



## PHYSICAL MODELLING OF VARIABLE CONTACT PRESSURE AND VARIABLE DRAWBEAD HEIGHT INFLUENCE ON DEEP DRAWING OF THIN SHEETS

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**Abstract:** For this experimental research, electro-hydraulic computerised device for sheet metal stripes sliding was made. Its main property is realisation of contact pressure and drawbead height as functions dependent on time, i.e. stripe travel. In addition, it is also possible to measure drawing force, pressure, drawbead displacement etc.

The paper presents the preliminary results of the investigation of decreasing drawbead height influence in combination with increasing-decreasing contact pressure function. The stripes are made of low-carbon steel sheet metal of 0,8 mm thickness. Contact conditions are influenced additionally in two ways - by mineral oil lubrication and dry surfaces application. Drawbead geometry, with rounding radii of 2 and 5 mm, is also varied.

The results indicate that simultaneous influence of variable drawbead height, variable contact pressure, drawbead geometry and proper friction conditions can influence substantially the plastic flow process.

**Keywords:** deep drawing, variable drawbead height, variable contact pressure.

### 1. INTRODUCTION

Due to the significance and complexity of the process of thin sheet metals deep drawing, the tendency to accomplish the control of forming process is the latest trend. In order to succeed in that, it is necessary to select, out of a large number of influential factors, the ones which can be varied throughout the forming process, thus correcting it until it is completed successfully. There are only two such factors: contact pressure and drawbead height [1].

Process control through active complex (closed-loop) systems requires constant dynamic feedback between the given function of the objective, controlled and controlling variables. The functions of the objective and controlled variable can be different: wrinkle height, thinning in critical zone, flange motion, 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 present the

controlling effects. High velocity of reacting to controlled values change and robust controlling hardware and software apparatus are required, which all implies significant investments [2, 3].

There is also the alternative – a much simpler approach – used in this paper. However, first it is necessary to define optimal functions of pressure and drawbead height according to proper criterion (drawing depth, piece quality etc.). This often requires comprehensive experiments [4, 5] in order to identify the character of specified factors influence. With such information, it is possible to form the controlling apparatus for practical application whose main objective is to realise previously defined optimal functions of pressure and drawbead height. Such equipment requires considerably smaller investments regarding hardware and software and is far more accessible to a wide range of users.

Application of constant height drawbeads is still most often applied and well known [6, 7]. The same goes for application of constant blank holding force on flange. The main reasons for this are smaller

forming process costs. However, due to the development of new materials of more complex formability properties, in most cases it is not possible to accomplish the satisfactory results by classical methods.

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° [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 draw beads is the subject of separate researches

based on the same aforementioned principles [10, 11, 12].

In this paper, the emphasis is on investigation of the character of the connection between drawing force and various influences combinations. They include friction conditions (dry, application of lubricant), drawbead geometry (two rounding radii), one variable function of pressure of increasing-decreasing character, two functions of drawbead of decreasing character and corresponding constant values of both pressure and drawbead height for comparison. The significance of the physical model applied in actual experiments is clearly seen in fig. 1 [7].

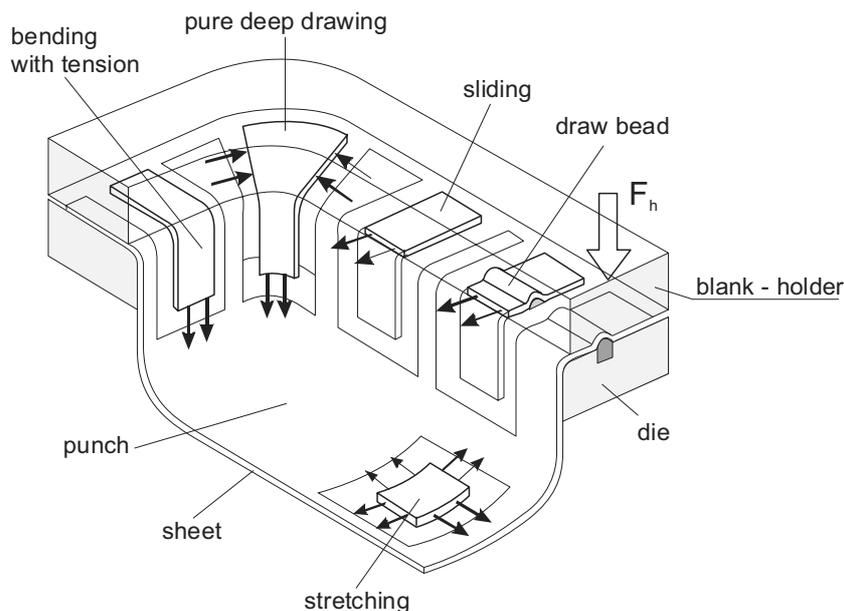


Figure 1. Scheme of physical models at deep drawing of complex geometry parts

## 2. EXPERIMENTAL CONDITIONS

### 2.1 Material

The material of which the stripes used in the experiment are made is classic low-carbon steel sheet metal of quality DC04 and 0.8 mm thickness. The main mechanical properties, properties of formability and roughness are given in table 1.

Table 1. Material properties

A. Mechanical properties, DC04					
	R <sub>p</sub> , MPa	R <sub>m</sub> , MPa	A <sub>80</sub> , %	n	r
Average	200.2	350.6	36.06	0.235	1.51
Strengthening curve (0°): K = 204.9 + 388.9φ <sup>0.448</sup> , MPa					
B. Roughness properties					
R <sub>a</sub> , μm	R <sub>t</sub> , μm	R <sub>z</sub> , μm	R <sub>p</sub> , μm	pike/cm	
0.5	3.9	2.9	1.6	57	

In one case, the friction conditions are dictated by dry surfaces – completely degreased and cleaned by acetone. In the other case, the contact surfaces

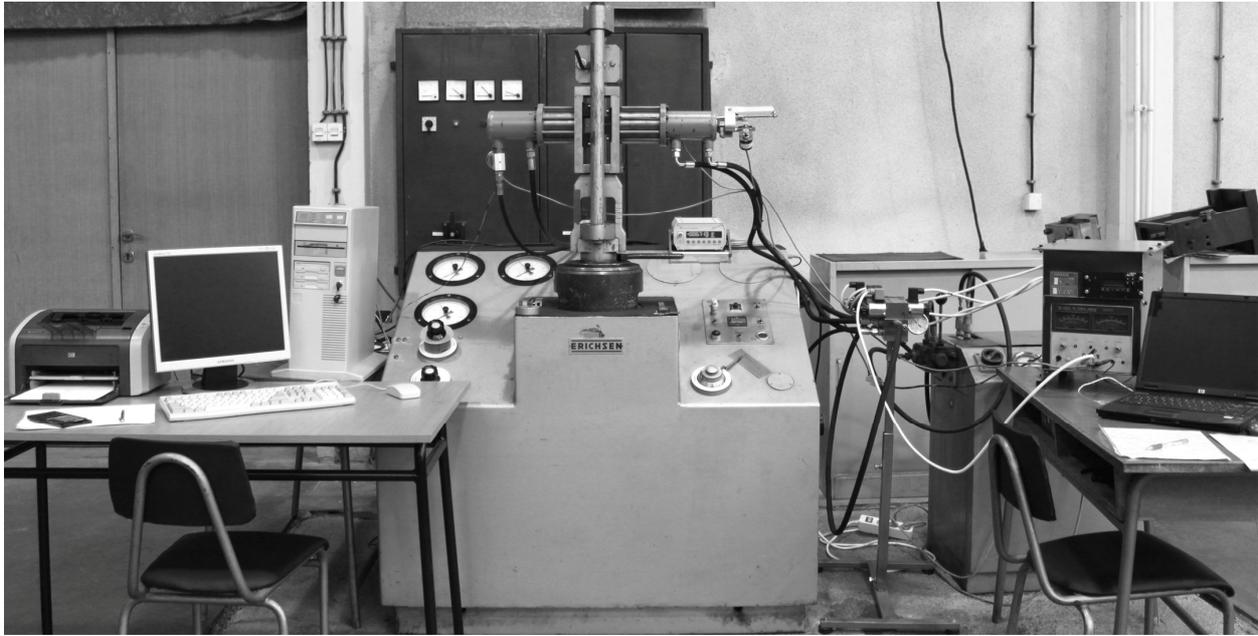
were richly covered (by sponge) with oil for deep drawing of the following properties at 40°C: kinematic viscosity 45 mm<sup>2</sup>/s, dynamic viscosity 42 mPas and density 0,93 kg/dm<sup>3</sup>.

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 6. 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.





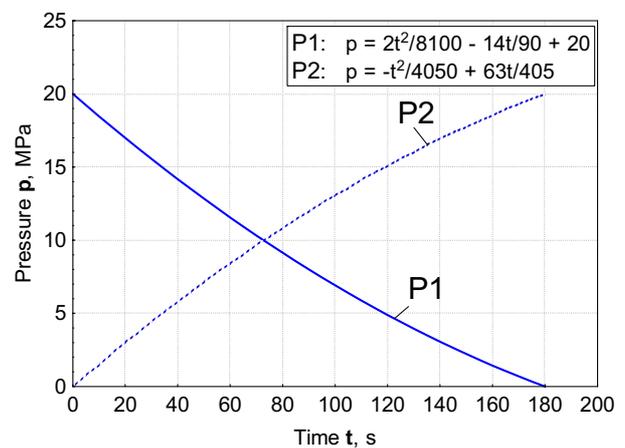
**Figure 6.** Physical appearance of experimental apparatus

Figure 3 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 4 and figure 5). 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.

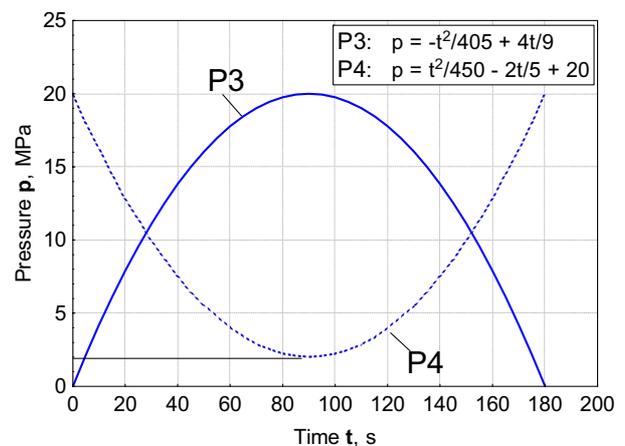
### 3. EXPERIMENTAL RESULTS AND DISCUSSION

#### 3.1 Pressure and drawbead displacement functions

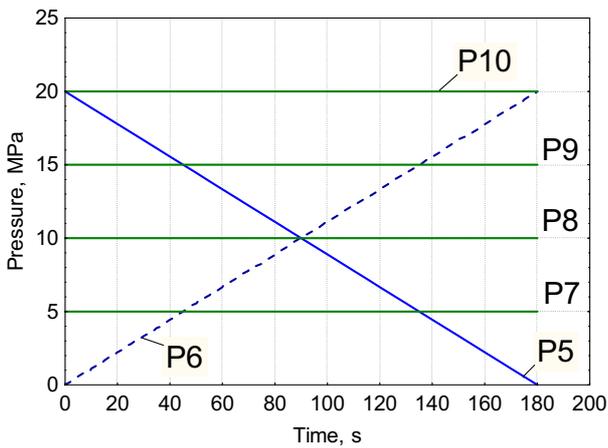
For the needs of planned comprehensive experiment, 6 variable dependencies of both pressure and drawbead motions on time, as given functions, were defined. In figures 7 to 12, those functions are marked with numbers 1 to 6. Dependencies 5 and 6 are linear, and 1, 2, 3 and 4 non-linear – parabolic. Functions were defined based on empiric values of minimal and maximal pressure (0-20 MPa) and drawbead height (0-8 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.



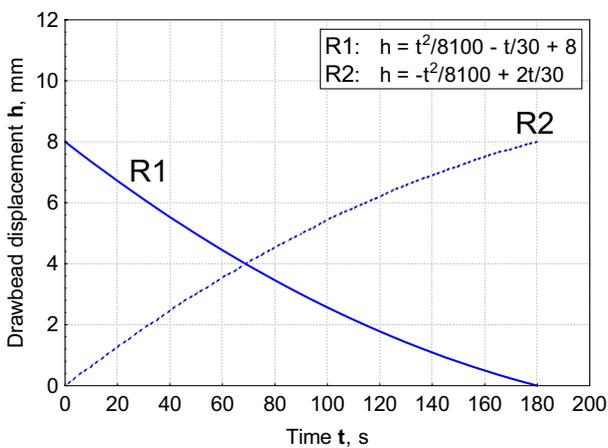
**Figure 7.** Previously defined dependencies of contact pressure on time



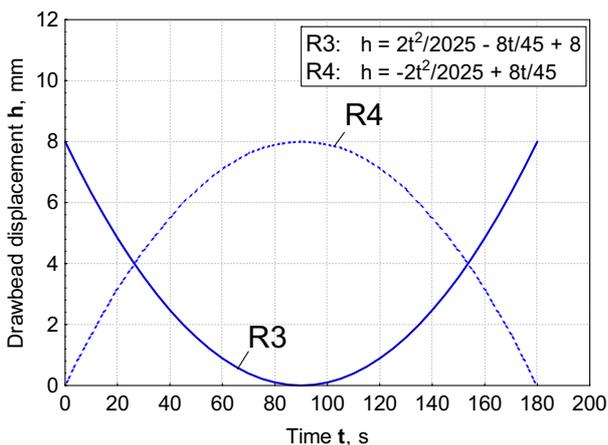
**Figure 8.** Previously defined dependencies of contact pressure on time



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



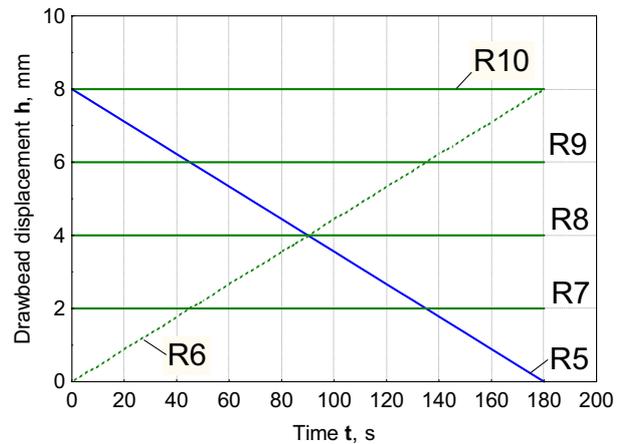
**Figure 10.** Previously defined dependencies of drawbead height on time



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

The purpose of so defined functional dependencies, which have different characters, is the inclusion of wide range of possible influences: decreasing, increasing, combined decreasing-increasing and increasing-decreasing, linear and non-linear. Monitoring of the response of drawing force regarding the performance of such

dependencies together with friction conditions and drawbead geometry is the most important part of this research.



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

### 3.2 Measured drawing force values

Figure 13 shows given and truly achieved dependence of pressure P3 change according to marks from figure 8. Figure 14 shows given and truly achieved decreasing dependencies of drawbead height with marks according to figure 10 and figure 12. Truly achieved constant values of pressure according to scheme P8 and constant drawbead height according to scheme R9 are corresponding, with insignificant deviations. Fig. 9 and figure 12 are not shown here. Such a combination was selected with the purpose of checking the response of drawing force to complex increasing - decreasing dependence of contact pressure during the process together with decreasing functions of drawbead height. The investigation of the following combinations was also carried out: constant pressure P8 – decreasing drawbead function R1 and variable pressure P3 – constant drawbead height R9. The purpose of such combinations is the evaluation of separate influences of variable pressure and drawbead height influence. In addition to that, it was necessary to estimate the influence of friction conditions and drawbead geometry.

Figure 15 shows the influence of drawbead functions R1 regardless of variable pressure. Constant pressure was applied according to scheme P8. Drawing force increases until it reaches the critical value, and then it decreases in proportion to drawbead height decrease. Oscillatory phenomena caused by drawing force sensitivity to gradual change of real function R1 can be observed. Drawbead geometry influence exceeds the varying of contact conditions (mixed to dry). The change of drawbead radius from 5 mm to 2 mm makes stripe

sliding conditions more difficult than the change of friction conditions caused by oil application on dry surfaces. Curve character L2 (lubrication,  $r=2$  mm) is different compared with curve L5 (lubrication,  $r=5$  mm) and D5 (dry,  $r=5$  mm).

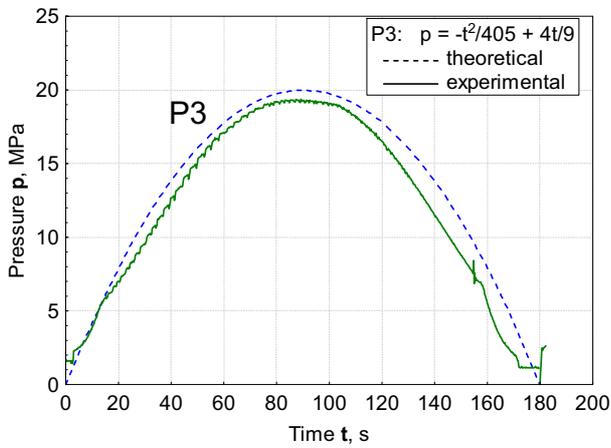


Figure 13. True dependence of pressure on time

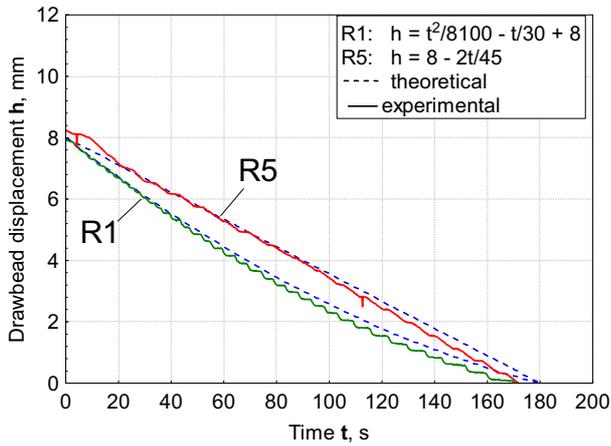


Figure 14. True dependencies of drawbead height on time

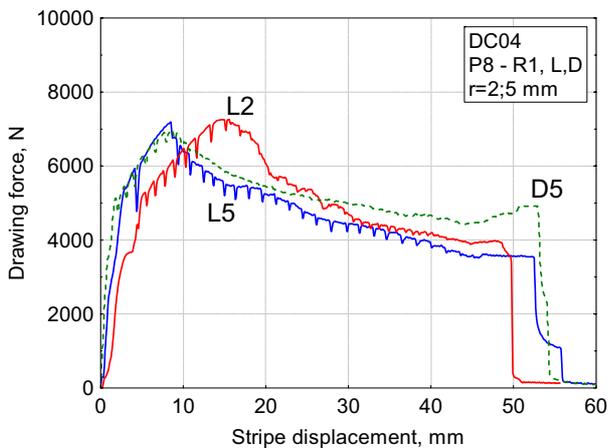


Figure 15. Drawing force dependencies of on stripe displacement

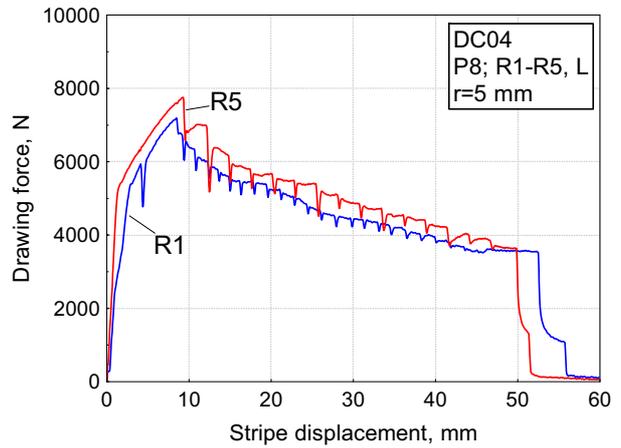


Figure 16. Drawing force dependencies of on stripe displacement

Figure 16 shows the influence of relatively small difference in character and intensity between functions R1 and R5 (figure 14). In line with somewhat higher intensity of R5 change, the reaction of drawing force is obvious and difference in comparison with function R1 application is shown.

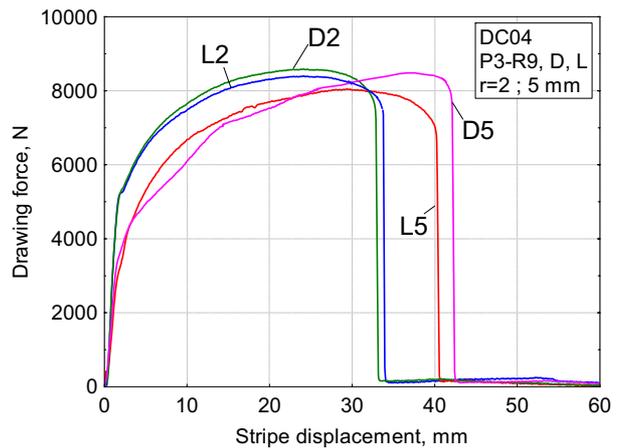


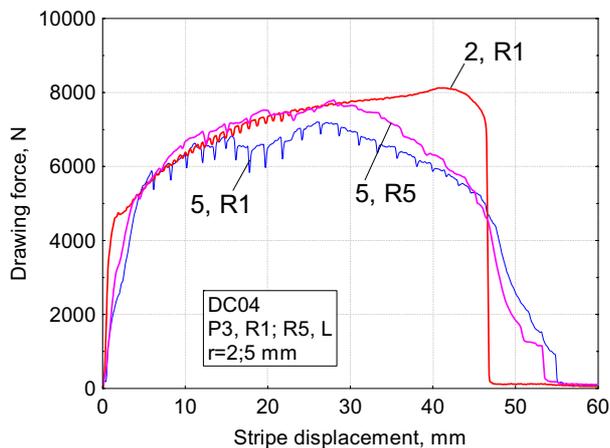
Figure 17. Drawing force dependencies of on stripe displacement

The separate influence of pressure function P3 (at constant drawbead R9 from fig. 12) in all 4 variants is shown in figure 17. The dominant influence of decreased drawbead rounding radius can be seen even more clearly than in fig. 15. Drawing force dependencies for 2 mm radius are separate and of somewhat higher intensity. The change of friction type is noticeable, but it is of smaller intensity. The character of drawing force curves is proportional to the pressure function P3 and is very different from curves in figures 15 and 16.

Figure 18 shows drawing forces at simultaneous actions of pressure functions P3 and drawbead functions R1, i.e. R5.

At 5 mm rounding radius, drawing force curves represent a combination of dependencies from fig.

15 (figure 16) and figure 17. Major part of stripe travel and oscillatory changes were caused by drawbead influence, and general curve form and maximal intensities were caused by pressure influence. By making sliding conditions difficult due to the application of radius  $r=2$  mm, curve form changes and the influence of pressure P3 becomes dominant. Oscillatory disturbance is diminished, and intensity of maximal drawing force somewhat smaller in comparison with figure 17.



**Figure 18.** Drawing force dependencies of on stripe displacement

#### 4. CONCLUSION

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

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) the response of drawing force is approximately equally influenced by simultaneously applied functions of pressure and drawbead height in milder sliding conditions, at larger drawbead rounding radius and smaller friction,

b) in more difficult sliding conditions, at smaller drawbead radius, the influence of pressure function is more significant,

c) drawbead rounding is more influential than friction conditions,

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

e) the character of drawing force response shows that the favourable combination of simultaneous

performance of contact pressure change, change of drawbead height, friction conditions and drawbead geometry makes it possible to control and influence the course of sheet metal forming process

f) 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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