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INFLUENCE OF GEOMETRIC PARAMETERS ON FORCES IN SINGLE POINT INCREMENTAL FORMING PROCESS FOR VARIOUS PARTS

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ABSTRACT

The purpose of this study was to investigate the influence of geometrical parameters on the forces in two directions in a single point incremental forming process. For this purpose, the authors have chosen three types of components: a dome, a truncated cone and a truncated pyramid. The parameters taken into account are the punch diameter and the step down diameter. Tests were made on two thicknesses of the same material but having different mechanical characteristics. To determine the forces, a dynamometer was used. Conclusions regarding the influence of geometrical parameters on the forces for the three types of pieces are also presented.

KEYWORDS: single point incremental forming, experimental research, force measurement, sheet metal

1 Introduction

Recently, the diversity of customers' requirements in the field of metal forming have led to the development of new flexible sheet metal forming processes, like incremental sheet forming (ISF). This process is very suitable for the production of small quantities of metal and for rapid prototyping applications. With this process, it is possible to form sheet metal parts without manufacturing specialized dies and punches. There are many variations of ISF, like hammering [1], incremental forming with water [2] jet or with rollers [3], but the most used method is with a solid hemispherical punch. There are two types of incremental forming with a small punch, single point incremental forming (SPIF), which uses a single punch and two points incremental forming (TPIF), which uses besides the small punch, a male or female die, a support post or a second intender. In both cases, the tool path is controlled by a CNC program. In this metal forming process the tool produces small localized plastic deformations.

The latest research in the area includes studies investigating the possibility to form new materials through ISF, like: sandwich panels, which have ductile and largely incomprehensible cores [4], tailored blanks produced by friction stir welding [5] or polymer sheet components [6]. Other research directions is the optimization of tool path in two points incremental forming [7], to increase the geometrical accuracy of the parts by using an offline model derived from an online sensors-based strategy [8] or to investigate the suitable tool and lubricant for pure titanium sheet [9]. There are also researches that used multi-step tool path to obtain parts with vertical walls having 90^0 [10] or to investigate hybrid processes [11], a combination of ISF with stretch forming.

The paper intends to determine the influence of geometrical parameters on forces and to elaborate mathematical models that would allow the determining of forces in the process for cone frustum, pyramid frustum and dome parts.

2 The experimental layout

The experimental testing installation is composed of the CNC milling machine, the dynamometer and the forming equipment. The data acquisition system is composed of four modules: the transducers (the force transducer for the z direction, the force transducer for the x direction consisting of tensometric devices HBM 350XY11) placed on the two rings of the dynamometer, the signal conditioning modules, the analogue digital conversion device (KPCI 3108, Keithley Instruments Inc.) and a software package that controls the acquisition system and processes the collected data (Mathlab).

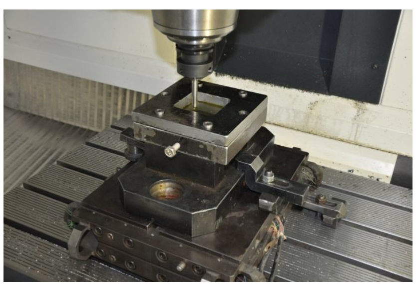

Figure 1. Experimental equipement used for SPIF

For practical implementation of single point incremental forming samples, a DMG Veco 635 CNC milling machine was used. The forming equipment was installed on the machine CNC. It is composed of a bottom plate that has two carriers that support the die, a punch and a retaining ring. Dies have various shapes such as circular, square, triangular and other. For the dome and cone frustum parts was used a circular die, with the inside circle having a diameter of 55.5 mm and 6 mm rounding radii. For pyramid frustum parts was used a square die with the inside side of 60 mm and 6 mm rounding radii. For both components were used two types of punches, one with a diameter of 6mm and another with a diameter of 10 mm. For each type of part, two advances were used on z direction, 0.25 mm and 1 mm.

To move the punch was used a feed rate of 240 mm / min with a punch rotary speed of 180 rpm. To reduce friction at the contact between the punch and the material, drawing oil was used. The material chosen to produce single point incremental forming parts is a deep drawing DC04 steel. The mechanical characteristics of the sheets were determined on a tensile test machine Roell RKM & Korthaus 100/20.

Table 1

The mechanical characteristics of materials

t [mm]	K [Mpa]	n	ε_u [%]	R_{00}	R_{45}	R_{90}
0,5	547	0,212	46,8	1,42	1,38	1,72
0,9	524	0,185	47,4	1,35	1,02	1,59

3 The results of experimental researches

The object of this study was to determine the force in the single point incremental forming process, on two components: a vertical one and a horizontal one. For this, we selected various shapes of parts to see how the shape of the part and punch path influence the force shape.

For each part we selected as influence factors the punch diameter and punch penetration depth in vertical direction. The selected independent variables, the variation domain and their variations levels are presented in Table 2.

Table 2

The independent variables selected for the experiment

Variable	**Natural units**	
Vertical step pz (mm)	0.25	1
Punch diameter dp (mm)	6	10

We have taken into account the following objective functions of the single point incremental forming process: maximal forming force on the z direction – perpendicular on the sheet metal and the maximal forming force in x direction – a direction in the sheet metal plane.

For determining the two forces we used a 2^2 factorial program with the help of the answer surfaces method for all types of parts.

3.1. Forces for dome parts

To determine the forces, we have performed a set of four tests. In Figure 3 can be seen the punch trajectory. Punch penetrates the specimen on the z direction and executes in the sheet plan a circular motion with a certain radius. After each circular motion in the sheet metal plane, the punch performs a simultaneous penetration on z direction, each time constant, and on x direction, varying with radius as in Figure 2. Dome pieces have an inner radius of 44 mm.

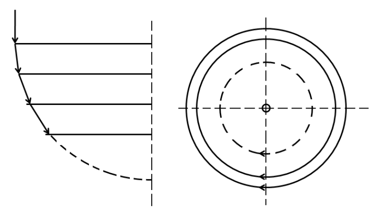

Figure 2. Trayectories for dome parts

Following the parts measuring, it was noticed that, for the variation domains of the two independent variables, the value of the considered parameters varies within the limits: F_{xmax}=98,588-306,18 N and F_{zmax}=256,76-841,26 N for the material with 0.5mm thickness and F_{xmax}=252,84-616,84 N and F_{zmax}=1032,92-1726,2 N for the material with 0.9mm thickness.

The models resulted for the two measured forces are:

- For 0.5 mm thicknesss

$$F_{xmax} = -53.111 + 15.582dp + 193.685pz \quad (1)$$

$$F_{zmax} = -320.553 + 65.415dp + 530.453pz \quad (2)$$

- For 0.9 mm thicknesss

$$F_{xmax} = 17.967 + 26.197dp + 345.613pz \quad (3)$$

$$F_{zmax} = 517.463 + 54.267dp + 634.947pz \quad (4)$$

The graphic spatial display of the connections between each influence factor and the two response functions F_{xmax} and F_{zmax} is given in Figure 3.

In Figures 4 and 5 can be observed the variation of forces on both sides.

In the Figure 4 it is observed that the force in direction x has a maximum in the area of the punch penetration into the material, then has a sinusoidal shape at each xOy plane movement, followed by a sharp decline when it returns to the initial point. The force increasing with each penetration is oscillatory. This is because the punch at a moment, as can be seen in Figure 2, penetrates in the non-hardening material, leading to a force decreasing in that area.

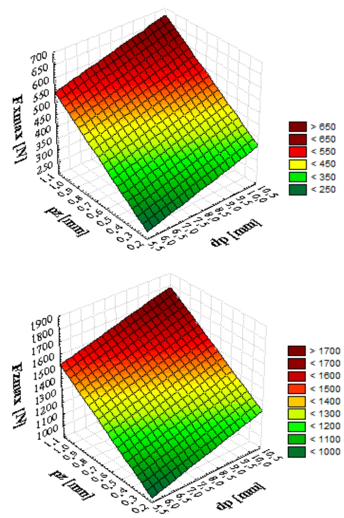

Figure 3. The dependence chart for F_{xmax} and F_{zmax} function pz and dp for 0.9 mm thickness

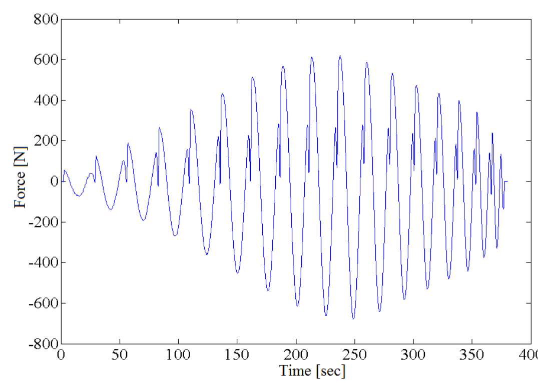

Figure 4. F_x for a 10 mm punch diameter, 0.9 mm material thickness and 1 mm vertical step

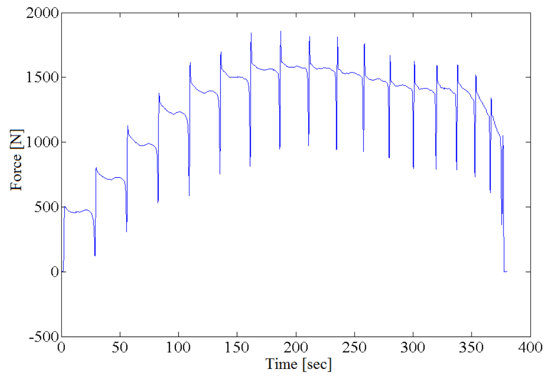

Figure 5. F_z for a 10 mm punch diameter, 0.9 mm material thikcness and 1 mm vertical step

The same phenomenon can be observed for the z forces, but with a more pronounced peak force when the punch penetrates into the material in z direction and a sudden drop in force when the punch return to initial point The force has also a sinusoidal variation, as when the punch is moving in the sheet metal plane, but is much less sinusoidal.

3.2. Forces for piramid frustum parts

To determine the forces in two directions for the truncated pyramid parts, just as in the case for dome a set of four tests was made. Figure 6 summarizes the punch trajectories to achieve a truncated pyramid part trough single point incremental forming. Penetration into the material is done in the same place, in a corner. After the punch entering with a step in z direction, he performs a rectangular move on the plane xOy. Pyramid frustum has a height of 10 mm and 46 mm of the bottom side.

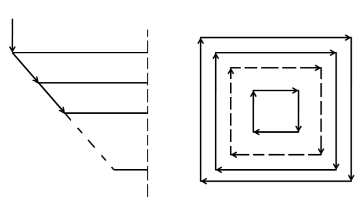

Figure 6. Traiectories for cone frustum parts

Following the parts measuring, it was notice that, for the variation domains of the two independent variables, the value of the considered parameters vary within the limits: F_{xmax}=90-212,7 N and F_{zmax}=383,3-924,9 N for the material with 0.5mm thickness and F_{xmax}=180-439,1 N and F_{zmax}=922,8-1708 N for the material with 0.9mm thickness.

The models resulted for the two measured forces are:

- For 0.5 mm thiknesss

$$F_{xmax} = 44.3 + 2.3dp + 149.2pz \tag{5}$$

$$F_{zmax} = -16.817 + 42.2dp + 497.067pz \tag{6}$$

- For 0.9 mm thiknesss

$$F_{xmax} = 126.333 + 0.175dp + 281.867pz \tag{7}$$

$$F_{zmax} = 357.167 + 53.213dp + 763.133pz \tag{8}$$

The graphic spatial display of the connections between each influence factor and the two response functions F_{xmax} and F_{zmax} is given in figure 7.

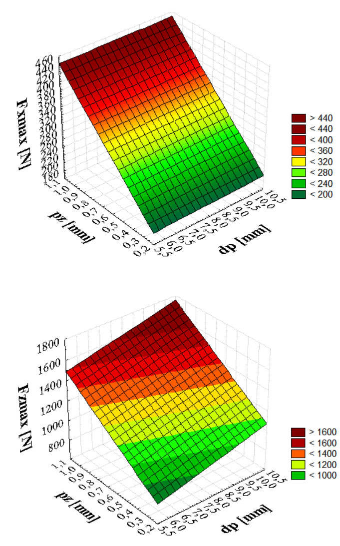

Figure 7. The dependence chart for F_{xmax} and F_{zmax} function pz and dp for 0.9 mm thickness

In figures 8 and 9 can be observed the variation of forces on both directions. It is noted in this case that the force in e vertical direction (F_z) has a peak at the end phase of the punch penetration of sheet and then the local maximum at each change of direction a punch. Force in x direction has maximum values at each punch return in the start position.

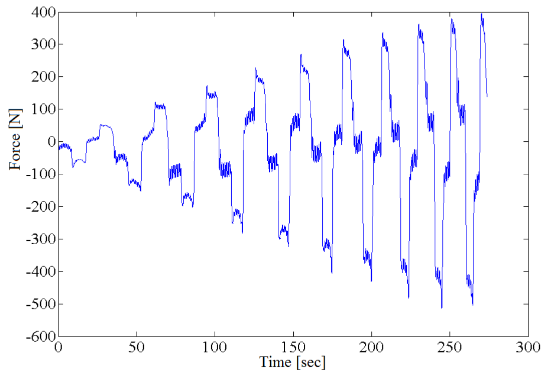

Figure 8. F_x for a 10 mm punch diameter, 0.9 mm material thikcness and 1 mm vertical step

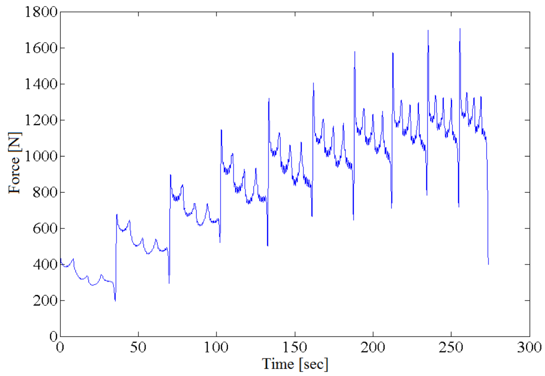

Figure 9. F_z for a 10 mm punch diameter, 0.9 mm material thikcness and 1 mm vertical step

3.3. Forces for cone frustum parts

To determine the forces on truncated cone pieces were performed four separate tests for each material thickness. In figure 10 are shown punch paths to achieve a truncated cone parts through single point incremental forming.

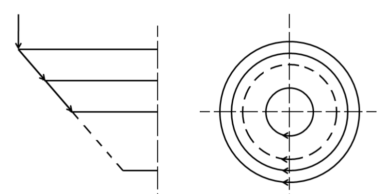

Figure 10. Traiectories for cone frustum parts

Penetration in the material is done in the same place. After the punch penetrates with a step in z direction, it performs a circular motion in the sheet plane. Cones have a height of 10 mm and 44 mm bottom basis.

Following the parts measuring, it was notice that, for the variation domains of the two independent variables, the value of the considered parameters vary within the limits: F_{xmax}=101,22-260,26 N and F_{zmax}=314,72-789,18 N for the material with 0.5mm thickness and F_{xmax}=244,58-513,66 N and F_{zmax}=1012,34-17620,6 N for the material with 0.9mm thickness and .

The models resulted for the two measured forces are:

- For 0.5 mm thiknesss

$$F_{xmax} = -36.517 + 16.389dp + 124.647pz \quad (9)$$

$$F_{zmax} = -104.767 + 47.023dp + 381.827pz \quad (10)$$

- For 0.9 mm thiknesss

$$F_{xmax} = 44.3 + 2.3dp + 149.2pz \quad (11)$$

$$F_{zmax} = -16.817 + 42.2dp + 497.067pz \quad (12)$$

The graphic spatial display of the connections between each influence factor and the two response functions F_{xmax} and F_{zmax} is given in figure 11.

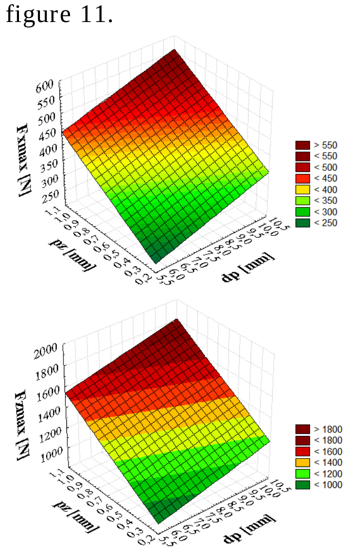

Figure 11. The dependence chart for F_{xmax} and F_{zmax} function pz and dp for 0.9 mm thickness

In figures 12 and 13 are forces on both directions x and z. From the graphics can be seen that the forces, while the punch moves circular in sheet plane, have a sinusoidal form of variation, a phenomenon more pronounced in case of x force.

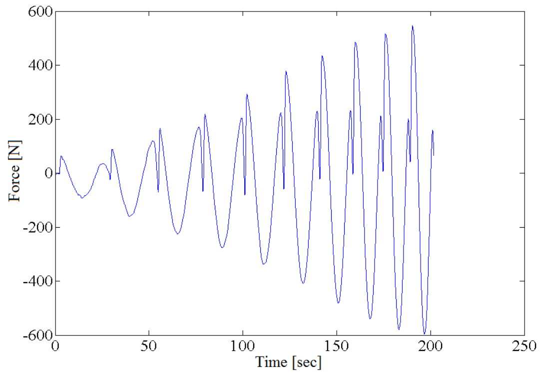

Figure 12. F_x for a 10 mm punch diameter, 0.9 mm material thikcness and 1 mm vertical step

On returning punch in the initial point, just before making a new penetration on z, we can see if a sudden drop in both deformation forces, followed by a sudden increase when the punch penetrates again into the material. With every penetration force peak is becoming higher.

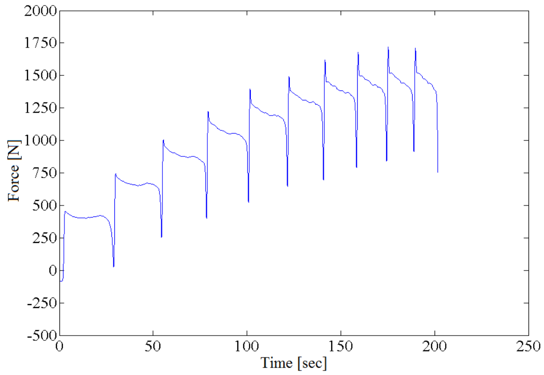

Figure 13. F_z for a 10 mm punch diameter, 0.9 mm material thikcness and 1 mm vertical step

4. Conclusions

In the case of determination the forces for the three components types the most influential factor to consider is the step growth on z direction. As the step is greater the forces are greater. Punch diameter has a smaller influence on forces and as in the step case, the higher it is larger the forces are except the forces on x direction for the truncated pyramid parts which growth for small punch radius.

The authors have elaborated mathematical models that could determine the maximum force values in the single point incremental forming for three types of parts: a dome, a truncated con a pyramid frustum.

In the future will carry out an experiment of type 3^3 for more detailed evaluation of the forces and to take in to account others process parameters like material type, material thickness, because in this paper we could not take into account sheet thickness, the mechanical parameters were different or to use others punch trajectories like helical trajectories.

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