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INFLUENCE OF VARIABLE CONTACT CONDITIONS ON THIN SHEETS METALS FORMABILITY BY DEEP DRAWING

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ABSTRACT

Presented in the article is comparative view of experimental results of pure deep drawing (deep drawing of cylindrical cup with flat bottom) in conditions of constant blank holding force with different contact conditions (dry, oil, polyethylene foil) on one side and the results of deep drawing with variable blank-holding force and different contact conditions on the other side. Variable blank-holding force implies the possibility of programme control of any kind of force dependence on travel. Classical autobody steel sheet metal is used, and strain distributions j_1, j_2 *and* j_3 *(in dependence on location on work piece and in forming limit diagram –FLD), drawing force, work piece depth and the appearance of defects (wrinkles and fracture) are being observed. Three program controlled variable blank-holding force models are used: decreasing, increasing and combined. First results, presented here, show that variable blank-holding force has significant influence on conditions of friction on work piece flange, and thus on deep drawing process and work piece characteristics. That influence may result in significant improvement in technology of deep drawing of thin sheet metals.*

1. INTRODUCTION

In structure of total tribological scheme of deep drawing process duration, the sheet metal blank-holder zone has special significance (fig. 1). On one side the friction on blank-holder significantly influences the course and result of plastic forming process, and on the other side blank holding force is a very convenient parameter for monitoring and control. That is the most important reason for many current researches of blank holding force influence in many research and industrial world centres /1, 2/.

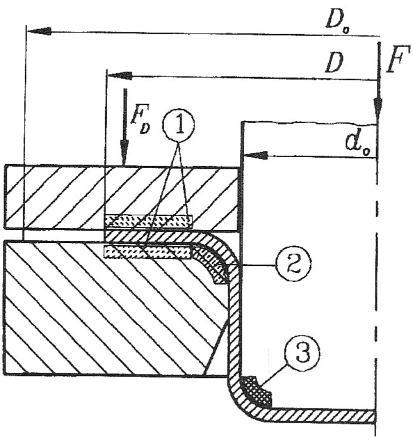


Fig. 1 - Friction zones

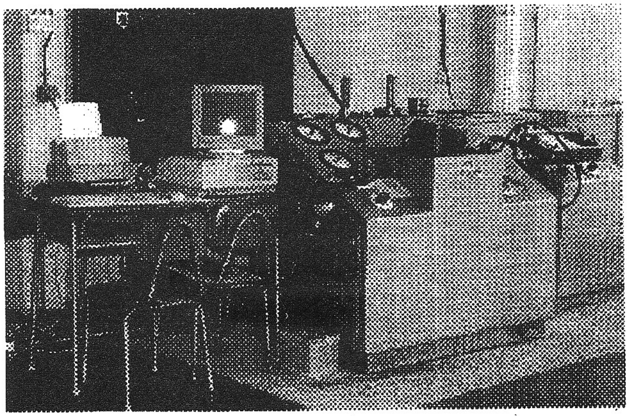
Two types of defects may appear in course of drawing: wrinkles at sheet metal surface and fracture. These appearances, so to speak, form the framework for successful continuance of the process. Besides material characteristics and tool and machine condition, the process and finished work piece can be influenced by drawing ratio, condition of tool-sheet metal contact surfaces and blank-holding force. The other group of influential factors is much more convenient for change, if necessary. This mostly applies to the lubricant application and blank-holding force control. For example, it is relatively easy to replace the lubricant, but it is much more difficult to replace the tool or press. In general, deep drawing realization so far implied constant blank-holding force and it was considered generally accepted. Not until the development of new sheet metals generation and increased demands, in the last few years, did the intensive work start on researching the influence of variable blank-holding force (VBF) by application of modern computer systems for acquisition and control.

At faculty of Mechanical Engineering in Kragujevac the modification of laboratory press for investigation of sheet metal – ERICHSEN 142/12 was carried out, by computer system which, besides acquisition, makes possible the obtaining of programme defined blank-holding force (phot. 1).

2. EXPERIMENTAL RESEARCHES

In the context of planned comprehensive researches of the variable blank-holding force influence, preliminary results of experiments realized so far are given here. The machine on which experimental researches are performed is already mentioned hydraulic triple action laboratory press-ERICHSEN 142/12. Maximal measuring force range is 0-130 kN, forming speed is 0-200 mm/min and blank holding force is 0-32 kN. Maximal punch diameter is 50 mm and maximal drawing ratio is 2.4. On the whole, in machine there are inductive transducers of force and travel with standard manometers with Bourdon`s tubes for all working actions. Blank-holding force is controlled by hand regulated hydro-valve.

For the purposes of these researches, the modification in part for blank-holding force realization was carried out. Modification includes built-in electromotor drive with DC motor and two connected reduction worm gears, applied on hydraulic valve for blank-holding force regulation. Control of electromotor drive is performed in closed loop based on hydro-valve axle angle position, which is measured by multirotating potentiometer. Control of electromotor drive is integrated in data acquisition and control computer system because process speed is relatively small (phot. 1). Data acquisition and control system contain PC computer with built-in 12-bit AD-DA card and accessory moduls: driver for control of DC electromotor, signal amplifier with filter and switch elements. In that system, based on previously recorded blank-holding force dependence on angle position of valve axle (i.e. potentiometer voltage) would make possible the obtaining of valve axle position dependence on time during drawing process, and in that way variable blank-holding force.



Phot. 1 View of complete equipment

Table 1: Material properties

Č0148P5 s_o=0,8 mm				
R_M, MPa	R_P, MPa	A_{80}, %	n	r
385,5	234	34,0	0,23	1,242

By switching DC electromotor drive in desired moments with the use of specialy developed electronic unit change of blank-holding force to programme defined value measured indirectly by axle angle position potentiometer, may be obtained. The choice of any kind of force dependence was provided through software, developed for service of the experiment. Because of limited space, it is impossible to give all details about design, making and application of this system, so, for all further information, the authors must be consulted.

Material used for investigation was steel sheet metal from class Č0148P5 (foreign manufacturing) with characteristics given in the tab. 1 which gives medium values considering the plane anisotropy of sheet metal. Fig. 2 shows the strengthening curve and fig. 3 shows the forming limit diagram (FLD).

In course of experiment planning, the model of pure deep-drawing (cylindrical part with flat bottom) was chosen, with punch diameter 50 mm, bottom radius 6.5 mm and die radius 3.5 mm. Forming speed was fixed to 20 mm/min. Drawing ratio had to be chosen in a way to be close to the limit value, so that the differences caused by the influence of VBF could be noted. With ratio 2 and techicaly dry contact surfaces with constant blank-holding force F_D=15 kN the process had its course towards the end without any defects. With ratio 2.2 and dry surfaces (degreased by acetone) and with the application of oil (of a domestic producer) for deep drawing (F_D=6-10 kN) the fracture appeared. With the application of polyethylene foil and oil and F_D=10 kN at the end of travel wrinkles appeared, while with force F_D=12 kN, the process ran successfully to the end, which meant that blank diameter 110 mm is adequate for such investigation. Knowing that conditions at contact surfaces very significantly influence the drawing /3/, one out of previously three mentioned types had to be chosen. Lubrication by oil was chosen from two reasons: it doesn't belong to the extreme conditions and it satisfies the commonest operating conditions in industry. The general approach in the realization of experiment is to put the work piece of chosen geometry (with mentioned contact conditions) under investigation by constant blank-holding force of appropriate intensity on one hand, and on the other hand with the application of VBF of appropriate intensity range and law of change as well, in dependence on travel, i. e. time.

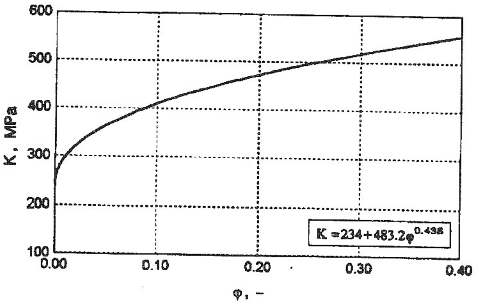


Fig.2 - Strengthening curve

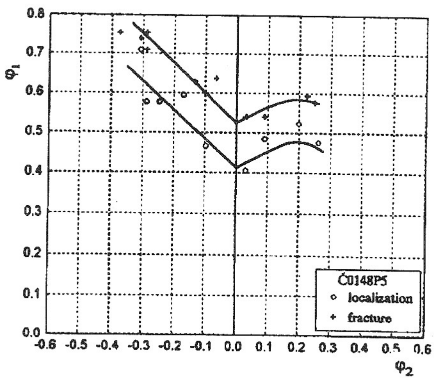


Fig.3 - Forming limit diagram (FLD)

2.1 The choice of constant blank holding force (CBF) and variable blank holding force (VBF)

In choosing CBF generally accepted principle was adopted: $F_D=q \cdot A$, q being the specific holder pressure and A being the maximal contact surface (at the beginning of drawing) of holder and sheet metal. In this particular case:

$$A=\frac{D_o^2-(d_1+2s+2r_M)^2}{4}\pi=\frac{110^2-(50+2\cdot 0.8+2\cdot 3.5)^2}{4}\pi=6806.3\ mm^2$$

Concerning the values of q, eight following approaches given in the tab. 2 were considered. Examining the values in the tab. 2 and taking into consideration our own experimental data from previous researches /2, 4/ and this one, CBF was adopted as medium value from sections 3 and 4, F_D=12.2 kN. In choosing the decreasing dependence of VBF, the principle of constant specific holder pressure realization was set, with regard to decrease of contact surface from the start value to zero. During that, the flange diameter takes values from D_0=110 mm to 58.6 mm on die radius. After that, at the very end of process, when full work piece depth is realized, there is no sheet metal holding. The surface of flange is $A=0.7854 \cdot D^2$ - 2697 mm^2. Because of the control of valve requirements for VBF it is necessary to ascertain F_D dependence on time. At adopted forming speed for total work piece depth (54 mm) the process lasts 165 s. For the purposes of simplification, it is considered that the flange maintains circular shape and that there is linear connection between flange diameter and time. Finally, for decreasing regime, VBF has the folowing form:

$$F_D = qA = 12200 - 96.9\,t + 0.137\,t^2,\ \text{N},$$

where is q=1.8 MPa=const. considering CBF being 12.2 kN and A_{max}=6806.3 mm^2.

This dependence is represented in fig. 4 by dashed line. Three steplike lines correspond to truly realized change. By the application of VBF according to scheme 1, which is the closest to the given curve, 23.3 mm depth is obtained. For line 2, depth 25.6 mm is obtained and 26.7 mm for line 3, so that the work piece obtained by that dependence is chosen for comparison with other types of VBF.

Table 2

Ord. num.	Manner of determining q, author and year	q, MPa	F_D, kN
1	$q=\frac{1}{200}(R_M+R_P)$, G. Sachs, 1931. /4/	3.1	21.08
2	$q=0.002\div0.0025(\beta-1)^2 R_M$, E. Siebel, 1954. /4/ β=2.2 drawing ratio	1.11-1.388	7.55-9.45
3	E. Siebel, H. Beisswanger, 1955., /4/ $q=0.002\div0.0025\left[(\beta-1)^3+0.5\frac{d}{100\cdot s}\right]R_M$	1.351-1.689	9.2-11.5 F_{Dsr}=10.35
4	B. Zunkler, 1985. /4/ $q=0.0757\frac{\beta^{\frac{2}{n+1}}-1}{\beta^2-1}R_M\cdot n\cdot e^n\left(\frac{\ln\beta}{n+1}\right)^{n+2}$, n-strain hard. exp.	2.125	14.05
5	L. A. Schofman, 1964., /5/ Empiricaly dependent on the material (steel with <0,5% C)	2-2.5	13.6-17
6	L. A. Schofman, 1964., /5/ $q=0.0056\cdot R_M(\beta-1.1)\frac{D_o}{100\cdot s}$	3.265	22.22
7	L. A. Schofman, 1964., /5/ $F_{D\,min}=0.0045\cdot R_M(\beta-1.1)\left(1-\frac{1}{\beta^2}\right)\frac{D_o^3}{100\cdot s}$	/	25.08
8	E. A. Popov, 1968., /6/ $F_D=0.1\left(1-\frac{18\beta}{\beta-1}\frac{s}{D_o}\right)\beta^2\cdot F_{max}$ $F_{max}=\pi ds(\beta-1)R_M$	/	21.38

For increasing dependence, the shape of VBF according to detailed research conducted in /7/ was applied. Empiric equation is as follows: $F_D = (1.1 \div 1.25) F_{D max} \cdot sin\left(\frac{\pi}{2}\frac{h}{h_{max}}\right)$, h being the punch travel (argument) and h_{max} being the maximal work piece depth. For this particular case (according to the medium coefficient value) the following equation is obtained:

F_D=14340 sin(1.667h), N or in function on time

F_D=14340 sin (0.546 t), N

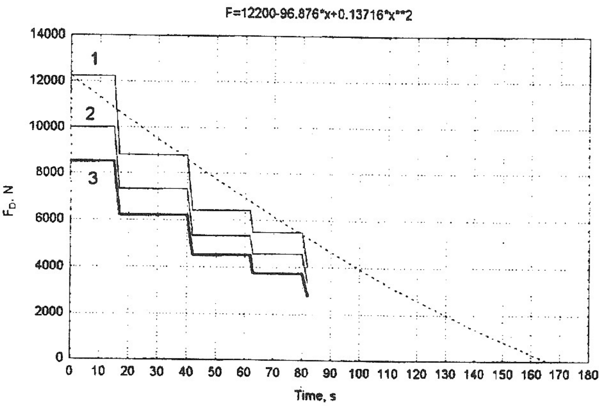


Fig.4 - Decreasing dependence of VBF

Fig. 5 gives the shape of this curve with experimentally realized gradual dependence. The argument of sinus function in the previous equation is obtained in degrees and in fig. 5 in radians.

In determining combined dependence, analytical expression for drawing force obtained by analysis and modifications of classic approach was used as basis /3, 5, 6/. Because of limited space the finished formula will be given:

$$F = \pi d_1 s\left[\left(1.15\frac{K_M}{1-\varphi_M} ln\frac{\sqrt{1+m^2-\rho^2}}{m \cdot \rho} ln\frac{\rho}{m} + \frac{2\mu F_D}{\pi d_1 s}\right)e^{\mu\frac{\pi}{2}} + \frac{R_M}{2\frac{r_M}{s}+1}\right]$$

In the previous formula $d_1=d_o+s$ is medium work piece diameter, $\varphi_M=n$ is maximal value of uniform natural strain, K_M is equivalent stress for φ_M, $m=d_o/D_o=r_o/R_o$ is drawing coefficient, $\rho=D/D_o=R/R_o$ is flange deformation (argument) and r_M is die radius. The obtained shape of curve corresponds to experimental results relatively well. Analytical shape of VBF is obtained in order to perform certain unloading of drawing force F with help of F_D. Horizontal axis of symmetry was set (empirically determined as F_C=28.8 kN) and mentioned curve was copied so that (for this example) equation in function on time (t, s) was obtained:

$$F_D = 2F_C - F = 57600 - 127.67\left[\left(724.65\,ln\frac{\sqrt{1.206-z^2}}{0.454 \cdot z} ln\frac{z}{0.454} + 19.1\right)1.17 + 39.5\right],\ N$$

$$z = \frac{t}{302.198} + 0.534$$

In fig. 6 the curve is represented by dashed line according to previous dependence, and steplike line shows experimentaly realized VBF.

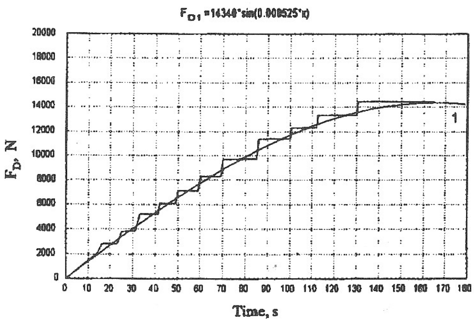


Fig.5 - Increasing dependence of VBF

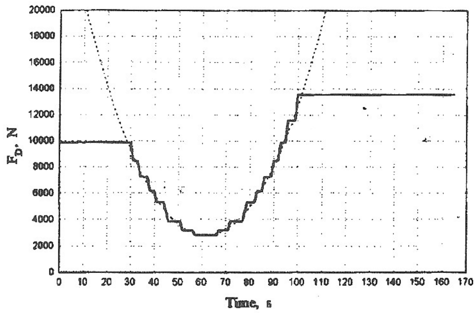


Fig.6 - Combined dependence of VBF

2.2 Results

Figure 7 shows strain distributions (strain paths in FLD) for case of CBF and for all of the three used conditions of contact surfaces. In fig. 8 drawing forces dependence on travel is noted. Curve 1 is at CBF and curves 2, 3 and 4 are at VBF. Curves shapes are ordinary, but the period of the process duration is changed. For case 2 the increase of depth is 27.8 %, in case 3 it is 15.3% and for case 4 it is 10.05% (in relation to case 1) which is one of the indicators of significant positive impact of VBF.

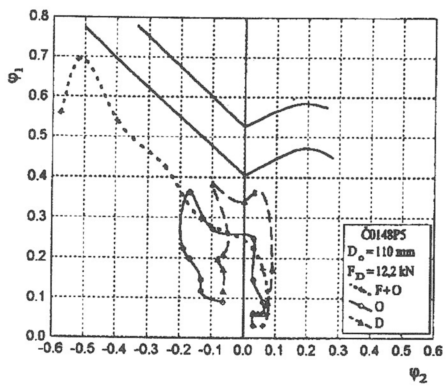


Fig.7 - Strain distributions in FLD

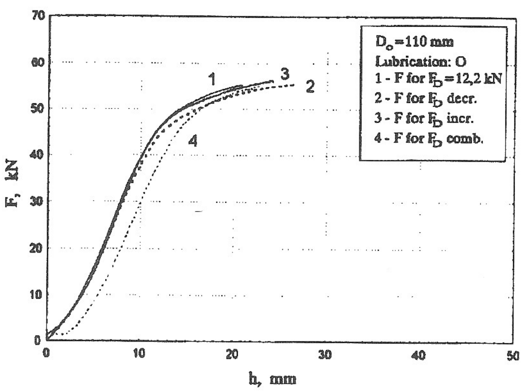


Fig.8 - Drawing forces dependence on travel

Fig. 9 gives comparative survey of strain distributions in coordinate system of main strains in sheet metal plane (FLD). The shape and uniformity of realized knot is the best in case of increasing and combined VBF. It is more obvious in the third main strain distribution diagram (thickness strain, that is thinning) in dependence on the location at the work piece. The most uniform curve, with no particular thinning, was obtained for combined VBF.

Previous results were accompanied with drawing depth and blank-holding force dependence diagram in limit cases of appearance of wrinkles or fracture (fig. 11). This diagram was obtained afterwards, although the knowledge of position of twisted limit wrinkles and fracture before choosing the type of dependence and intensity range of VBF is very usefull.

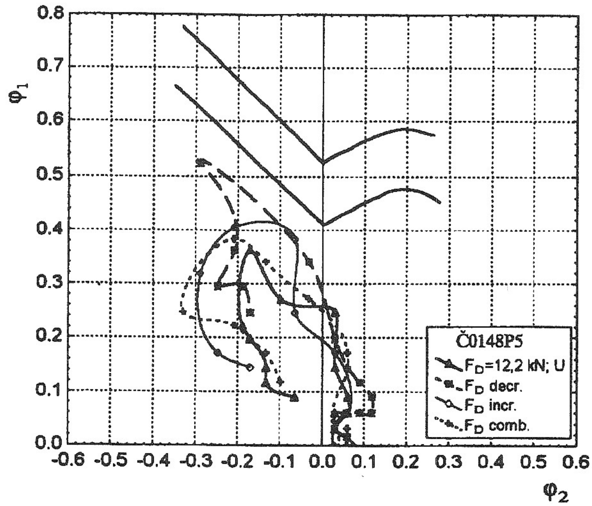


Fig.9 - Strain distributions in FLD

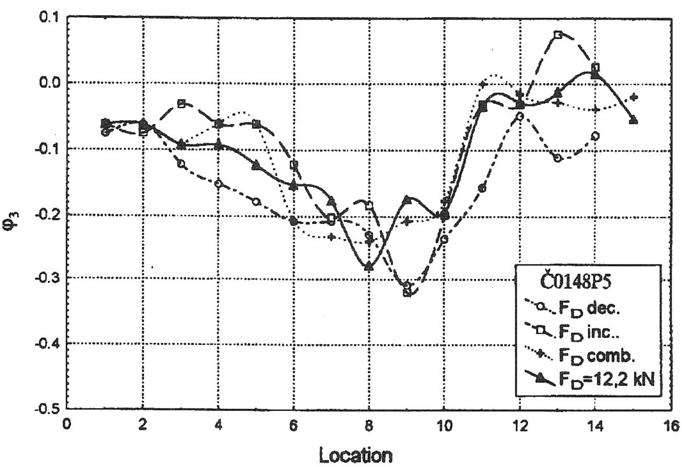


Fig.10 - Distribution of thinning strain

Diagram is determined by series of drawing depth measurements at varying CBF, and in appropriate contact conditions. For each work piece (one point of curve) the measurement ends with finding the location of wrinkles or fracture. The moment of the appearance of wrinkle is determined by instrument with comparator with reading precision 0.01 mm. Criterion for the appearance of wrinkles adopted in this paper is sheet metal holder displacement in the direction oposite to blank-holding force for 0.05 mm. In different researches (/7/ for example), similar indicator is used. In the mentioned paper the displacement value was 0.1 mm. Here, much more rigorous condition was adopted for the purposes of more effective distinction between the appearance of wrinkles and fractures in the zone where limit lines of these defects are joining.

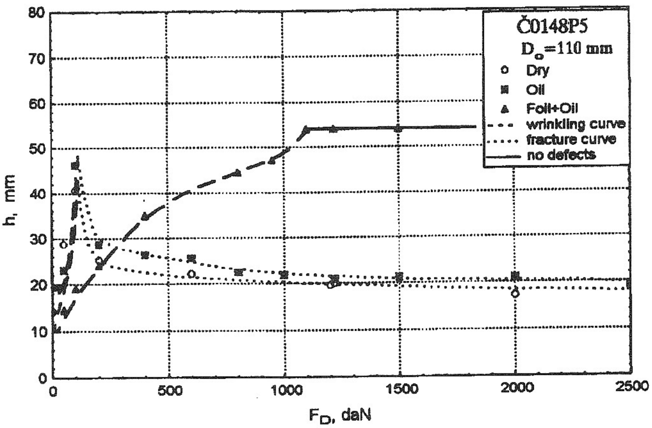


Fig.11 - Limit curves of wrinkling and fracture

3. CONCLUSION

The area of VBF influence in deep drawing of thin sheet metals can be significant for the improvement of technological results of forming and more thorough knowledge of the process itself. Researches are in progres in many world centres as well, but there are no results which would bring to unequivocal conclusions. Besides experiments, which are of main importance, process simulations in big software packages were also included (PAM-STAMP, LS-DYNA 3D, ABAQUS etc /8/).

Results presented in this paper (in reduced form) obtained at Faculty of Mechanical Engineering in Kragujevac, suggest the positive influence of the decreasing blank-holding force on the drawing depth (increase is about 27%) and influence of applied combined dependence of VBF on the strain distribution with depth increase about 10%. Results are preliminary and in the following period different materials, work piece geometries, contact conditions and types of VBF dependence will be considered.

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UTICAJ PROMENLJIVIH KONTAKTNIH USLOVA NA OBRADIVOST TANKIH LIMOVA DUBOKIM IZVLAČENJEM

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REZIME

Rad daje uporedni prikaz eksperimentalnih rezultata za duboko izvlačenje cilindričnog komada u uslovima konstantne sile držanja sa različitim kontaktnim uslovima (suvo, ulje, polietilenska folija sa uljem) s jedne strane i za izvlačenje sa promenljivom silom držanja i različitim kontaknim uslovima, s druge strane.Promenljiva sila držanja podrazumeva mogućnost programskog zadavanja bilo koje zavisnosti sile od hoda uz pomoć specijalnog uređaja sa DA sistemom. Koristi se klasičan karoserijski čelični lim, a prate se distribucije deformacija j_1, j_2 *i* j_3 *zavisno od lokacije na komadu i u dijagramu granične deformabilnosti, sila izvlačenja, dubina komada i pojava defekata (nabori i razaranje). Primenjuju se tri modela programski zadate sile držanja:opadajući, rastući i kombinovani. Prvi rezultati ukazuju da je promenom sile držanja moguće značajno uticati na uslove trenja na obodu komada, a samim tim i na proces dubokog izvlačenja i karakteristike gotovog komada. Taj uticaj može rezultirati značajnim poboljšanjem tehnologije dubokog izvlačenja tankih limova.*