A Special Tool for Making a Detail of the T-groove

Josef Sedlak, Radek Oprsal, Ales Polzer, Ales Jaros, Josef Chladil
Department of Machining Technology, Institute of Manufacturing Technology, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, Brno 616 69, Czech Republic. E-mail: sedlak@fme.vutbr.cz, 152986@vutbr.cz, polzer@fme.vutbr.cz, jaros.a@fme.vutbr.cz, chladil@fme.vutbr.cz

The paper deals with the design of a special machining tool for efficient production of detail on the T-groove of the clamping part. The introductory part of the paper is focused on introducing the Czech company. The practical part of the paper deals with the analysis of the existing state of machining of the clamping body and of the production of the T-groove detail and proposes an innovative solution in the form of more efficient machining process (partial production modification), which consists in the development and production of a special tool with replaceable inserts. The main reason for this partial modification is a significant reduction in unit machine time in the production of the T-groove detail on clamp body parts. Part of the contribution is in the process of streamlining the innovation made in the form of changes to the manufacturing process and the design of the cutting conditions required to produce the T-groove detail on the clamp body parts. The contribution is completed by a technical and economic evaluation, which is related to the analysis and comparison of both proposed production variants in terms of machine times, tool consumption / replaceable inserts and total production costs for the T-groove detail production on the clamp body parts.

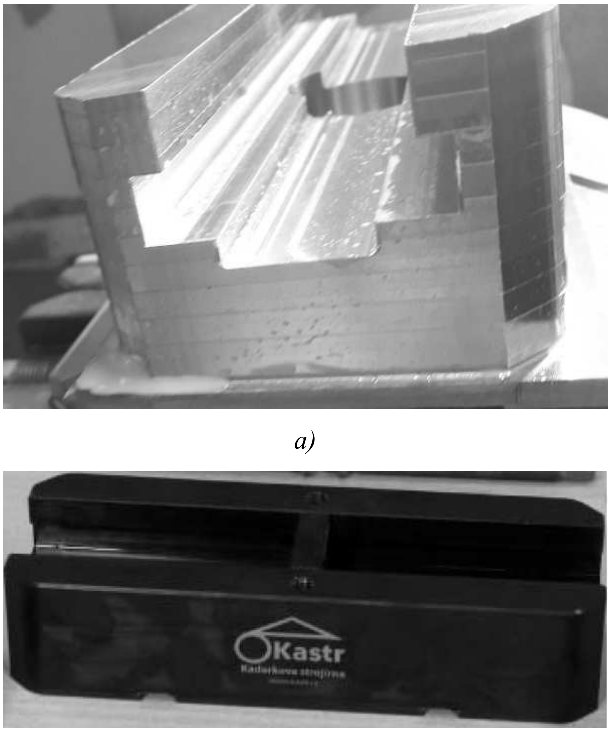
Keywords: Special Machining Tool, Production Efficiency, Detail of T-groove, Milling Technology, Innovation, Production Process

1 Introduction

The paper deals with the serial production of the component of the clamping body at Czech company. It is a small family business located in the village (Rozhraní,) which was founded in 1992. This company specializes mainly in custom production. In 2000, a construction department with AutoCAD Inventor and GibbsCAM software was built here, allowing designers to design their own products and produce them directly in the company. One of its own products is the central clamp KASTR CU-T 77, part of which is the production of the body of the clamp, respectively the detail of the T-groove, whose fabrication is solved in the following paper [1, 2].

2 Clamping Body

This is the main part of the KASTR CU-T 77 central clamp with a total length of 210 mm, 77 mm wide and 47 mm high (see Fig. 1). The clamping body includes a T-groove for guiding the jaws, guide grooves and a hole for pressing the centering pin, which allows easy adjustment of the clamp so that it is possible to clamp the two components at once. The problematic location of the clamping body is machining the T-groove detail by Iscar's monolith carbide milling cutter, which is performed at the Okuma MB-66 VB milling machining center. The disadvantage of this tool is mainly the small width of the shot, but also the change in dimensions when the tool is sharpened after dulling. In order to sharpen the tool and subsequently reduce it to a new value, it is necessary to adjust the production program to achieve the required dimensional accuracy. The material of the clamping body is structural steel 16 343 [1, 2].



a)

b)

Fig. 1 *a) Machining tool holder at Okuma MB-66 VB milling centre, b) The finished body of the clamp [1, 2]*

3 Original Cutting Tool

Machining T-groove detail is performed on the milling centre Okuma MB-66 VB using solid carbide cutters from Iscar. In this operation, the component is clamped into the KASTR CU-T central clamp [1].

3.1 Solid Carbide Milling Cutter

The cutting tool originally used for machining the T-groove detail is Iscar SD D32-8.0-R0.4-SP15 IC908. The cutting tool is designed for cutting a T-groove detail with a maximum depth of 7.75 mm. The cutting part is made of sintered carbide coated with TiAlN coating. The cutting tool is suitable for machining steel, stainless steel, cast iron and hard materials. Further parameters are given in Tab. 1 [1, 3, 4].

Tab. 1 *Technical parameters of Iscar SD D32-8.0-R0.4-SP15 cutting tool IC908 [1, 3, 4]*

Tool diameter	31.250 [mm]
Width of the tool	8 [mm]
Number of blades	8 [-]
Rounding the tip	0.4 [mm]

The SD-S-A-L100-C16-SP15 shank is made of steel to clamp the cutting tool. The shank is clamped in the machine spindle collet. For more information on the shank, see Tab. 2. The original monolithic cutting tool mounted on the shank is shown in Fig. 2 [1].

Tab. 2 *Technical Specifications of SD S-A-L100-C16-SP15 [1, 3, 4]*

Clamping dimension	M5 x 0,5
Diameter	16 [mm]
Length	100 [mm]
Shape of the stopwatch	ring
Measurement system	metric

Fig. 2 *Original cutting tool for machining the T-groove detail profile [1, 3]*

4 Requirement for Innovation

The main reasons for the innovation of the chuck body component are the small width of the monolithic carbide cutter and the dimension of the cutting tool after sharpening. Each monolith cutter can be sharpened and coated up to five times. However, after sharpening, the dimensions of the cutting tool change to a previously undetectable value. This dimensional change is then negatively reflected during production, and it is therefore necessary to correct this change directly in the machine's production program [1].

Due to the small width of the cutting tool, six passes are required to rough the T-groove detail and to complete four passes. Also due to the total length of the 210 mm clamping body, its machining is time-consuming [1].

5 Proposal for a New Cutting Tool

The new cutting tool (see Fig. 3), manufactured by Czech company, should take the place of the existing Iscar SD D32-8.0-R0.4-SP15 IC908 cutting tool. In comparison with it, it should have the following benefits [1]:

- shorter machining times, thanks to the larger cutting tool width,
- improved cutting production conditions that allow for more firm clamping through the centre of the cutting tool,
- eliminating the need for sharpening the cutting tool after dulling, thanks to the use of indexable inserts,
- lower purchase price of the indexable inserts than the original cutting tool.

Fig. 3 *New cutting tool for machining the T-groove detail [1]*

5.1 New Cutting Tool Material

The new cutting tool is made of chrome-molybdenum structural steel ČSN 15 142.6. It is a material suitable for finishing and surface hardening, which is used for the production of heavy-duty machine parts and road vehicles (mainly shafts and couplings where it is necessary to provide high strength at the same time with higher toughness). The properties of steel 15 142 are shown in Tab. 3 [1, 5-7].

5.2 Description of the Production of a New Cutting Tool

The production of a new cutting tool took place on three machines. This is a BOMAR Proline 320.280 band saw. ANC, Okuma LB-3000EX and Okuma MU500-VA 5-Axis machining centre [1].

***Tab. 3** Marking, chemical composition, heat treatment and properties of steel ČSN 15 142 [1, 5, 6]*

		Mark				**Standard**	
ČSN		15 142				41 5142	
EN		41CrMo4				86-70	
DIN		41CrMo4				17 212	
C	**Mn**	**Si**	**Cr**	**Ni**	**Mo**	**P**	**S**
0.43	0.71	0.29	1.12	0.28	0.21	0.015	0.015
Normalizing annealing		**Soft annealing**		**Hardening temperature**		**Hardening medium**	
840 up to 880 °C		680 up to 720 °C		820 up to 860 °C		Oil, Water	
Diameter [mm]		**R_e min. [MPa]**		**R_m [MPa]**	**A min. [%]**	**Z min. [%]**	**KV min. [J]**
40 < d ≤ 100		650		900 up to 1100	12	50	35

Dividing the Material

The first operation in the production of a new cutting tool is cutting the blank, which runs on the BOMAR Pro-line 320.280 ANC iron band saw. Here is the material that is imported into the company in the form of three-meter rods for semi-finished products of the required length of 36 mm [1].

Turning Blank

The second operation takes place at the Okuma LB-3000EX Turning Centre. Here, the blank prepared in the previous operation is machined from one side to the other (see Fig. 4). In this operation, the material is clamped in the chuck [1].

***Fig. 4** Semiproduct for machining on turning centre [1]*

Milling of Beds for Indexable Inserts

This operation was performed at the Okuma MU500-VA machining center. Due to the clamping of the blank in the machine with the highest precision, a special clamping device, which is shown in Fig. 5, was made [1].

***Fig. 5** Clamping tool for the blank [1]*

In the clamping tool, the blank was clamped with an internal diameter screw 16H7. Using a dial gauge, the inaccuracy of the clamping with the requirement to position the blank exactly in the axis of rotation was determined. In this way, after the machining, the same distance of the beds for the indexable insert is ensured. If the blank was clamped outside of the axis of rotation, the spacing of the beds could be varied, and the cutting process could cause unwanted vibration of the cutting tool [1].

After machining the new cutting tool to its final form (see Fig. 6), it was necessary to remove all sharp edges and chips that were trapped in the holes. In particular, they were the edges on the bearing surfaces for the indexable insert. Deburring was performed manually at the locksmith workshop [1].

***Fig. 6** Cutting tool after machining according to program O03252 [1]*

The last operation in the production of a new cutting tool was the nitriding that was done in cooperation. After nitriding, a hardness of 600 HV was required to a depth of 0.3 mm [1].

Indexable Inserts

For the new cutting tool, six tangential DGB 212R101

IN2015 inserts were selected, as shown in Fig. 7. The advantage of these inserts is their robustness and storage in the bed where they are clamped behind the center hole by means of a bolt. The insert is characterized by high stability and therefore it is possible to process higher feeds with a greater thickness of the material to be picked. Inserts are suitable for machining cast iron, steel and stainless steels [1, 8-13].

6 Assessment of Original and Innovated Production

According to the Tab. 4 a new cutting tool when compared to the original has larger width. Thanks to this, it is possible to machine the detail of the T-groove on fewer passages. Cutting tools also differ in the way they are clamped. The original cutting tool - the shank cutter is clamped into the collet. In the case of a new cutting tool is a push-milling cutter, which is clamped at the inner diameter of 16H7, which should ensure stable clamping during production, and increases the cutting speed [1, 8-13].

***Fig.** 7 Insert DGM 212R101 [1, 8]*

***Tab.** 4 Comparison of the original and new cutting tool for machining the T-groove detail [1]*

	Original cutting tool SD D32-8.0-R0.4-SP15	New cutting tool New cutting tool at body CU-T 77
Width [mm]	8	11.6
Revolutions [min^{-1}]	1200	1400
Feed [mm.min^{-1}]	400	750
Tool life [min]	170	30
Number of edges [-]	5	4

6.1 The Original Unit Machining Time

Using the original cutting tool is to completely unbalance one side of the profile T-grooves need two crossings, due to the small width of the cutting tool. To ensure the accuracy of all dimensions, three passes are applied to the finishing operation of one side [1, 8-13].

Calculation of the cutting tool path [1, 14-16]:
l = 210 mm, ln = 5 mm, lp = 5 mm, D = 32 mm

$$L = l + l_n + l_p + D = 210 + 5 + 5 + 32 = 252 \text{ [mm]} \quad (1)$$

Where:
l [mm] – the length of the work surface,
ln [mm] – length of inlet,
lp [mm] – length of outlet,
D [mm] – cutter diameter.

Calculation of the unit machining time [1, 14-16]:
v_f = 400 mm.min^{-1} (value provided by company)

$$t_{AS} = \frac{L}{v_f} = \frac{252}{400} = 0.63 \text{ [min]} \quad (2)$$

Tab. 5 shows the unit machine times for roughing and finishing the detail of the T-groove. So it is only times when the cutting tool performs the cutting process (unit machine times). At these times, it is necessary to add the additional machine times that are required to move the cutting tool off the workpiece. These minor machine times were measured directly on the machine during machining. For roughing, tASB = 0.43 min. For finishing, tASB = 0.62 min. The total unit machine time of the T-groove profile is shown in Tab. 6 [1].

Where:
tASB [min] – time needed for tool out-lets.

***Tab.** 5 Unit machine times of original T-groove profile production [1]*

Operation	Operation time [min]
Roughing	4 x 0.63 = 2.52
Finishing	6 x 0.63 = 3.78
Total	6.30

***Tab.** 6 Total unit time of original production [1]*

Operation	Operation time [min]
Roughing	2.52 + 0.43 = 2.95
Finishing	3.78 + 0.62 = 4.40
Total	7.35

6.2 Unit Machining Time of Innovated Production

When using a new cutting tool, only one pass is required for one side of the T-groove profile, which is made possible by its larger width compared to the original monolithic cutting tool. To ensure the required dimensions and surface roughness two passes are selected for the finishing operation of one side [1, 8-13].

Calculation of the cutting tool path [1, 14-16]:

l = 210 mm, ln = 5 mm, lp = 5 mm, D = 42 mm

$$L = l + l_n + l_p + D = 210 + 5 + 5 + 42 = 262 \text{ [mm]} \quad (3)$$

Calculation of the unit machining time [1, 14-16]:
v_f = 750 mm.min^{-1} (value provided by company)

$$t_{AS} = \frac{L}{v_f} = \frac{262}{750} = 0.35 \text{ [min]} \quad (4)$$

***Tab. 7** Unit machine times of innovated T-groove profile production [1]*

Operation	Operation time [min]
Roughing	2 x 0.35 = 0.70
Finishing	4 x 0.35 = 1.40
Total	2.10

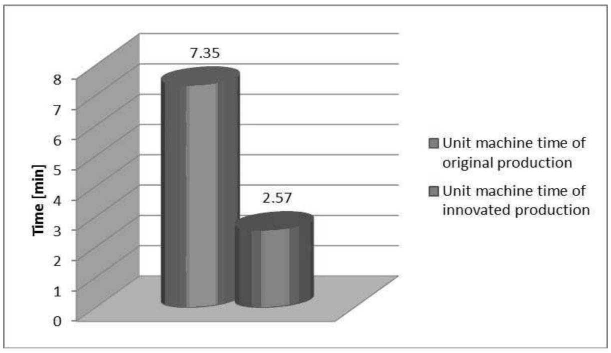


***Fig. 8** Comparison of unit machine times [1]*

Also in this case, Tab. 7 shows only the unit machine times when the cutting tool is engaged. For this reason, it is necessary to add again the secondary machine times that were measured directly in the production. For roughing tASB = 0.16 min. For finishing, tASB = 0.31 min. The total unit machine time is shown in Tab. 8. The comparison of the original and the upgraded unit machine time is shown graphically in Fig. 8 [1].

***Tab. 8** Total unit time of innovated production [1]*

Operation	Operation time [min]
Roughing	0.70 + 0.16 = 0.86
Finishing	1.40 + 0.31 = 1.71
Total	2.57

6.3 The Cost of Buying and Sharpening a Monolithic Cutting Tool

The original cutting tool used for machining the T-groove detail was the SD D32-8.0-R0.4-SP15 IC908 monolith cutter manufactured by Iscar. It is a coated cutting tool with 8 blades. The tool-life of the cutting tool, which was measured directly during production, was determined at Tf = 170 min. After this time, it is necessary to re-grind and coat the cutting tool. Since Czech company does not have equipment that is needed for this technology, it is cooperative coating. The price is 26 EUR for cooperation. After the first sharpening is applied, the cutting tool's tool-life is reduced by 30%. The average number of sharpening before the cutter cutout is a = 5. The cost of buying and maintaining the monolithic cutting tool is shown in Tab. 9 [1, 14-16].

$$S_f = \frac{t_{AS} \cdot N}{T_f + (T_{fo} \cdot a)} \text{ [pcs]} \quad (5)$$

Where:
Sf [pcs] – consumption monolithic mills,
tAS [min] – unit machine time for machining the T-groove detail,
N [pcs] – number of pieces produced per year,
Tf [min] – tool-life of monolithic mill,
Tfo [min] – tool-life of monolithic mill after sharpening,
a [-]– number of tool sharpening.

$$S_f = \frac{6.3 \cdot 300}{170 + (119 \cdot 5)} = 2.47 \Rightarrow 3 \text{ [pcs]}$$

***Tab. 9** The cost of buying and sharpening a monolithic mills [1]*

Tool	SD D32-8.0-R0.4-SP15 IC908
Number of pieces	3 [-]
Purchase price	61 [EUR]
Price for sharpening and coating	26 [EUR]
Number of possible sharpening one tool	5 [-]
Total costs	574 [EUR]

6.4 The Cost of Producing a Innovated Cutting Tool

Material 15 142.6 was chosen to produce a new cutting tool for machining the T-groove detail. The material is imported into the Czech company in the form of three-meter rolled bars Ø45 mm. The bars are then divided into a 36 mm length. The rest of this material is used for further production and therefore the price is only for the required part of the material. To suppress errors in event incorrect machining of a new cutting tool, three pieces of this cutting tool were produced at the same time. During this production there were no problems, so it is possible to include all three innovated cutting tools in production. The price of the required material is shown in Tab. 10 [1].

***Tab. 10** Cost of material [1]*

Costs of semiproduct	0.036 [m]
Number of produced pieces	3 [-]
Price of blank	7.5 [EUR/m]
Total price	0.81 [EUR]

It is necessary to add to the price of the material also the costs associated with machining a new cutting tool, which is carried out on three machines [1]:

- BOMAR band saw,
- Okuma LB3000 EX machining centre,

- Okuma MU500 machining centre.

The cost of machining is determined from the hourly rates of the machines, which also include the cost of the service, see Tab. 11. Since Czech company does not have the necessary equipment for nitriding and blackening parts, these operations are dealt with within the framework of cooperation. The price for the co-operation is 8 EUR. All values required to calculate the costs, together with the total price, are shown in Tab. 11 [1].

Tab. 11 *Cost of manufacturing a innovated cutting tool [1]*

Workplace	Operation	Unit machine time [min]	Hourly rate [EUR/hour]	Price [EUR]
BOMAR Proline	Material dividing	3 · 10	13	6.5
Okuma LB3000 EX	Turning part	3 · 25	20	25
Okuma MU500	Milling part	3 · 30	25	37.5
Cooperation	Blackening and nitriding	-	-	8
Total	-	195	-	77

6.5 Cost for Purchase of Indexable Inserts

Inserts DGM 212R101 IN2015 are used on the new cutting tool for machining the T-groove detail. The purchase price of one piece is 10.5 EUR. However, since only one piece can be ordered, it is necessary to buy an entire pack containing ten of these plates. Their durability, measured during machining at the machining centre, was set at TVBD = 30 min. After this time, cut the cutting edges to dull, so insert should be rotated or replaced. There are four cutting edges on each insert of this type. The cost of purchasing insert is shown in Tab. 12 [1, 14-16].

$$S_{VBD} = \frac{t_{AS} \cdot N}{T_{VBD} \cdot b} \cdot n_{VBD} \,[\text{pcs}] \qquad (6)$$

Where:
SVBD [pcs] – consumption of inserts,
tAS [min] – unit machine time for machining the T-groove detail,
N [pcs] – number of pieces produced per year,
TVBD [min] – insert tool-life,
b [pcs] – number of edges,
nVBD [pcs]– number of inserts at tool.

$$S_{VBD} = \frac{2.1 \cdot 300}{30 \cdot 4} \cdot 6 = 31.5 \Rightarrow 40 \text{ [pcs]}$$

Tab. 12 *Cost to purchase insert [1]*

Name replaceable inserts	DGM 212R101 IN2015
Purchase price	10.5 [EUR/pc]
Quantity required	40 [-]
Total price	420 [EUR]

6.6 Cost Comparison of Cutting Tool

The price of the SD S-A-L100-C16-SP15 shank to clamp the original cutting tool is not included in the cost calculation. Czech company already owns several pieces of these shakers, and because they do not wear during production, there is no need to make new ones. Comparison of prices of both embodiments can be seen in Tab. 13 and Fig. 9. The annual cost of the cutting tool drops by almost 15% [1].

Tab. 13 *Comparison of costs of cutting tools [1]*

Total cost of original cutting tool	574 [EUR]
Total cost of innovated cutting tool	491 [EUR]

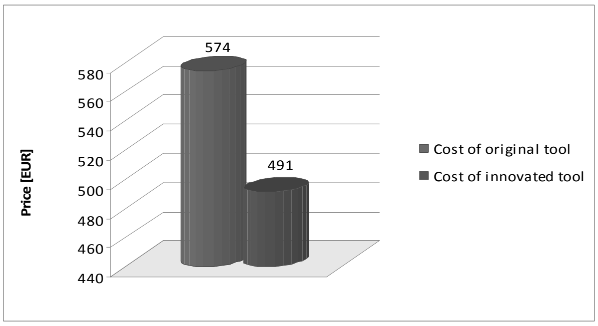


Fig. 9 *Cost Comparison of cutting tools [1]*

6.7 Cost Comparison of T-groove Detail Production Before and After Innovation

For a full cost comparison, it is necessary to take into account the price of cutting tools, inserts, or sharpening, monolithic cutting tool coating, and costs associated with operator and operating the machine. The cost of operating and operating the machine only relates to the machining of the T-groove detail. The difference between the prices of the original and the innovated production is shown in Tab. 14 and Fig. 10 [1].

From the values in Tab. 6 and Tab. 8 it is clear that the largest part of savings is associated with shorter unit machine times. This change is achieved thanks to the increased width of the new special cutting tool. For total T-groove cost savings, see Tab. 14 and Fig. 10 is about 53% [1].

Tab. 14 *Total cost comparison [1]*

	Cost for operator and operation the machine [EUR]	Cost of acquisition and maintenance tools [EUR]	Total cost for T-groove production [EUR]
Original production	1 076.5	574	1 650
Innovated production	377.1	491	868

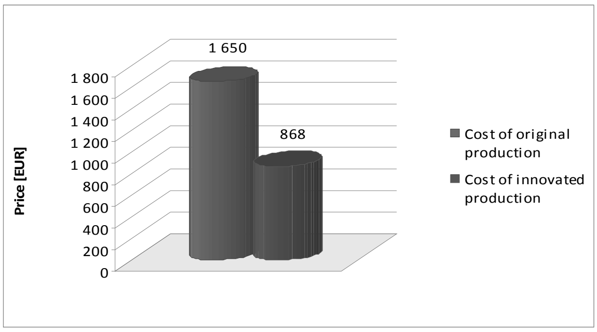


Fig. 10 *Total cost comparison [1]*

7 Conclusion

Improving the production process of the clamping body was achieved by replacing the original monolithic carbide cutting tool from Iscar with a new cutting tool fitted with tangential insert. Due to the increased width of the new cutting tool and the corrected cutting conditions, the production time was reduced by 65%. The use of a new cutting tool also leads to the elimination of the need for complex machine correction after the blades of the cutting tool are dull. In this case, you only have to rotate or replace the insert, thus not changing the dimensions of the new cutting tool.

When comparing original and innovated production, a total cost reduction of about 53% was achieved. This was achieved by shortening production times and reducing the cost of purchasing and maintaining cutting tools. The total annual savings in production is more than 782.5 EUR.

Acknowledgement

This article was supported and co-financed from a specific research FSI-S-16-3717 called "Research in Field of Modern Production Technologies for Specific Applications".

References

[1] OPRŠÁL, R. (2017). Návrh výroby speciálního obráběcího nástroje pro zhotovení detailu T-drážky. Brno 2017. *Diplomová práce*. Vysoké učení technické v Brně, Fakulta strojního inženýrství, Ústav strojírenské technologie. 59 s., 3 přílohy. Vedoucí práce doc. Ing. Josef Sedlák, Ph.D.

[2] Kastr. *O společnosti Kastr* [online]. c2014 [vid. 2017-02-15]. Dostupné z: http://www.kastr.cz/firma.php.

[3] CMT industrial solutions. *Catalogue* [online]. c2017 [vid. 2017-04-01]. Dostupné z: http://www.cmtindustrial.com/catalogue/group/103.

[4] *Iscar* [online]. c2017 [vid. 2017-06-07]. Dostupné z: http://www.iscar.com/Ecatalog/item.aspx?cat=5668130&fnum=3328&mapp=ML&ap%20p=63&GFSTYP=M.

[5] PRECIZ s.r.o. *Převodník materiálů* [online]. c2012 [vid. 2017-03-10]. Dostupné z: http://www.preciz.cz/sluzby/jakosti-dle-norem.

[6] BOLZANO. *Přehled vlastností oceli 42CrMo4* [online]. [vid. 2017-03-10]. Dostupné z: http://www.bolzano.cz/assets/files/TP/MOP_%20Tycova_ocel/EN_10083/MOP_vlastnosti_42CrMo4.pdf.

[7] Ferona. *Materiálové normy* [online]. 2014 - 2017 [vid. 2017-03-10]. Dostupné z: http://www.ferona.cz/cze/katalog/mat_normy.php.

[8] MM Průmyslové spektrum. *Nové trendy produktivního frézování* [online]. c2017 [vid 2017-04-02]. Dostupné z: http://m.mmspektrum.com/clanek/nove-trendy-produktivniho-frezovani.

[9] SEDLAK, J., DRABEK, T., MOURALOVA, K., CHLADIL, J., KOURIL, K. (2015). Machining Issues of Titanium Alloys. *International Journal of Metalcasting,* 2015, Vol. 9, No. 2, p. 41-50. ISSN 1939-5981.

[10] DVORACEK, J., POLZER, A., ZOUHAR, J., SEDLAK, J., PISKA, M. (2010). On the Application of the PVD Hard Coatings for Ball Milling of Shaped Surfaces. *Internet Journal of Engineering and Technology,* 2010, Vol. 1, No. 1, p. 11-18. ISSN 1338-2357.

[11] SEDLAK, J., MUZIKANT, D., VALASEK, P., KOURIL, K. (2017). Production of High Frequency Elliptic and Hyperbolic Optic Mirrors. *Manufacturing TECHNOLOGY,* 2017, Vol. 2017, No. 1, p. 86-94. ISSN 1213-2489.

[12] SEDLAK, J., TROPP, P., CHLADIL, J., OSICKA, K., SLIWKOVA, P. (2015). High-Speed Cutting of Bearing Rings from Material 100Cr6. *Manufacturing TECHNOLOGY,* 2015, Vol. 2015, No. 5, p. 899-908. ISSN 1213-2489.

[13] OSICKA, K., FISEROVA, Z., OTOUPALIK, J. (2015). Influence of cutting tool overhangs at machining of hardened steels. *Manufacturing TECHNOLOGY,* 2015, Vol. 2015, No. 2, p. 188-191. ISSN 1213-2489.

[14] KOCMAN, K., PROKOP, J. (2001). *Technologie obrábění.* 1. vyd. Brno: Akademické nakladatelství CERM s.r.o., 2001. 270 s. ISBN 80-214-1996-2.

[15] HUMÁR, A. (2003). *Technologie I: Technologie obrábění – 1. část* [online]. 2003 [vid. 2017-02-12]. Dostupné z: http://ust.fme.vutbr.cz/obrabeni/opory-save/TI_TO-1cast.pdf4.

[16] ČEP, R. (2008). *Technologie II 2.díl* [online]. 2008 [vid. 2017-02-20]. Dostupné z: http://homel.vsb.cz/~cep77/PDF/skripta_Technologie_II_2dil.pdf.

DOI: 10.21062/ujep/63.2018/a/1213-2489/MT/18/1/117