Journal for Technology of Plasticity, Vol. 31 (2006), Number 1-2

# AN EXPRESSION SUGGESTED TO DETERMINE THE BLANK HOLDER PRESSURE IN THE OIL HYDRAULIC PROCESS OF SQUARE CUPS DEEP DRAWING

*Rančić Bojan, Janković Predrag, Stoiljković Vojislav*
*University of Niš, Mechanical engineering faculty, Serbia*

## ABSTRACT

*Siebel's analytic-experimental expression is used to determine the blank holder pressure in the process of deep drawing of cylindrical and conical cups. Its application in industry has given good results. This paper presents an adjustment of Siebel's expression to the purpose of square cups deep drawing in oil hydraulic forming process. The experimental check up has also been performed including the application of this expression to the deep drawing of square cups of both rectangular and square cross section. The values of blank holder pressure obtained by the suggested expression are within the range of boundary limits of a good area.*

## 1. INTRODUCTION

This paper is dealing with deep drawing of square cups in oil hydraulic forming process. The blank is of a square shape, and the role of a punch is performed by the working fluid. Under the influence of a working fluid the sheet metal is drawn into the die hole, trying to obtain the final shape defined by the shape of the die hole. A movable cup bottom holder is used to prevent destruction in the cup bottom, [1].

It is observed that, with certain sheet metal thickness and also taking into account the size of the initial blank and the size of a drawn cup, there is some instability of the sheet metal in the cup flange (particularly in corner zones) resulting in wrinkles formation.

To prevent wrinkles occurrence the sheet metal is exposed to the effect of cup bottom holder. In this case, the cup flange is affected by the blank holder pressure $p_{bh}$, i.e. the force $F_{bh}$ exerted by the holder. This force brings about the friction force on the contact surfaces between the sheet metal and blank holder and between the sheet metal and the die as well.

This paper presents experimental check up results and shows whether it is possible to apply the Siebel's expression [2], [3], (taking into account certain transformations) to calculate the blank holder pressure in the process of square cups drawing with the indirect influence of the working fluid exerted on the sheet metal (through the rubber membrane) with the use of a movable cup bottom holder.

## 2. BLANK HOLDER PRESSURE IN SQAURE CUPS DRAWING

Normal compressive stresses in the circumferential direction $\sigma_\theta$, occuring in the cup flange (over the whole circumference of the cylindrical and conical cups and in the corner zone of sqaure ones) bring about sheet bending, i.e. the occurrance of the wrinkles of the first order. The variance in metal displacemnt rates between the corner zone and the side zone can result in wrinkles occurrance within the flange transitional areas in the process of non-axisymmetric cups drwaing.

Wearing of the tool is more considerable in case there has been some straightening of wrinkles while moving over the rounded draw die. In addition to it, the lateral surface of the parts obtained in this way appear poor by look. The wrinkles of the first order can affect later usage of these parts, for instance in case of their joining by means of welding.

In case of excessive wrinkles which cannot be straightened by the rounded draw die, the in-flow of material into the die hole (mold) is hampered and there is a destruction of the part. To prevent wrinkles occurrence over the whole flange circumference it is necessary to apply a suitable pressure (force) by the blank holder.

### 2.1. Blank holder pressure for cylindrical and conical parts

The original Siebel's equation is used to determine the specific blank holder pressure to form rotary-symmetric parts, [2], [3]:

$$p_{bh} = (0.002 \div 0.003) \cdot \left[ \left( \frac{D_0}{d_{in}} - 1 \right)^2 + \frac{d_{in}}{200 \cdot s} \right] \cdot R_m \cdot \tag{1}$$

Where: $D_0$ – blank diameter, [mm],
$d_{in}$ –inward radius of the part, [mm],
s – sheet metal thickness, [mm] i
$R_m$ – tensile strength of the sheet metal, [N/mm$^2$].

In technical literature [4], [5], instead of a member $(D_0/d_{in} - 1)^2$, there is a member $(D_0/d_{in} - 1)^3$. It is supposed that an error has occured in the rewriting of the expression. The variance in blank holder pressures is negligible, since in case of Siebel's equation application, the mean value of dimensionless coefficient is most frequently adopted, i.e. 0.0025.

In technical literature [6] there is a substitution of the member $d_{in}/(200 \cdot s)$ by the member $D_0/(200 \cdot s)$, so that the expression (1) obtains the following form:

$$p_{bh} = (0.002 \div 0.003) \cdot \left[ \left( \frac{D_0}{d_{in}} - 1 \right)^2 + \frac{D_0}{200 \cdot s} \right] \cdot R_m \cdot \tag{2}$$

The value of the blank holder force $F_{bh}$, is obtained when the specific blank holder pressure $p_{bh}$ is multiplied by the flange surface $A_{fl}$, [7].

**2.2. Blank holder pressure for square cups**

The Siebel's equation can be applied in case of non-axisymmetric parts of rectangular cross section, however, in this case the following values should be inserted in expressions (1), and (2), respectively: $D_{0f}$ (factual blank diameter) and $d_{inf}$ (factual inward radius of the part).

Factual inward radius of the part $d_{inf}$, is determined by reducing the the inward area of the part cross section to the circle of the same area:

$$d_{inf} = \sqrt{\frac{4}{\pi} \left[ a_{in} \cdot b_{in} - (4 - \pi) \cdot r_{cin}^2 \right]}, \tag{3}$$

where: $a_{in}$, $b_{in}$ i $r_{cin}$ – are inward length, width and radius of the part corner (see Figure 1).

Since a non-axisymmetric part of rectangular cross section can be obtained from the blanks of various shapes, an inverse procedure is applied to obtain the blank area of $A_0$. Namely, to begin with, it is assumed that we are dealing with an ideal flange of the part drawn (the flange which has the same width $x_{fl}$ over the whole circumference), then the calculation is performed as to the flange area and the factual flange diameter respectively according to the following:

$$A_{fl} = b_{fl} \cdot a_{fl} - b_{in} \cdot a_{in} - (4 - \pi) \cdot \left( r_{cfl}^2 - r_{cin}^2 \right), \tag{4}$$

$$d_{flf} = \sqrt{d_{inf}^2 + \frac{4}{\pi} \cdot A_{fl}}, \tag{5}$$

And finally, according to a well known expression given by ([4], [5], [6]), the factual circular blank radius is determined as follows:

$$D_{0f} = \sqrt{d_{flf}^2 + 4 \cdot d_{inf} \cdot \left[ h + 0.57 \cdot (R + r) \right]}, \tag{6}$$

While analysing the force, namely the pressure of the working fluid required to form a non-axisymmetric part, an assumption regarding the even distribution of specific blank holder pressure is adopted. In real forming processses, the variance of sheet metal thickness within the part flange region result in partial adherence of of blank holder to the sheet metal, consequently leading to surface pressures which cannot be defined precisely oposed to the adjusted specific blank holder pressure being the constant one.

Besides, in a machine/tool system forming the non-axisymmetric parts, there is some non-symmetric load present, resulting in press askew position in reference to press bench and uneven distribution of blank holder pressure over the part flange. Owing to this, it is necessary to know the the thickness variance in the flane region, i.e. the distribution of strain.

With higher blank holder pressures, the sheet thickness growth is not only reduced but also equalized over the whole flange surface, which does not occur with lower blank holder pressure. Consquently, the even distribution of blank holder pressure in deep drawing of square cups occurs in case of almost equal inward and outward transitional areas of the flange.

On the grounds of the facts mentioned, it follows that the increase in blank holder pressure is favourable to the formation of the plastic yield within the flange region. However, the pressure must not exceed a certain value because in that case the flange material is hampered and the destruction of either the bottom or the lateral casing can occur.

Thus, the specific blank holder pressure can be changed within the certain boundary range, the lower and upper values of which are being determined by the wrinckles and destruction occurence respectively.

It is established experimentally [1], that in standard forming of non-symetric parts with rectangular cross section, the maximum forming force is not considerably changed by the blank holder pressure if it is within the permissible boundary range. It is also found that the resistance to wrinkle formation is as high as the value of normal anizothropy factor and the exponent of the blank material strenghtening are, therefore it is necessary to apply lower pressure to the blank holder.

## 3. EXPERIMENTAL CHECK UP

Some experimental testing has been performed with the square cups of rectangular and square cross sections drawn in working fluid to confirm the validity of theoretical expressions.

Three types of material have been used for that purpose: electrolytical copper (E1-Cu58, DIN 1708), brass (CuZn37, DIN 17660) and steel (RSt13, DIN 17007), and the thickness of s = 1.0 mm was the same in each case. The corner zone radius (Figure 2) was given the value of $r_c = 16.0$, or $r_c = 12.5$ mm.

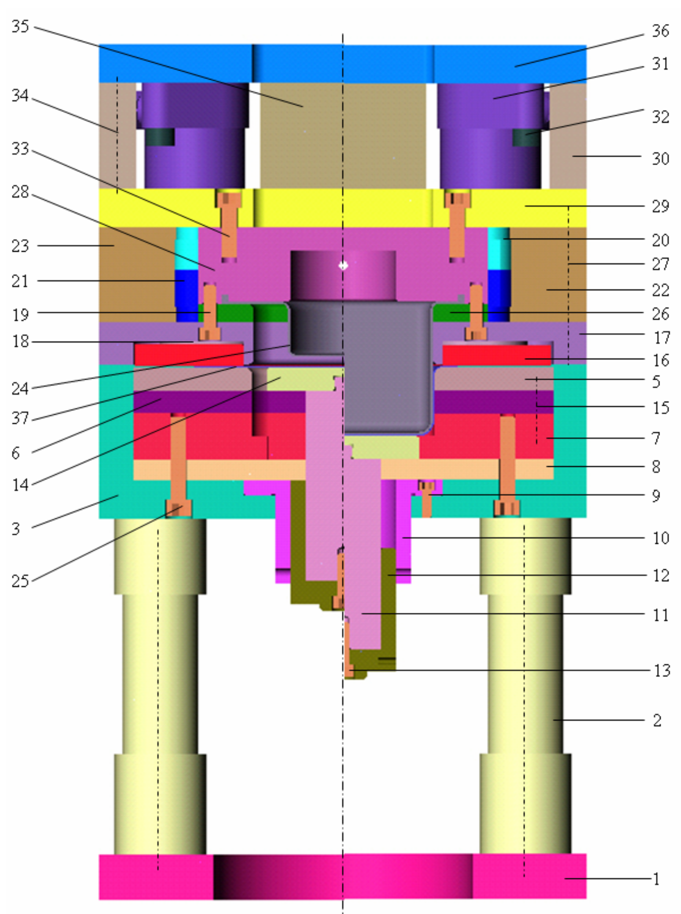

*Figure 1: Square cup of rectangular cross section with a flange*

*a – width of the cup (part);*
*b – length of the cup;*
*h – height (depth) of the cup;*
*s – sheet metal thickness;*
*$r_c$ – corner zone radius;*
*$r_d$ = 7 mm – die edge radius;*
*$r_p \approx 10$ mm – punch (bottom) radius;*
*$x_{fl} \approx 7$ mm – flange width.*

The following input values were adopted: part size, i.e. the ratio of the longer to shorter side of the part c = b/a, and the part height h (Fig. 1); whereas the blank holder pressure was taken as an output value. The values of h = 30 mm and h = 45 mm were adopted for the lower and upper part height respectively (with the assumption that the same part height could be achieved in deep drawing with working fluid and the use of a cup bottom holder as in standard drawing [4], [9], [10]).

The following values were adopted as the part size (the dimensions of the square cup cross section): c = b/a = 80/80 = 1.0, c = 120/80 = 1.5 and c = 160/80 = 2.0 (based on the suggestions provided by the technical literature [4], [9], [10]).

The tool used in experimental testing, Figure 2, was positioned in the work area of the hydraulic press of 1600 kN. The mold was firm and it included replacable plates (Pos. 5, 6, 7 i 8), enabling different parts height obtaining. The role of a punch was performed by the working fluid, and its effects were transmitted through the special rubber membrane (Pos. 24) to the sheet metal (Pos. 37). To prevent fast destruction of the part bottom, a movable cup bottom holder (Pos. 14) was used. The movable cup bottom holder exerted a constant pressure provided by the force $F_h$. This force was provide by the press element exerting pressure, which was adjusted to be a cup bottom holder., [8].




1 - Basic plate
2 - Post
3 - Tool casing
4 - Lateral casing plate
5 - Die
6 - Drawing mold plate
7 - Mold basic plate
8 - Retaining plate
9 - Screw M6
10 - Guiding bush
11 - Bottom holder carrier
12 - Bush
13 - Screw M8
14 - Bottom cup holder
15 - Screw M8
16 - Blank holder
17 - Blank holder plate
18 - Pressure plate
19 - Screw M8
20 - Pressure exerting element
21 - Blank holder carrier
22 - Right retainer
23 - Lefr retainer
24 - Membrane
25 - Screw M10
26 - Membrane carrier
27 - Screw M10
28 - Casing
29 - Internal plate
30 - Shorter retainer
31 - Hydraulic cylinder
32 - Screw M12
33 - Screw M10
34 - Screw M10
35 - Longer retainer
36 - Hydraulic cylinder plate

*Figure 2: The tool used in experimental testing*

The required blank holder pressure (Pos. 16) was provided by means of four hydraulic cylinders (Pos. 31).

The values of blank holder pressures for the above mentioned condition and two different values taken for corner zone radius are shown in Table 1 and Table 2.

*Table 1: The values of blank holder pressures, in MPa (corner zone radius $r_c$ = 12.5 mm)*

| Cup height (depth) | Material | | Cup length to width ratio | | |
|---|---|---|---|---|---|
| | | | c = 1.0 | c = 1.5 | c = 2.0 |
| h = 30 mm | steel (RSt13, DIN 17007) | calculated | 1.325 | 1.310 | 1.347 |
| | | experimental | 1.4 ÷ 1.6 | 1.4 ÷ 2.2 | 1.9 ÷ 2.3 |
| | brass (CuZn37, DIN 17660) | calculated | 1.279 | 1.264 | 1.300 |
| | | experimental | 1.4 ÷ 1.7 | 1.3 ÷ 2.9 | 1.8 ÷ 2.3 |
| | copper (E1-Cu58, DIN 1708) | calculated | 0.910 | 0.900 | 0.920 |
| | | experimental | 1.1 ÷ 1.3 | 0.9 ÷ 1.6 | 1.1 ÷ 1.9 |
| h = 45 mm | steel (RSt13, DIN 17007) | calculated | 1.748 | 1.653 | 1.647 |
| | | experimental | 1.4 ÷ 1.8 | 1.7 ÷ 2.7 | 1.7 ÷ 2.8 |
| | brass (CuZn37, DIN 17660) | calculated | 1.686 | 1.595 | 1.568 |
| | | experimental | 1.8 ÷ 2.3 | 1.6 ÷ 2.8 | 2.5 ÷ 2.9 |
| | copper (E1-Cu58, DIN 1708) | calculated | 1.200 | 1.135 | 1.131 |
| | | experimental | 1.4 ÷ 1.7 | 1.4 ÷ 1.8 | 1.3 ÷ 1.9 |

*Table 2: The values of blank holder pressures, in MPa (corner zone radius $r_c$ = 16.0 mm)*

| Cup height (depth) | Material | | Cup length to width ratio | | |
|---|---|---|---|---|---|
| | | | c = 1.0 | c = 1.5 | c = 2.0 |
| h = 30 mm | steel (RSt13, DIN 17007) | calculated | 1.322 | 1.306 | 1.346 |
| | | experimental | 1.4 ÷ 1.6 | 1.4 ÷ 2.2 | 2.0 ÷ 2.4 |
| | brass (CuZn37, DIN 17660) | calculated | 1.276 | 1.260 | 1.296 |
| | | experimental | 1.5 ÷ 1.7 | 1.3 ÷ 2.9 | 1.8 ÷ 2.2 |
| | copper (E1-Cu58, DIN 1708) | calculated | 0.908 | 0.896 | 0.920 |
| | | experimental | 1.1 ÷ 1.3 | 1.0 ÷ 1.6 | 1.1 ÷ 1.9 |
| h = 45 mm | steel (RSt13, DIN 17007) | calculated | 1.747 | 1.650 | 1.644 |
| | | experimental | 1.4 ÷1.8 | 1.6 ÷ 2.3 | 2.0 ÷ 2.4 |
| | brass (CuZn37, DIN 17660) | calculated | 1.685 | 1.592 | 1.586 |
| | | experimental | 1.8 ÷ 2.0 | 1.6 ÷ 2.2 | 2.5 ÷ 2.7 |
| | copper (E1-Cu58, DIN 1708) | calculated | 1.200 | 1.130 | 1.280 |
| | | experimental | 1.4 ÷ 1.7 | 1.4 ÷ 1.8 | 1.3 ÷ 1.9 |

It is well known that good parts can be obtained by exerting the blank holder pressure $p_{bh}$ falling within a certain interval of values. In case the selected blank holder pressure is above the interval limit value provided by the working fluid, the flange material is hampered and the cup bottom part is destroyed (Fig. 3, a). In case the blank holder pressure is below the interval limit value, wrinkles can be formed (Fig. 3, b). So the specific pressure of the blank holder can be altered within the interval of limit values, the lower and upper limits being determined by the wrinkle or destruction occurrence respectively.

Experimental testing has established favourable ranges for the blank holder pressure. The results are shown in Figure 4. The limit values are denoted by thin straight lines. The diagrams of blank holder pressure variation are shown in Fig.4 too, and they were obtained according to expression (1) – bold dash line and (2) – bold full line respectively.

a) b)

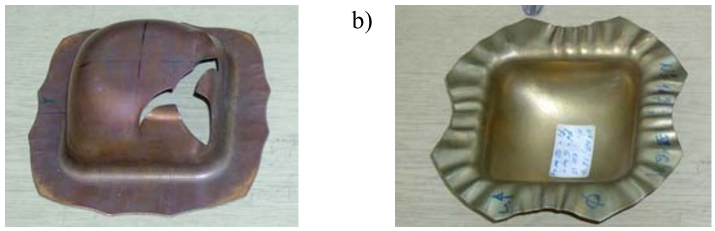


*Figure 3: Destruction of the part bottom (a) and wrinkles in the cup flange (b)*

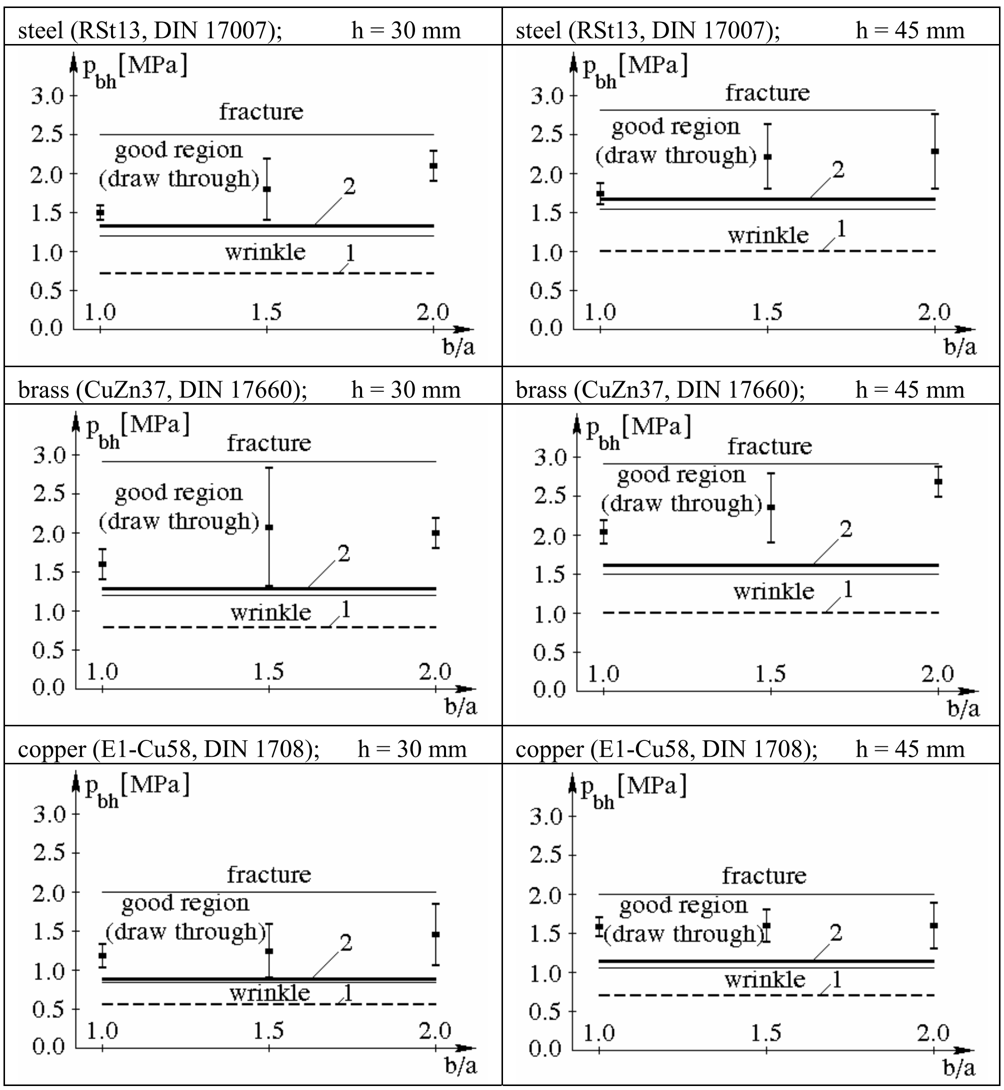



*Figure 4: The results of experimental testing*

The values for blank holder pressure obtained by means of calculation (curve 1 and 2 according to expressions (1) and (2) respectively) are approximately the same taking into account the same part height and the same material, therefore it is adopted that they are straight lines.

In real practice, in order to prevent the occurrence of flange wrinkles, the blank holder pressure should be increased along with the growth of ratio c = b/a, i.e. with the increase of the length retaining the same part width.

It can be observed that lines 1 (dash line in Figure 4), obtained according to the applied Siebel's empirical and theoretical expression (1) and expressions (3) do (6), fall within the range of excessive wrinkles. This phenomenon was observed even in the experimental researches carried out and presented in papers [11] and [12].

Only when the substitution of the member $d_{inf}$ /(200·s) by the member $D_{0f}$ /(200·s) is applied in expression (1) and by adopting the value of 0.003 for the dimensionless coefficient, i.e. when the expression (2) is applied, the curves 2 (bold full lines) obtained by calculation fall within the lower range of experimental values, in which good parts were obtained.

It is good, since according to the expression (2) the values obtained for the blank holder pressure are in the lower range of the good area interval, therefore there wil be no hampering of the flange material and consequently no destruction in the bottom part. Even if minor wrinkles have occured, they can be eliminated in the next forming phase by increasing the blank holder pressure.

## 4. CONCLUSION

Together with certain modifications Siebel's expression used to calculate the blank holder pressure in the process of deep drawing of cylindrical and cnical parts can be also applied to square cups oil hydraulic forming.

The values of blank holder pressure obtained in the process of square cups oil hydraulic forming were calculated according to Siebel's expression (1) and they fall below the lower boundary value of good area, namely in the region of marked wrinkles.

The values of blank holder pressure obtained according to the modified expression (2are within the good area somewhat above the lower limit value.
It is a guarantee that there will not be any hampering of the flenge material and destruction in the bottom area. Even if there has been some wrinkling on the flange, a slight blank holder pressure increase can eliminate them in the next working cycle.
The expression (2) has given favourable results in deep drawing by means of a working fluid in the following case of:

- Square parts of rectangular and square cross section;
- Square parts of various height (30÷45 mm) with the dimension of a cross section of (80×80, 80×120 and 80×160 mm),
- Square parts with different radius in corner zone (12.5 and 16.0 mm) and
- Square parts of three different materials: electrolytical copper (E1-Cu58, DIN 1708), brass (CuZn37, DIN 17660) and steel (RSt13, DIN 17007).

Owing to this the application of this expression has shown to be also justifiable square parts made of other materials in the process of oil hydraulic forming,

The application of expression (2) is justifiable only in case in which the square part length to width ratio is c = 2.0, because in cases where this ratio is higher the use of draw bed is a must.

## 5. REFERENCES


[1] Rančić B.:
Oblikovanje delova od lima nestišljivim fluidom, monografija, Mašinski fakultet, Univerzitet u Nišu, 2005.

[2] Siebel E.:
Niederhalterdruck beim Tiefziehen, Stahl und Eisen, 74 (1954), p. 155÷158.

[3] Dutschke W.:
Grundlagen des Tiefziehens nicht rotationssymetrischer prismatischer Teile, Dr.-Ing. Dissertation, Technische Hochschule, Stuttgart, 1958.

[4] Romanovskii V.P.:
Spravočnik po holodnoi štampovke, Mašinostroenie, Leningrad, 1979.

[5] Musafija B.:
Obrada metala plastičnom deformacijom, Svjetlost, Sarajevo, 1972.

[6] Stoiljković V.:
Teorija obrade deformisanjem, Mašinski fakultet u Nišu, Niš, 1980.

[7] Rančić B., Janković P.:
Determining the blank shape and size for square cups in oil-hydraulic forming process, 5th International conference "Research and Development in Mechanical Industry", RaDMI 2005, 04-07. September 2005, Vrnjača Banja, Serbia and Montenegro.

[8] Rančić B., Blagojević V.:
Praktično rešenje za povećanje radnih funkcija hidrauličke prese dvostrukog dejstva, HIPNEF '98, Zbornik radova, Beograd, oktobar 1998., (39÷44. str.)

[9] Strackerjahn W.:
Die Voraussage des Versagenfalls beim Tiefziehen rechteckiger Teile, Dr.-Ing. Dissertation, der Fakultät für Maschinenwessen der Universität Hannover, 1982.

[10] Hasek V.:
Bestimmung des Zieheverhaltnisses beim Ziehen von Blechteilen mit komplizierten Formen - Teil I, Blech Rohre Profile, 2, 1986., (57.÷61. str.).

[11] Stoiljković V.:
Naponsko deformaciono stanje pri izradi elemenata dubokim izvlačenjem nestišljivim fluidom sa pridržavačem i identifikacija uticajnih faktora sa uspostavljanjem njihovih korelacionih odnosa, doktorska disertacija, Mašinski fakultet u Nišu, Niš, 1977.

[12] Rančić B.:
Naponsko i deformaciono stanje pri oblikovanju nesimetričnih delova od lima nestišljivim fluidom sa određivanjem parametara procesa, doktorska disertacija, Mašinski fakultet u Nišu, Niš, 1993.

# PREDLOG IZRAZA ZA ODREĐIVANJE PRITISKA DRŽAČA LIMA PRI DUBOKOM IZVLAČENJU KUTIJASTIH DELOVA NESTIŠLJIVIM FLUIDOM

*Rančić Bojan, Janković Predrag, Stoiljković Vojislav*
*Univerzitet u Nišu, Mašinski fakultet, A. Medvedeva 14, 18000 Niš, Srbija*

## REZIME

Pri dubokom izvlačenja cilindričnih i koničnih delova primenjuje se Siebel-ov analitičko-eksperimentalni izraz za određivanje pritiska držača lima. Primena ovog izraza daje dobre rezultate u industrijskoj praksi.

U ovom radu izvršeno je prilagođavanje Siebel-ovog izraza za primenu i kod izvlačenja kutijastih delova nestišljivim fluidom. Takođe, izvršena je i eksperimentalna provera primene navedenog izraza pri dubokom izvlačenju kutijastih delova pravougaonog i kvadratnog poprečnog preseka.

Predloženi izraz dao je zadovoljavajuće rezultate pri dubokom izvlačenju nestišljivim fluidom:

- kutijastih delova i pravougaonog i kvadratnog poprečnog preseka,
- kutijastih delova različite visine (30÷45 mm) i dimenzija poprečnog preseka (80×80, 80×120 i 80×160 mm),
- kutijastih delova sa različitim vrednostima radijusa u uglu dela (12.5 i 16.0 mm) i
- kutijastih delova od tri različita materijala: elektrolitički bakar (ECu), mesing (Cu63Zn) i čelik (Č.0147.P5.m).

Primenom predloženog izraza dobijaju se vrednosti pritiska držača lima na donjoj granici dobre oblasti, tako da njegova primena opravdana i za druge materijale i debljine lima, ali samo u slučaju da nije potrebno korišćenje kočećih rebara.