ADJUSTABLE DRAWBEAD AND VARIABLE CONTACT PRESSURE AS TRIBOLOGICAL INFLUENCES IN SHEET METAL STRIPE SLIDING TEST

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ABSTRACT

The paper presents the experimental analysis of the influence of variable drawbead height and variable contact pressure on drawing force in thin sheet metal stripe drawing test. For the needs of experiment, a computerized device was made which enables the accomplishment of previously specified functional dependencies of drawbead height and contact pressure on duration of stripe drawing process. It is possible to monitor the simultaneous influence of friction conditions (dry or application of lubricant), drawbead roundness radius (2mm and 5 mm), 10 functional dependencies of drawbead height and 10 functional dependencies of contact pressure on drawing force of sheet metal stripes made of various materials. Stripe dimensions are 250 x 30 mm, and drawbead thickness is 10 mm. Maximal pressure value is 20 MPa, and maximal drawbead height value is 8 mm.

Within the results presented here, the influence of two types of variable pressure function in combination with one constant value and two variable drawbead height functions are monitored. Dependencies of drawing force indicate the possibility for applying the specified influences in order to correct the forming process course in computer simulations and systems for deep drawing processes control.

KEYWORDS: Sheet metal, Stripe test, Variable pressure, Adjustable drawbeads

1. INTRODUCTION

The process of deep drawing of thin sheet metals is influenced by many factors, but they can all be adjusted before the beginning of the forming process, with the exception of two factors which can be controlled during the process. Those are - contact pressure on work piece flange and drawbeads height /1/. Controlling of both parameters requires rather complex devices. Optimal functions of pressure and drawbeads height are not easy to define, especially if the drawing depth and work piece quality are set as a criterion. By knowing the concept of those functions well, it is possible to upgrade the results of forming process by applying somewhat simpler equipment (tools and machines) with smaller investments. Such systems are usually called open-loop and they need control devices only for realization of previously defined pressure and drawbead height functions /2, 3/. Active systems, which need constant dynamic feedback between the given function of the objective and controlled and controlling variables throughout the process, are much more complex. The functions of the objective and controlled variable can be different: wrinkle height, thinning in critical zone, flange displacement, flange thickness change, friction force, forming force, stress in work piece wall etc. The given objective functions are defined either by computer simulations or by previous experiments. Pressure on flange and drawbead height are the controlling actions. This requires high velocity of reacting to controlled values change and robust controlling hardware and software apparatus, which implies significant investments /4, 5/.

Application of drawbeads on work piece flange at deep drawing of complex geometry parts is not an innovation. The use of fixed drawbeads and constant blank holding force on flange are

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the most frequent even nowadays. The reason for this is simple. The forming processes can often be successfully performed with minor costs. However, due to the development of new materials of worse formability properties, in most cases it is not possible to accomplish the satisfactory results by classical methods.

Classic application of constant height drawbeads is well known /6, 7/. There are also some new ideas, such as application of drawbeads in which the angle between drawbead axis and sheet metal plane is different from 90^{o} /8/. There is also the increased interest in many numeric simulations and virtual application of drawbeads in processes of complex work pieces forming /9/.

The application of blank holding force without drawbeads has been the subject of separate researches based on same aforementioned principles /10, 11, 12, 13/.

In this paper, the emphasis is on investigation and understanding of the connection between drawing force and influences combinations which include: friction conditions (dry, application of lubricant), drawbead geometry (two rounding radii), two variable functions of both pressure and drawbead and one constant drawbead height value. The significance of the physical model applied in actual experiments is clearly seen in Figure 1 /7/.

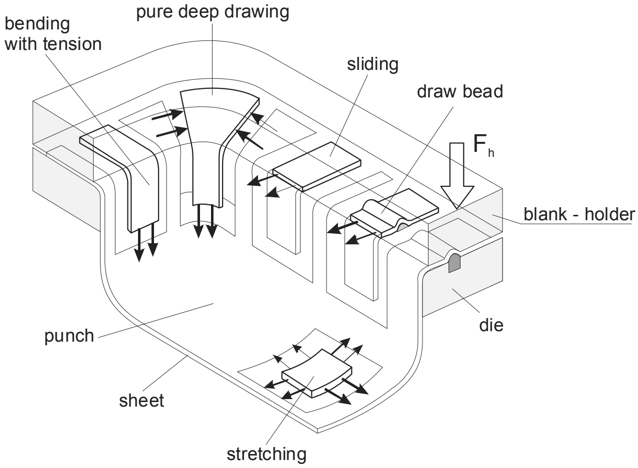

Figure 1: Scheme of physical models at deep drawing of complex geometry parts.

2. EXPERIMENTAL CONDITIONS

2.1 Material

Stripes used in the experiment are made of classic low-carbon steel sheet metal, quality DC04, thickness 0.8 mm. The basic mechanical and formability properties are given in Table 1.

Table 1: Material properties.

<table>
<tr><td colspan="6">A. Mechanical properties, DC04</td></tr>
<tr><td></td><td>R_p, MPa</td><td>R_m, MPa</td><td>A_{80}, %</td><td>n</td><td>r</td></tr>
<tr><td>$\overline{X}$</td><td>200,2</td><td>350,6</td><td>36,06</td><td>0,235</td><td>1,51</td></tr>
<tr><td colspan="6">Strengthening curve (0^{o}) : $K = 204.9 + 388.29\varphi^{0.448}$, MPa</td></tr>
<tr><td colspan="6">B. Roughness properties</td></tr>
<tr><td>R_a , μm</td><td>R_t , μm</td><td colspan="2">R_z , μm</td><td>R_P, μm</td><td>pike/mm</td></tr>
<tr><td>1,81</td><td>12,40</td><td colspan="2">10,89</td><td>6,19</td><td>≈10</td></tr>
</table>

In one case, the friction conditions were directed by dry surfaces which were provided due to degreasing and cleaning by acetone. In the other case, the contact surfaces were richly covered (by sponge) with oil for deep drawing of the following properties at 40°C: kinematic viscosity 45 mm^2/s, dynamic viscosity 42 mPas and density 0,93 kg/dm^3.

Dimensions of applied stripes were: length 250 mm, width 30 mm and thickness 0,8 mm.

2.2 Experimental device

The general scheme of the apparatus is shown in Figure 2, and physical appearance in Figure 3 . Sheet metal stripe is positioned vertically between contact pairs, drawbead and die, which are variable. Drawing force is obtained from laboratory press ERICHSEN 142/12 in range 0-20 kN, as well as stress signal for measuring the force of proper sensor. Hydro-cylinders for drawbead displacement and pressure realization are fed by aggregate ERICHSEN of nominal pressure 100 bars and flow 1,5 l/s. The oil from the aggregate runs through the series of controllable proportional hydro valves to both cylinders. Measuring and pressure controlling branch consists of pressure sensor which gives the current true value signal and control unit (micro-controller) which receives the given desired value from the software and sends signal D/A to the convertor. The received analogous signal is transmitted to the control card of the proper hydro-valve connected to the pressure cylinder. In controlling branch, due to drawbead motion, the current true drawbead position is read by rotation encoder. After processing, the signals are sent to the control unit (micro-controller), and then to the card for control of hydro-valve for drawbead cylinder. One signal is related to the direction change, and the other one to the value of drawbead motion function. For measuring and reading the true drawbead position, supporting branch with inductive sensor and proper amplifier is made. All true values signals are brought into PC computer with integrated A/D card and proper original software, which enables monitoring of all its values, their memorizing, presentation as well as generating of pressure and drawbead motion functions necessary for micro-controller performance.

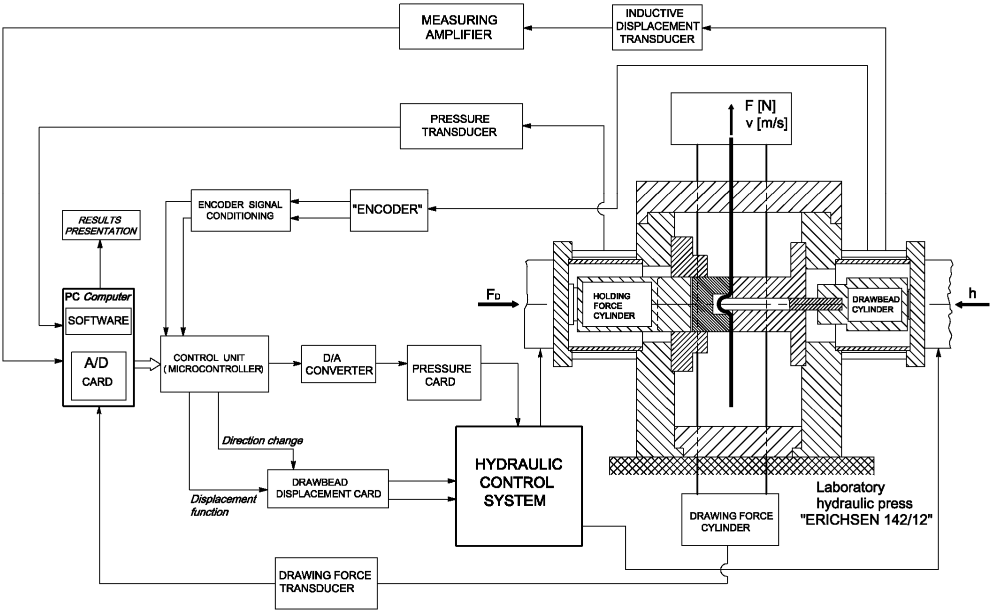

Figure 2: Block scheme of experimental apparatus.

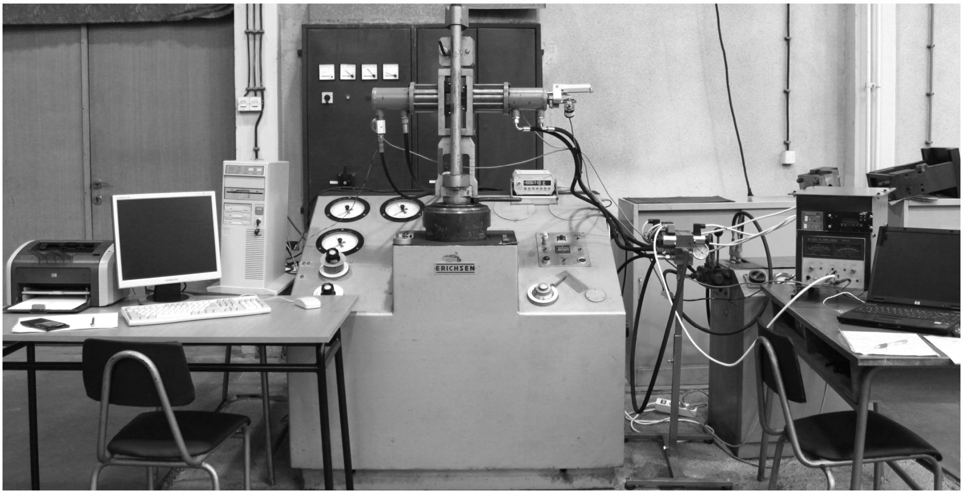

Figure 3: Physical appearance of experimental apparatus.

Figure 4 shows the sketch of drawbead (1) and die (2). Drawbead is 10 mm thick and is applied with two radii: 2 mm (shown in the sketch) and 5 mm (shown in the photo, Figure 5 and Figure 6). Die rounding radius is 2 mm, and die opening is 12 mm. Both drawbead and die can be varied with the aim of monitoring the influence of drawbead geometry change. Active surfaces of drawbead and die are fine grinded and polished.

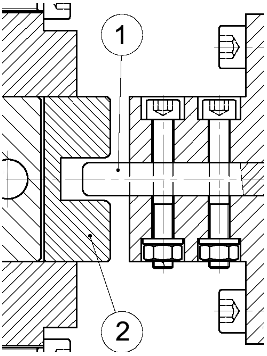

Figure 4: Scheme of drawbead action.

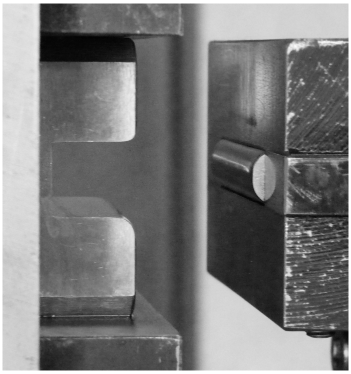

Figure 5: Drawbead and die before contact.

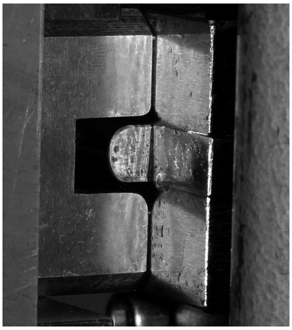

Figure 6: Drawbead and die in contact.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Pressure and drawbead displacement functions

For the needs of planned comprehensive experiment, 6 variable dependencies of both pressure and drawbead motions on time, as given functions, were defined. In Figures 7 to 12, those functions are marked with numbers 1 to 6. Dependencies 5 and 6 are linear, and 1, 2, 3 and 4 non-linear – parabolic. Functions were defined based on empiric values of minimal and maximal pressure (0-20 MPa) and drawbead height (2-8 mm). Process duration was conditioned by limited stripe displacement and adopted sliding velocity of 20 mm/min. This conditioned maximal process duration of 3 min. Dependency signed from 7 to 10 are related to constant values of pressure and drawbead height.

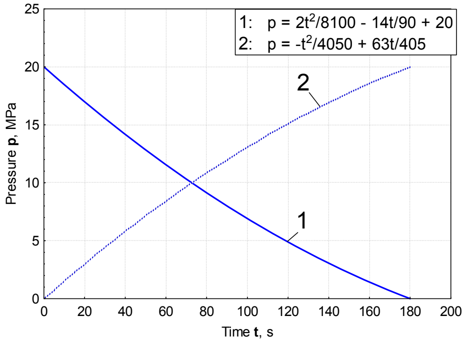

Figure 7: Previously defined dependencies of contact pressure on time.

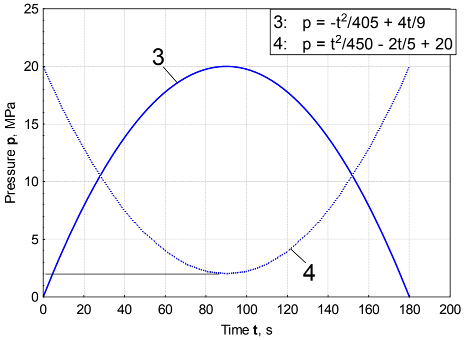

Figure 8: Previously defined dependencies of contact pressure on time.

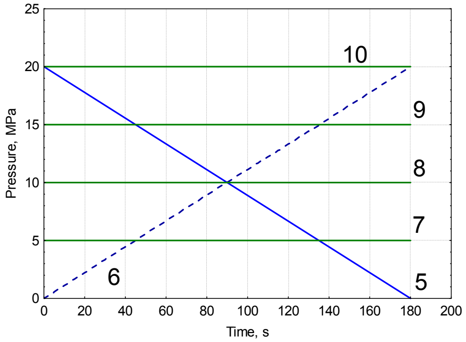

Figure 9: Previously defined dependencies of contact pressure on time.

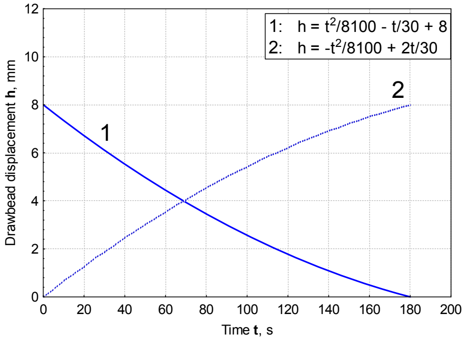

Figure 10: Previously defined dependencies of drawbead height on time.

The purpose of functional dependencies defined in such a way is the inclusion of wide range of possible actions: decreasing, increasing, combined decreasing-increasing and increasing-decreasing, linear and non-linear. Monitoring of the response of drawing force change to performance of such dependencies together with friction conditions and drawbead geometry is the most important part of this research.

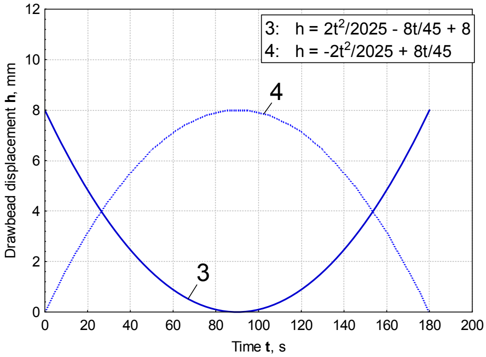

Figure 11: Previously defined dependencies of drawbead height on time.

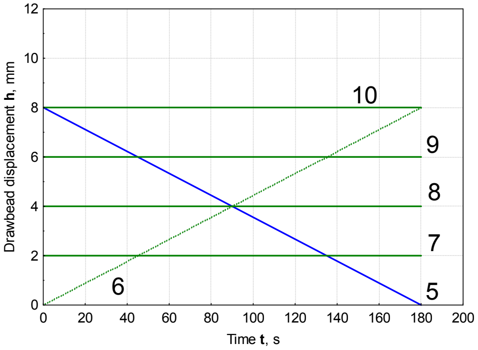

Figure 12: Previously defined dependencies of drawbead height on time.

3.2 Measured drawing force values

Figure 13 shows the realy achieved dependencies of pressure change regarding given functions marked with P4 and P3 in figure 8. Figure 14 shows the constant dependence of drawbead height (h≈6 mm) marked with R9 in figure 12. Such a combination was selected with the purpose of checking the response of drawing force to complex decreasing-increasing dependence of contact pressure during the process, whereat the drawbead height is constant with value which matches practical conditions for applied sheet metal type. In addition to that, it was necessary to estimate the influence of friction conditions and drawbead geometry.

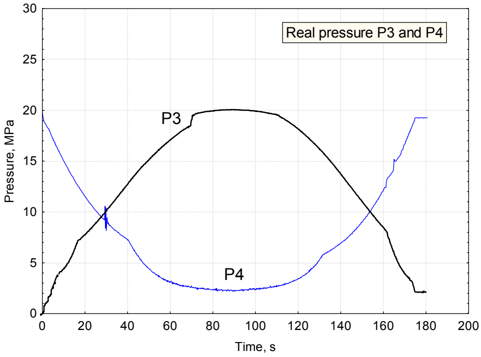

Figure 13: Real dependencies of pressure on time.

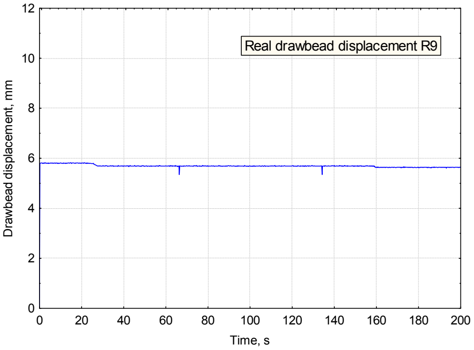

Figure 14: Real dependencies of drawbead height on time.

Figures 15 and 16 present the responses to previous requests. In Figure 15, dependence of drawing force shows the typical reaction to change of pressure P4 at drawbead height R9. The response is more intensive for drawbead with rounding radius 5 mm, i.e. intensity decrease is higher. The influence of friction conditions change is almost negligible. In major part of the stripe travel, curves related to dry friction (mark D – dry, in figure 15) are equivalent to oil application curves (mark L – lubricant). In maximal force zone, on the right side of the diagram, in dry

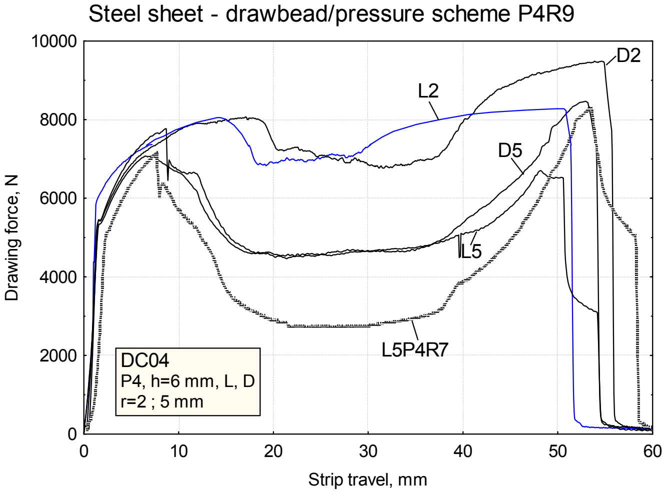

Figure 15: Comparative presentation of drawing force dependencies on stripe travel at various conditions.

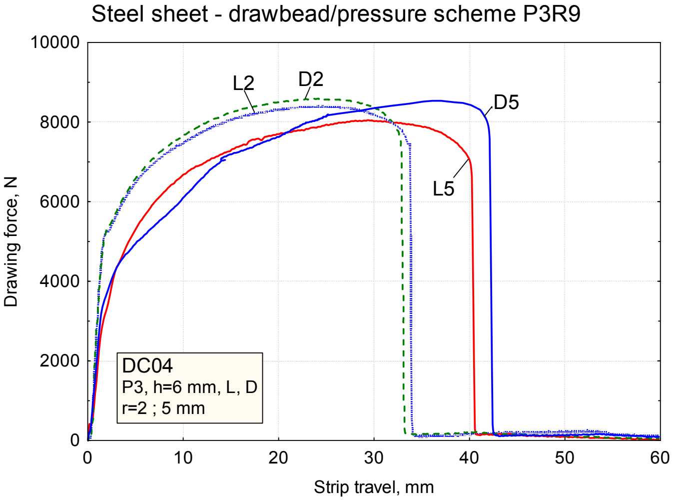

Figure 16: Comparative presentation of drawing force dependencies on stripe travel at various conditions.

friction conditions, force intensity is higher. In conditions with somewhat difficult stripe sliding, with drawbead radius 2 mm (curves L2 and D2), force intensity decrease is considerably smaller and equivalence of curves L2 and D2 is weaker. As a confirmation of the observed trend, curve marked L5P4R7 is shown, measured in even milder sliding conditions, with lubricant and constant drawbead height of 2 mm (R7 according to Figure 12).

The reaction of drawing force to pressure, according to the function P3 (Figure 8 and Figure 13) is followed by pressure increase, but the difference between application of drawbead with radii 2mm and 5mm is not as prominent as in figure 15. The reason for this is the fact that the pressure intensity at change P3 is higher than P4 on major part of stripe travel, which additionally complicates sliding conditions.

Figure 18 shows realy realized functions of drawbead height change R2 and R6 (according to Figure 7, Figure 12 and Figure 17). Dependences are increasing, whereat parabolic

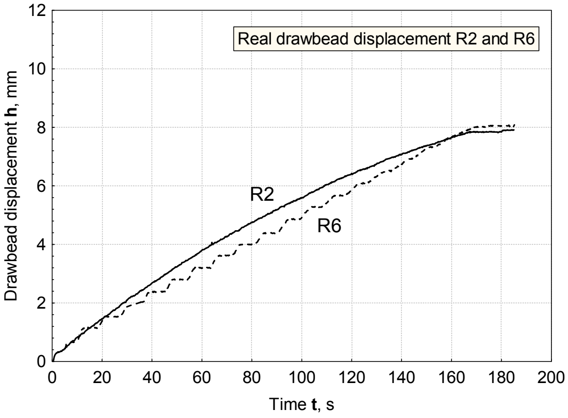

Figure 17: Real dependencies of drawbead height on time.

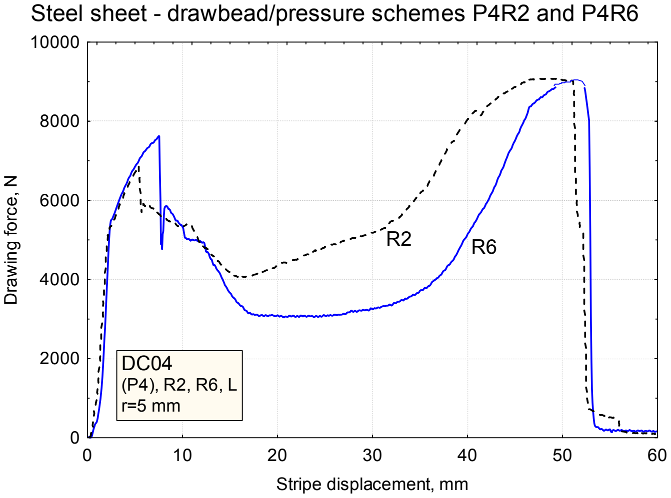

Figure 18: Comparative presentation of drawing force dependencies on stripe travel at various conditions.

dependence R2 has more intensive increase in the first half of the travel. This difference contains the cause for drawing force reaction which shows higher intensity decrease for milder process conditions at linear dependence of drawbead height R6.

4. CONCLUSIONS

The presented apparatus for testing the tribological influence on drawing force in the process of stripe sliding over drawbead in conditions of variable contact pressure and variable drawbead height enables accurate registering of drawbead geometry change, friction conditions, pressure action and drawbead height.

This paper presents a part of experimental results for the sliding test for low-carbon steel sheet metal stripe. Based on the presented results, the following conclusions can be made:

a) response of drawing force is more intensive in milder sliding conditions, at larger drawbead roundness radius, smaller drawbead height and smaller pressure,

b) drawbead roundness is more influential than friction conditions,

c) response of drawing force is registered even at relatively small differences in drawbead height change during the process,

d) by favourable combination of simultaneous performance of contact pressure change, change of drawbead height, friction conditions and drawbead geometry, it is basically possible to upgrade the course of sheet metal forming process,

e) by such investigations, with rather simple apparatus, it is possible to define significant data for numerical simulations and immediate application in practice at deep drawing of complex geometry parts.

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