected experimentally.
For further use of the selection results, it is necessary to create a database of normative and reference information on the types of processing for specific materials, tools, machines for accuracy standards, taking into account minimizing the number and size of burrs.

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