ABOUT THE ACCURACY OF THE SHAPE AND DIMENSIONS OF THE HYDRAULIC CYLINDERS MACHINED THROUGH THE COMBINED TOOLS FOR SURFACE PLASTIC DEFORMATION

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Abstract: For machining of the deep holes the movable two-blade blocks have mostly widely spreading because of, they have comparatively a simple and technological construction. Because of mistakes in the basing, inaccuracy of the bored hole and in the making of the technological equipment, between the axis of symmetry of the cutting unit and the opening may not coincide with each other as with the axis of rotation of the machine. This is crucial for the accuracy of skiving.
In the present work are established the influence of the position of the movable two-blade blocks on the accuracy of the hole obtained during the period of the established cutting. There is done experimental research of the influence of the axial displacement of the cutting inserts of the movable two-blade block, which have a straight cutting edge to the diametrical dimension of the aperture.
Key words: deepholes, combined tool, skiving, movable two-blade block

1. INTRODUCTION

Processing of internal cylindrical surfaces having a ratio of length to diameter more than $5(L/D > 5)$, or the so-called deep holes, is significantly more labor-intensive than external ones. The share of deep holes in various branches of engineering is significant and continues to expand.In their processing need to overcome the disadvantages in connection with the stability and vibration resistance of the system machine-device-instrument-detail (MDID) and removal of the chips.For their finishing treatment, combined tools for surface plastic deformation (SPD) are used [8,10,11,12,14], which use for the boring part the movable two-blade blocs (MTB) [1,9,16].During processing characterize different periods of MTB operation (primary self-establishment, estab-lished cutting and final self-establishment), which are discussed in detail in [4,5,7,15,18].The behavior of MTB during the different periods of work affects the accuracy and quality of the surfaces received and is, therefore, the subject of research [2,3,6,13,17].The periods of initial self-establishment of MTB with straight and round cutting edges were already analyzed.

The purpose of this work is to examine the behavior of MTB in the period of established cutting when cutting with axially displaced cutting edges.

2. THEORETICAL RESEARCH

During the established cutting period, the shape of the cutting edges of the oppositely spaced in MTB inserts and their axial displacement did not affect the behavior of the block. Conditional, the formation of the holes in machining with MTB during the period of established cutting in the absence and presence of axial displacement of the inserts is shown in Figure 1. In addition, it will be appropriate for the first two prerequisites of those adopted in [4] to be corrected in the following way:

- the symmetry axes of the inner and outer surfaces of the workpiece O_0 coincide with the axis of the holder but do not coincide with the axis of rotation O;
- the central axis of symmetry of the block O_B does not coincide with the axis of rotation O, but the two axes lie in a single line.

This is one of the available options to the axes, which allows to reliably revealing how affects the behavior of MTB on the shape of the resulting opening cross-section.
In addition to those indicated in Figure 1, the following indications are entered:
YOZ - coordinate system rigidly connected to the machine;
Y_iOZ_i-movable coordinate system rigidly coupled to the workpiece rotating about axis O;
P_{2Y_i},P_{2Z_i}- projections of the tip P_1 on the corresponding coordinate axes $Y_i$and Z_i;
$OO_0 = e$ - radial displacement of the axis of symmetry of the workpiece with its axis of rotation;
α_i - a current rotation angle of the workpiece relative to the coordinate system of the machine;
$OP_{2Y_i} = Y_i$,$OP_{2Z_i} = Z_i$- coordinates of dimensioning tips in the systemY_iOZ_i;
$O_B^{'}$and$O_B^{''}$ - coincide with the central axes of symmetry of the block respectively in Figures 1(a) and (b).

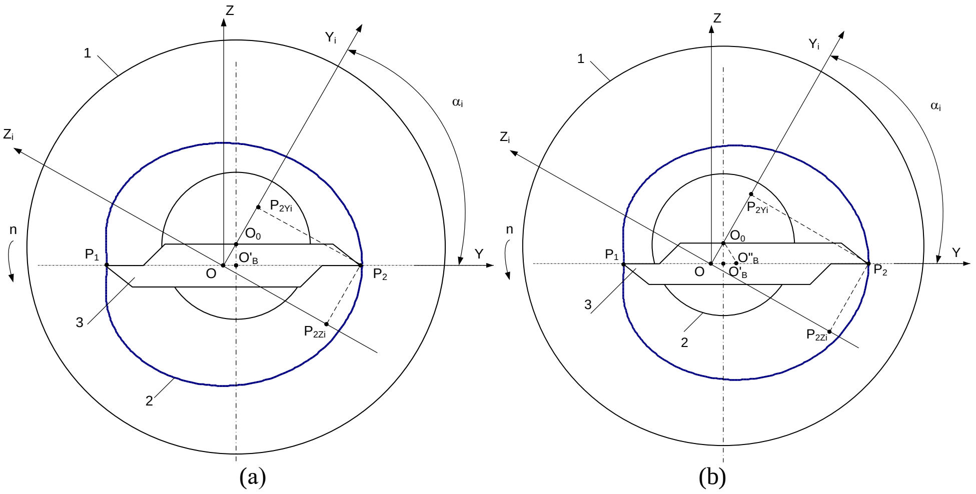

Fig.1. Shaping with a MTB in the period of established cutting at $X_0 = 0$(a) and $X_0 \neq 0$(b)
1 - outer contour of the workpiece; 2 - holder; 3 - movable block

In the absence of axial displacement between the two inserts ($X_0 = 0$), their cutting depths are the same, and both tips P_1 and P_2 are involved in the cutting.The contour described by any of them represents a set of points in the moving coordinate system$Y_i O Z_i$, the coordinates of which depend on the angle of rotationα_i.The equation of this contour (shape of the hole) for one full rotation of the workpiece can be represented by current coordinates of the constituent points having species, Figure 1(a):

$$Y_i = OP_2 . \cos\alpha_i$$
$$Z_i = -OP_2 . \sin\alpha_i \quad (1)$$

where:$OP_2 = OO'_{\text{B}} + O'_{\text{B}}P_2$
it obviously, that (when $\alpha_1 = \alpha_2 = \alpha$)

$$OO'_{\text{B}} = OO_o . \cos\alpha_i = e . \cos\alpha_i$$
$$O'_{\text{B}}P_2 = \frac{P_1P_2}{2} = \frac{L_H}{2} \quad (2)$$

After substitution:

$$Y_i = e . \cos^2\alpha_i + \frac{L_H}{2} . \cos\alpha_i$$
$$Z_i = -e . \sin\alpha_i . \cos\alpha_i - \frac{L_H}{2} . \sin\alpha_i \quad (3)$$

In the case of axial displacement ($X_0 \neq 0$), direct participation in shaping has the second (delay) insert, whereby, as a result of the displacement, it moves radially away from the axis of rotation and the diameter of the machined hole increases with the double size of the displacement. In Figure 1(b) this is segment $O'_{\text{B}}O''_{\text{B}} = \Delta r_i$ and its value is determined by the size of X_0.
In this case the equations are:

$$Y_i = e . cos^2\,\alpha_i + \left(\frac{L_H}{2} + \Delta r_i\right) . cos\,\alpha_i$$
$$Z_i = -e . sin\,\alpha_i . cos\,\alpha_i - \left(\frac{L_H}{2} + \Delta r_i\right) . sin\,\alpha_i \quad (4)$$

At $X_o < X_{lim}$the radial displacementΔr_i is determined at different cutting depths according to the formula:

$$\Delta r_i = \frac{X_o . (L_{\text{H}} - D_o) . \tan\kappa_r}{3f . \tan\kappa_r + 2 . (L_{\text{H}} - D_o)} \quad (5)$$

At$X_o \geq X_{lim}\Delta r_i$for the equal cutting depths is determined by formula:

$$\Delta r_i = \frac{L_{\text{H}} - D_0}{6} \quad (6)$$

Equations (3) and (4) are similar in appearance, and if the Cartesian coordinates are converted into polar, it will be received an equation of the type $\rho = b - a . \cos\varphi$, which is known as the "Pascal snail".This will be the contour of the hole in cross section, formed during this period.
It is obvious that the deviation from coaxiality determined by the position of the central symmetry axis of the block with respect to the axis of the hole of the workpieceO_0.
At $X_0 = 0$, the deviation from coaxiality is equal to the distance $O_o\, O'_{\text{B}}$, - Figure 1(a):

$$O_o\, O'_{\text{B}} = e . \cos\alpha_i \quad (7)$$

The value of the variance changes from 0 (at $\alpha_i = 0^o$) to e(at $\alpha_i = 90^o$).
At $0 < X_0 < X_{lim}$, the deviation from coaxiality is the distance $O_o\, O''_{\text{B}}$ - Figure1(b), which from the rectangular triangle $O_o\, O'_{\text{B}}O''_{\text{B}}$ is:

$$O_o\, O''_{\text{B}} = \sqrt{e^2 . \sin^2\alpha_i + \Delta r_i^2} \quad (8)$$

With increasing$\alpha_i$from $0^0$to 90^0,Δr_i uncreases to $\sqrt{e^2 + \Delta r^2}$.
For $X_0 \geq X_{lim}$, the change of angle α_i from 0^0 to

90^0results in a variation of the deviation of $\frac{\alpha}{3}$ to $\frac{\alpha}{3}.\sqrt{\left(\frac{3.e}{\alpha}\right)^2+1}$, respectively, where α is the cuttingdepth.

The deviation from circularity is due to the change of e which depends from the shifting position of the dimensioning tip $P_2(P_1)$ relative to the axis of the opening O_0 and is dependent on the value of the current angle α_i.

The magnitude Δ of this deviation is not affected by axial displacement X_0:

$$\Delta = O_oP_2 - O'_{\text{В}}P_2 \tag{9}$$

From the rectangular triangle $O_oP_{2Y_i}P_2$:

$$O_oP_2 = \sqrt{(Y_i - e)^2 + Z_i^2} \tag{10}$$

After replacing (1) and (10) in (9):

$$\Delta = \sqrt{(Y_i - e)^2 + Z_i^2} - \frac{L_{\text{Н}}}{2} \tag{11}$$

If equations (3) are substituted in formula (11) and convert it is obtained

$$\Delta = \sqrt{\frac{{L_{\text{Н}}}^2}{4} + e^2.\sin^2\alpha_i} - \frac{L_{\text{Н}}}{2} \tag{12}$$

Obviously, at $\alpha_i = 0^o$ the deviation is zero and at $\alpha_i = 90^o$is its maximum value:

$$\Delta_{max} = \sqrt{\frac{{L_{\text{Н}}}^2}{4} + e^2} - \frac{L_{\text{Н}}}{2} \tag{13}$$

Figure 2 illustrates schematically the formation of the hole according to the conditions of Figure 1(a) and equation (3). The starting position of the block is the straight line $P_1P_2 = L_{\text{Н}}$and corresponds to Figure1(a) at $\alpha_i = 0^o$.

Under these conditions, and given the prerequisites, the symmetry axis of the workpiece corresponds to the central axis of the block and they lie on one straight line with the axis of rotation located at a distance from it $OO_o = OO_{\text{В}} =$ e.

When rotating the workpiece at an angle $\alpha_i < 90^o$, the block occupies the position $P'_1P'_2$, whereby its center remains on the circle with diameter e and is on one line with the axis of rotation O.

By observing this condition for all angular valuesofα_i, tips P_1 and P_2 create a set of points that lie on the outline of the figure which is the mentioned curve.

For $\alpha_i = 0^o$, the eccentricity is in the position $P_1 - P_2$ and the deviation from circularity is zero. If $e = 0$, the theoretical form of the treated hole will be a circle of diameter $P_1P_2 = L_{\text{Н}}$.

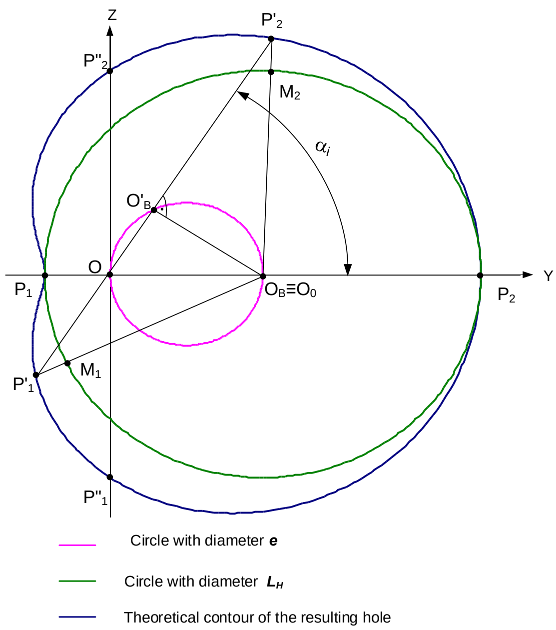

Fig. 2. Formation of the hole profile by MTB in the period of established cutting ($X_0 = 0$)

At $0^0 < \alpha_i < 90^0$, the deviation of the shape at a set value of $e \neq 0$ will be different for each value of α_i. For the case shown in Figure 2:

$$\Delta = M_1P'_1 = M_2P'_2 = O_{\text{В}}P'_2 - O_{\text{В}}M_2 \tag{14}$$

From the rectangular triangle $O_{\text{В}}O'_{\text{В}}P'_2$:

$$O_{\text{В}}P'_2 = \sqrt{O'_{\text{В}}{P'_2}^2 + O_{\text{В}}{O'_{\text{В}}}^2} \tag{15}$$

where:$O_{\text{В}}O'_{\text{В}} = \frac{L_{\text{Н}}}{2}$ and $O_{\text{В}}O'_{\text{В}} = e.\sin\alpha_i$(from the rectangulartriangle$OO'_{\text{В}}O_{\text{В}}$).

After substituting in (15) and (14) and taking into account that$O_{\text{В}}M_2 = \frac{L_{\text{Н}}}{2}$:

$$\Delta = \sqrt{\frac{{L_{\text{Н}}}^2}{4} + e^2.\sin^2\alpha_i} - \frac{L_{\text{Н}}}{2} \tag{16}$$

Formula (16) is identical to formula (12) which is outputted by the above considerations on the basis of Figure 1.This confirms its credibility in determining the theoretical value of the expected variations in the hole shape during the established cutting period and the obtaining of the Pascal Snail curve.

3. EXERIMENTAL RESEARCH

To examine the effect of axial displacement of the cutting edges of the inserts on the diameter of the treated hole, an experimental study was conducted. It is used samples cut from workpieces for hydraulic cylinders. In advance, their holes are skiving and their front surfaces are pruned. By fitting between centers with large diameters and an angle at the tip of 20^0, at the end faces of the samples are turned

chamfers $3x30^0$ for locating it in the device in which the experiments are carried out.With its help, it makes finite skiving before each experiment and providing augmentation $1^{+0.02}mm$.
The samples are placed in a special device (Figure 3) placed in the spindle of a universal lathe C11M.It consists of a holder 1 with holes for the chips and a counter-center. To it is attached a cylindrical body 3 with a support step 4 and a nut 6 carrying the other counter-center 7. The support step serves to stabilize the fitment by means of an immovable lunette 5.

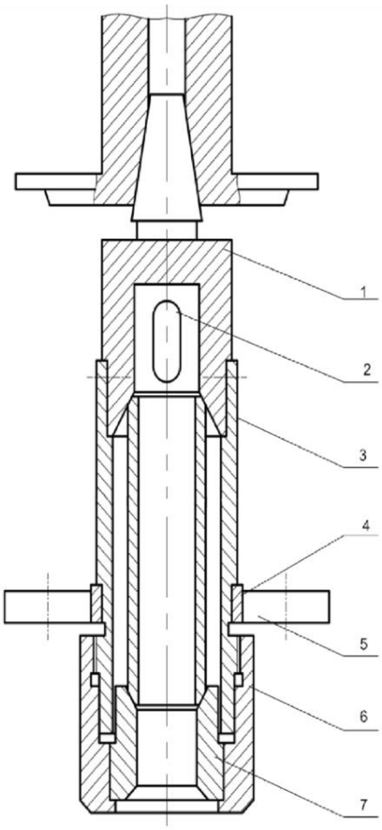

Fig. 3. Device for establishing the hydraulic samples on outer chamfers

Skiving of the holes is carried out with MTB (Figure 4) which is used for a cutting part of an instrument for combined processing (CP). The MTB consists of two identical movable holders 2 and 6 to which, in slots, are assembled the cutting inserts 1 and 7 by means of screws 11. For adjusting cutting edge angles it uses the adjusting screws screwed by the key 9.The dimension of static tuning is set as the distance between the tips of the cutting inserts by means of two opposite screws 4 and a movable wedge 5, pressed to each other by means of two springs 10.
The axial displacement of the cutting inserts is provided by pads of the desired size, placed between the support pin 8 of one of them, which is overtaking.
The general appearance of the unit is shown in Figure 5.
The selected cutting regime includes cutting depth $\alpha = 0.5mm$; feed speed $f = 3mm/rev$; cutting speed $V_c = 50m/min$ ($n = 180min^{-1}$). The geometry of the cutting inserts is: $\alpha_0 = 7^0$; $\gamma_0 = 3^0$; $\lambda_s = 0^0$; $r_e = 0.2mm$; $\kappa_r = 9^0$; $\kappa_r' = 1^0$.The experiments were conducted without a cooling liquid, as for ejection of the chips before the instrument is used compressed air.

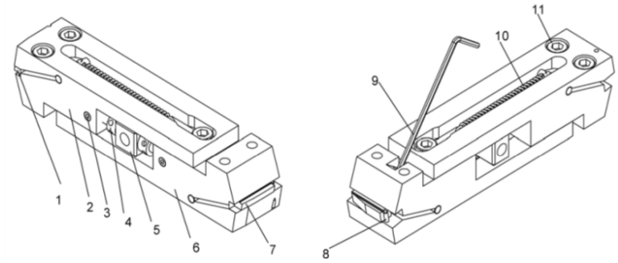

Fig. 4. Movable two-blade block

The limit axial displacement, after which the radial displacement of the block does not change, is determined by the dependence [2]:

$$X_{lim} = \frac{f}{2} + \frac{L_{Н} - D_0}{3 \tan \kappa_r} \quad (17)$$


Fig. 5. Device for skiving hydraulic samples with MTB

Under these processing conditions, the limit axial displacement is $X_{lim} = 3.87mm$. The experiments are carried out at evenly increasing displacement values in the range $0 \leq X_0 \leq X_{lim}$. The value of D_i is averaged by three measurements - one in middle and two end sections, on the spacing $20mm$ from the frontal surfaces (Table 1). The dimensions of the samples are measured with a caliper (with an accuracy of $0.02mm$) and an indicator reader with a value of one division of $0.001mm$. The dimension of the static adjustment $L_{Н}$ of the MTB is adjusted by steel gauge block sets, as the use of a micrometer with axial displacement parts does not provide convincing results. Samples are processed at static adjustment size $L_{Н} = 90mm$.
The theoretical expected diameter is determined by the following formula [2]:

$$D_i = L_{Н} + \frac{X_0 \cdot (L_{Н} - D_0) \cdot \tan \kappa_r}{1.5 \cdot f \cdot \tan \kappa_r + L_{Н} - D_0} \quad (18)$$

Table 1. Results of the experimental study

X_0, [mm]	D_i, [mm]- theoretical	D_i, [mm] - exerimental			Average value of measurements, [mm]	Average deviation from the theoretical value, [mm]
		Section I	Section II	Section III		
0	90	90.062	90.064	90.058	90.061	0.061
0.5	90.043	90.098	90.097	90.104	90.100	0.067
1	90.086	90.229	90.139	90.143	90.170	0.084
1.5	90.129	90.17	90.194	90.186	90.183	0.054
2	90.172	90.22	90.324	90.218	90.254	0.082
2.5	90.215	90.303	90.349	90.288	90.313	0.098
3	90.258	90.302	90.338	90.388	90.343	0.085

The results are presented graphically in Figure 6, which allows a comparative evaluation of the theoretical and experimental influence of axial displacement of the cutting inserts on the radial movement of the block.The calculated coefficient of correlation between the two variables - the theoretically calculated diameter (VAR2) and the measured as a result of the experimental study (VAR1) is high - $r = 0.86107$ (Figure 7). This confirms the correlation between the derived theoretical dependencies and the obtained experimental results for the influence of the axial displacement of the cutting edges of the inserts on the diametric size of the treated hole.

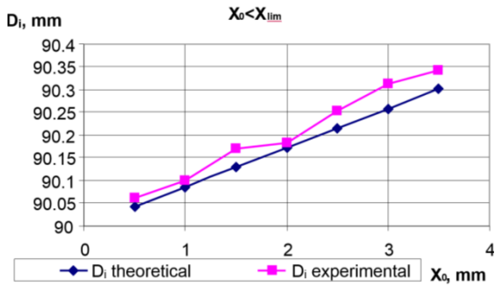

Fig. 6. Diameter variation at axial displacement in the range $0 < X_0 < X_{lim}$

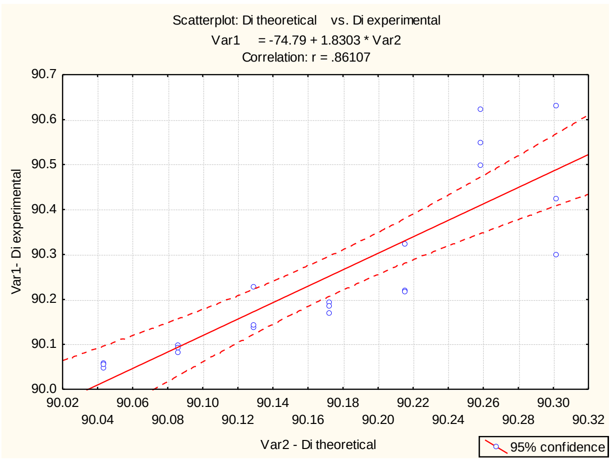

Fig. 7. Correlation between the theoretical and experimentally obtained values of the diametric size at axial displacement in the range $0<X_0<X_{lim}$

4. CONCLUSIONS

In conclusion, the following results can be formulated:

- During the processing with MTB, its tips of the oppositely located cutting inserts describe the Pascal Snail curve.
- The axial displacement of the cutting inserts of MTB causes its radial movement to the delaying insert, which leads to an increase in the diameter of the resulting hole in relation to the adjusting size of the block.
- The increase in the diameter of the treated hole (up to 0.3mm) by MTB with axial displacement cutting inserts is essential. This makes possible to remove the tool from the treated hole without damaging its surface. This increases the reliability of the CO by skiving and SPD.
- The increase in the diameter of the treated hole (up to 0.3mm) by machining with MTB with axial displacement cutting inserts is essential. This makes possible to remove the tool from the treated hole without damaging its surface. This increases the reliability of the CP by skiving and SPD.
- The results of the experimental studies confirm the reliability of the derived theoretical dependencies (with a correlation coefficient r=0.86107). This enables they be applied in practice in order to make more effective use of the full PSP capabilities of large-hole drilling.
- The CP tools with MTB for machining holes with dimensions Ø180mm and Ø200mm are introduced for use in production conditions of "Hydraulic elements and systems –PLC". They prove the results of the theoretical and experimental studies. Studies have been carried out for the implementation of CP tools with MTB for the sizes of machined holes Ø90mm, Ø110mm, Ø125mm, and Ø250mm.

5. REFERENCES

1. Avramova, T. G., Stefanov, G. D., (2018). *Combined tools for surface plastic deformation with radial feed*, Proceedings of XXVII International

science and technical conference, ADP Sozopol, **3**(224), pp. 48 – 52, Technical University of Sofia, Bulgaria (Sozopol) (in Bulgarian).
2. Avramova, T.G., Lefterov, E.L., (2018). *Regarding the strength calculations of complex combined tools*, International Conference - Modern Technologies in Industrial Engineering (ModTech), IOP Conference Series: Materials Science and Engineering, **400**, 022005, pp. 1-7, doi:10.1088/1757-899X/400/2/022005.
3. Avramova, T.G., (2018). *Some Aspects of Designing Cutting Tools*, Eastern Academic Journal, **1**, 79-85.
4. Avramova, T.G., Lefterov, E.L., (2018). *Influence of the Shape of the Tool Bodies For Machining Holes in Strength Calculations*, Eastern Academic Journal, **1**, 86-94.
5. Grigorov, V.I., Karshakov, M.K., Kostadinov, S.V., (2004). *Features of the schematic options for the combined processing of smooth shafts, determined by the positioning of the cutting elements with rectilinear cutting edges in the movable cutting block*, Scientific papers of "Angel Kanchev" University of Rousse, **XXXI**, pp. 139-146 (in Bulgarian).
6. Karshakov, M.K., Grigorov, V.I., Kostadinov, S.V., (2009*). Influence of drag friction on the behavior of a floating cutting unit with significant elastic properties*, Journal ofMechanical Engineering and Mechanics, **2**, Technical University of Varna, 39-42 (in Bulgarian).
7. Karshakov, M., Kostadinov, V., (2009). *About cutting forces for skiving by a movable two-blade block*, Mechanika,**4**, Technologija, Kaunas, 75 – 80.
8. Kostadinov, V.S., (2002). *Combined tool for mashinig of holes by surface plastic deformation*, Mechaninĕ Technologija, **XXX**, Kaunas, 136-139 (in Rusian).
9. Kostadinov, V. (2008).*Combined tools for surface plastic deformation with rsdial feed*, Mechanics 2008, Proceedings of the International Scientific Conference, pp. 185-188, Rzeszów, Poland.
10. Kostadinov, V. S. (2007). *The processing of electrochemical coatings through surface plastic deformation (SPD)*, The 2nd International Conference “Computational Mechanics and Virtual Engineering” COMEC-Brasov, pp. 554-559, Brasov, Romania.
11. Kostadinov V. S. (2007). *About quality and precision of inner tubular surfaces machining by surface plastic deformation*, The 2nd International Conference “Computational Mechanics and Virtual Engineering” COMEC-Brasov, pp. 561-556, Brasov, Romania.
12. Kostadinov, V.S., (2007). *Tool for surface plastic deformation with radial feed*, Collection of Scientific Works of Moscow State Technological University “Stankin”, Production. Technology. Ecology., **10**, pp. 681-685 (in Rusian).
13. Kostadinov, V., Karshakov, M., (2007). *Regarding cutting forces in combination machining*, Collection of Scientific Works of Moscow State Technological University “Stankin”, “Production. Technology Ecology”, **10**, pp. 686-690 (in Rusian).
14. Kostadinov, V., Karshakov, M., (2008). *Processing of the grooves through surface plastic deformation*, Mechanics, Proceedings of the International Scientific Conference, pp. 181-184, Rzeszów, Poland.
15. Kostadinov, V.S., Kostadinov,S.V., (2007). *Kinematic Analysis of a Self-Centering Tool for the Surface Plastic Flow*. MECHANIKA, Technologija, Kaunas, 163-167.
16. Kostadinov, V.S., Kostadinov,S. V., (2003). *Concerning the dimensioning of the combined processing with a movable cutting block*, "Mechanics of Machines", **48**, 74 – 77 (in Bulgarian).
17. Kostadinov, V.S, Kostadinov, S., Dimitrova, G., (2005). *Exploring the behavior of a deformation module from a combined shaft-processing tool*, “Mechanics of Machines”, **55**, 139-142 (in Bulgarian).
18. Topalova, M., Kostadinov, S., (2012). *About quality and precision of inner tubular surfaces machining by surface plastic deformation*, Proceeding of XXVII International scientific conference FIT’2012, AMTECH’2012, 237-240, Technical University of Sofia, Sofia, Bulgaria (in Bulgarian).

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