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COMPARATIVE STUDY ABOUT DIFFERENT EXPERIMENTAL LAYOUTS USED ON SINGLE POINT INCREMENTAL FORMING PROCESS

OLEKSIK Mihaela
Faculty of Engineering / Department of Management and Industrial Engineering, "Lucian Blaga" University of Sibiu, Sibiu, Romania, mihaela.oleksik@ulbsibiu.ro

Abstract: *The present paper proposes a comparative study between two of the most used experimental layouts on the single point incremental forming with the advantages and disadvantages of these experimental layouts. After a short presentation of the newest technological opportunities on single point incremental forming, the paper presents a classification of the experimental layouts used on this kind of forming process. The comparative study highlights the advantages and the disadvantages of using the universal milling machines and the industrial robots on single point incremental forming. There are presented the results focused on thinning and forces in the SPIF process.*

Key words: Incremental Forming, Experimental studies, Milling machines, Robots, Main strains, Forces

1. Introduction

In the last few years the single point incremental forming (SPIF) has imposed itself among the newest unconventional sheet metal forming processes due to the main advantages offered: the very high flexibility and the reduced costs of the forming tools [1,2]. An important criterion by which the incremental forming processes for metal sheets can be classified is the one related to the manner in which the force needed for the forming is applied. Thus, the following types can be distinguished:

- Incremental forming using punches with simple geometries;
- Incremental forming using punches with spherical balls;
- Shot peen incremental forming;
- Warm incremental forming.
- Electric combined with hot incremental forming;
- Electromagnetic incremental forming;
- Laser-assisted incremental forming;
- High pressure water jet incremental forming.

Depending on the manner in which the forming force is applied, these processes can be divided into:

- Continuous incremental forming;
- Intermittently incremental forming (e.g. incremental forming by hammering);

Since the middle of last century, the shot peen forming procedure has been applied industrially for making airplane parts. Known applications are especially slightly curved parts, for which the financial effort to die cast them seemed too big [3]. In terms of working principle, the shot peen forming is however also suited for larger curvatures. The blank, not fastened at all or fastened only on the sides, is bombarded with shot peen so that depending on the kinetic energy of the shot peen, a corresponding contour, concave or convex, is generated on the surface of the part. Therefore, this procedure makes it possible to form the sheets entirely. After an initial prestressing, the surface of the blank is bombarded so that after the shot peen jet is interrupted, the springback is reduced considerably.

For parts curved by several axes, a plastic flow on the thickness of the sheet is necessary, similar to the case of stretch forming. The difference consists in the fact that while in conventional stretch forming the applying of the forming force towards the middle of the blank is obtained with large forces applied in the fastening area, in shot peen forming, the forming is produced locally due to the energy of the impacting balls.

Ambrogio et all [4] proposes the hot incremental forming process for materials with low formability at low temperature such as the magnesium alloy AZ31. While the upper part of the equipment is similar to other kinds of equipment designed for SPIF, the lower part is composed of a die, a heater band and a water-based cooling system. So, the authors demonstrated that an increase in the sheet temperature to 250^0 C led to an increase in the formability of the magnesium alloy in terms of increasing the wall angle to 55 ... 60^0.

Husman and Magnus presented in their paper [5] a new method for determining the temperature during SPIF in real time. The method is based on thermography and allows the possibility to capture thermograms of the entire part during the forming process. The advantage of this technique for hot incremental forming processes consists in an increase in the accuracy of the SPIF through a good control of the temperature of the entire part.

Fan and his team [6] proposed an innovative method for incremental forming that uses the electric current to locally increase the temperature of the forming process near the contact area between the punch and the blank sheet. The authors used this technique for the incremental forming of two low formability sheets. The local increase of the temperature contributes to the increase in the formability of the material. The experimental layout is easy and simple compared to other types of non-conventional incremental forming such as laser assisted IF. In the paper, the formability is defined by the maximum slope wall angle of the parts produced without cracks.

A new SPIF process, namely the electromagnetic incremental forming process or EMIF, is studied in the paper of Cui and all [7]. In the electromagnetic incremental forming process (EMIF), the solid conventional punch is replaced by a coil. The particularity of this incremental forming process consists in the absence of any contact between the “punch” and the blank sheet. It is well known that the conventional incremental forming processes are slow and time consuming. The authors proposed two different plans. Firstly the sheet is fastened in the same position and secondly one the coil moves relative to the sheet. Secondly, the authors try to determine the feasibility of EMIF for producing large and complex parts.

Another innovative solution of the hot incremental forming process was developed by Duflou and others [8] and refers to the laser assisted incremental forming process. Thus, the experimental testing setup is composed of a 6-axis robot which provides the active, mechanical force needed in the forming process, of a vertical clamped support and of the heating source, more precisely a 500 W Nd-YAG laser with glass fibre beam. The laser system is mounted on a 3-axis positioning system and is linked to the robot controller in order to allow a good synchronisation between the punch position and the laser spot position. These allow creating a heated zone in the working zone and in fact an improved material ductility, while keeping the surrounding area at lower temperature. Keeping the surrounding area a low temperature allows the obtaining of relatively high yield strength and of sufficient stiffness in order to ensure an accurate incremental forming effect.

2. Equipment used on single point incremental forming process

A sorting of the incremental forming processes in terms of the forming strategies, which also implies different kinds of equipment, can be expressed as follows:

- Single point incremental forming, where the sheet is formed only by the punch which follows a designated trajectory;
- Double point incremental forming, where the sheet is formed by the punch and a support on the other side of the sheet;
- Multi point incremental forming, where the conventional tools (the punch and the die) are replaced by a set of height-adjustable punches.

The incremental forming process can be implemented using various machines, such as:

- Machines specially designed for incremental forming;
- Numerical control milling machines;
- Industrial robots.

Machines specially designed for incremental forming;

One of the first researchers who built specialised machines for the incremental forming process was Allwood [9].

Later, as the incremental forming process evolved, specialised machines for applying the incremental forming process have been developed. The construction of these machines is based on a technology developed by Amino [10]. The first prototype machine for incremental forming was created by the Amino Company in 1996. The machine controller is a 3-axis servo system. The geometry of the part is modelled by means of 3D commercial CAD software and converted through CAM to NC using the G code. The machine generates high feed rates, has a medium-sized work volume and is equipped with a numerically controlled system for the displacement of the blankholding equipment.

Numerically controlled milling machines

Besides the specialised machines, for incremental forming numerical control milling machines can also be easily used. These milling machines can be used for incremental forming due to the high movement speeds generated on the three numerically controlled axes, due to the large work area and due to the relatively high stiffness. Also, the control and correlation of movements are easily done because there is a normalised language for this (code G and code M).

Industrial robots

As alternative equipment for incremental forming one can use also industrial robots. These can be divided into three main categories:

- serial robots with up to six degrees of freedom;
- robots with parallel structure – the Stewart platform;
- hybrid robots.

The usage of serial industrial robots as work equipment for incremental forming has the following advantages [11]:

- large workspace;
- high motion speed on the programmed trajectory;
- good control and correlation of the motions.

Serial industrial robots are widely used and their preparation for the incremental forming procedure consists only in the equipping of the final effector with the forming punch and their programming [12].

However, apart from these advantages there are also certain disadvantages, such as:

- serial robots have lower stiffness compared to numerical control milling machines;
- serial robots can develop forces that are relatively low compared to numerical control milling machines;
- the final effectors of the robot can reach any point within the workspace, but not by any trajectory; this is called the singularity problem and is specific to serial industrial robots;
- programming these robots can be more difficult due to the necessity to use specialised software routines.

Industrial robots with parallel structure offer a higher stiffness compared to serial robots, but the workspace is limited.

3. Comparison between milling machines and robots used for single point incremental forming

The most used experimental layout for the single point incremental forming are the universal milling machines and industrial robots. In this paper I present the experimental researches that are done on a DMG milling machine (Figure 1) and a Kuka KR210 Robot (Figure 2).

Figure 1: The universal milling machine prepared for the single point incremental forming process

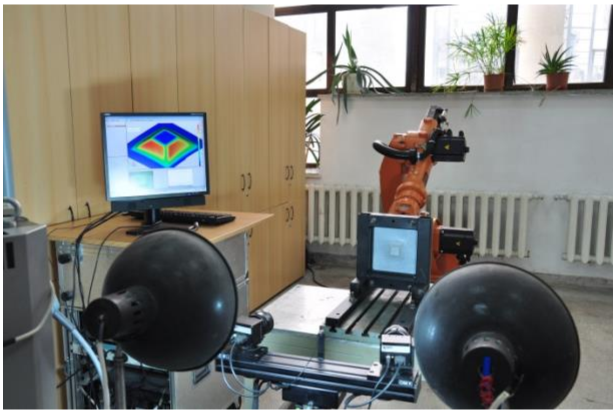


Figure 2: The robot and the Aramis optical system prepared for the single point incremental forming process

For the force measuring in the first case (milling machine) I needed a table plate extensometer specially designed for these (Figure 3) and for the second case (robot) I used a common force transducer (Figure 4). Both extensometers could measure forces on three perpendicular directions and both used for data acquisition the Quantum X system. I could not use the force transducer in the first case because in that case the punch has a rotational movement.

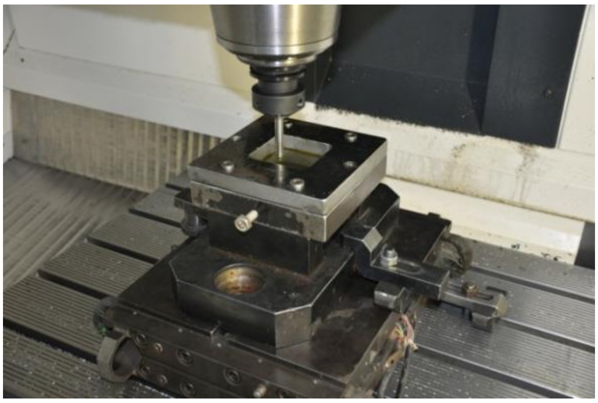


Figure 3: The table plate extensometer used for the first case (milling machine)

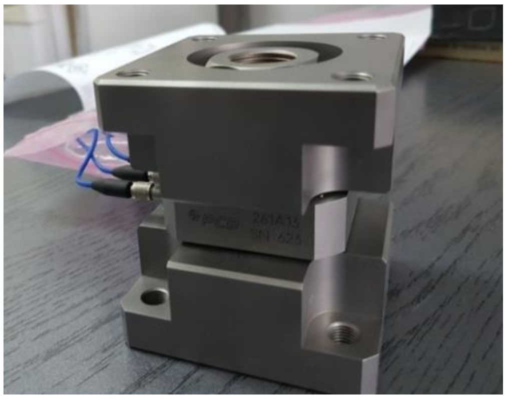


Figure 4: The force transducer used for the second case (robot)

For the first case the table plate extensometer is placed behind the lower part of the die and for the second case the force transducer is mounted between the robotic arm and the mandrel which fastens the punch.

For measuring the strains and the thickness reduction I also had to use different optical devices: Argus for the case of using the milling machine and Aramis for the case of using industrial robot. In order to use these two devices I needed to electrochemical depose a circular grid (Figure 5) (for the first case) and to depose a diffuse black paint powder over an antireflex white paint (Figure 6).

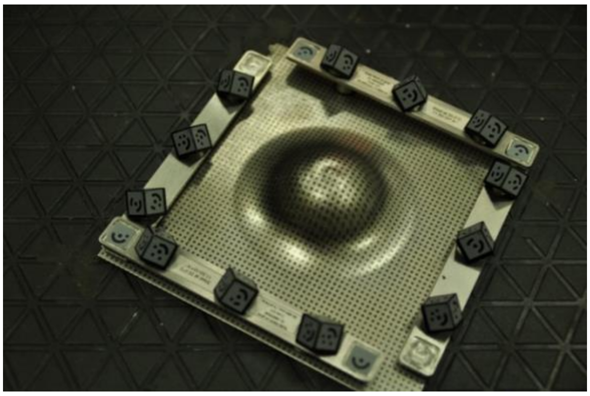


Figure 5: The part produced using the universal milling machine prepared for strain measurement

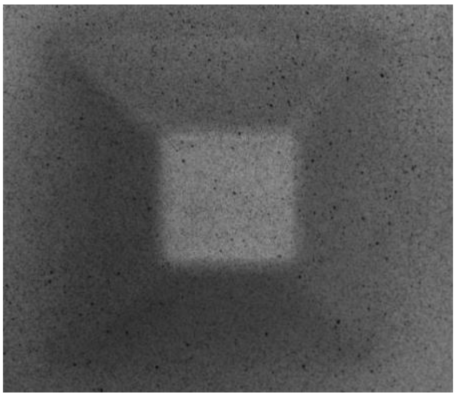


Figure 6: The part produced using the industrial robot after the measurement process

For the first case I produce a cup shaped part and for the second case a frustum of pyramid shaped part. The results are focused, for the both cases, on thickness reduction measurement and forces measurement. Figures 7…10 present the results for the first case (milling machine).

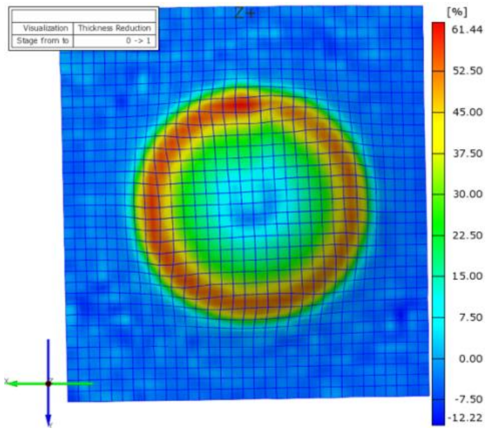


Figure 7: The thickness reduction on the final stage of the processed part for the first case (milling machine)

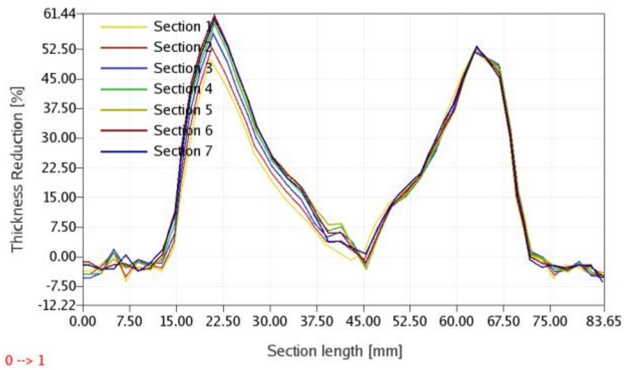


Figure 8: The thickness reduction on the final stage of the processed part for multiple sections for the first case (milling machine)

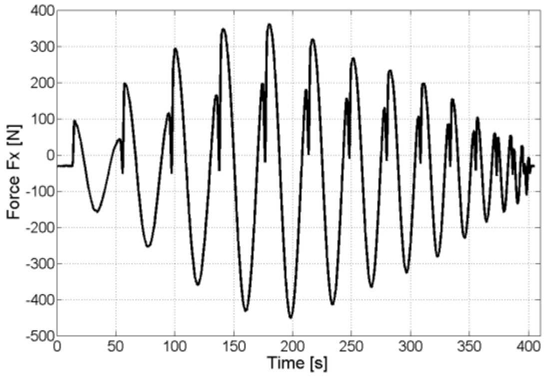


Figure 9: The force variation on Ox direction (horizontal) for the first case (milling machine)

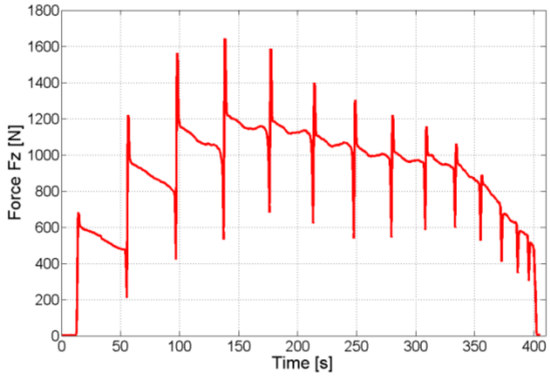


Figure 10: The force variation on Oz direction (vertical) for the first case (milling machine)

In Figures 9 and 10 I present the forces only on two directions (Ox and Oz directions) because the force on the Oy direction has a similar variation with the force on the Ox direction. The biggest disadvantage of this variant consists in the impossibility of measuring the strains and of course the thickness reduction during the forming process. I could evaluate these only at the end of the process. The biggest advantage consists in the possibility of using the spindle speed of the punch which has an important contribution in increasing the formability of the material (the frictional forces contribute in increasing temperature of the part). Another advantage consists in the rigidity of the milling machine which contributes to the growth of the accuracy of the produced part.

Figure 11 present the thickness reduction variation in the second case during the forming process in four different stages.

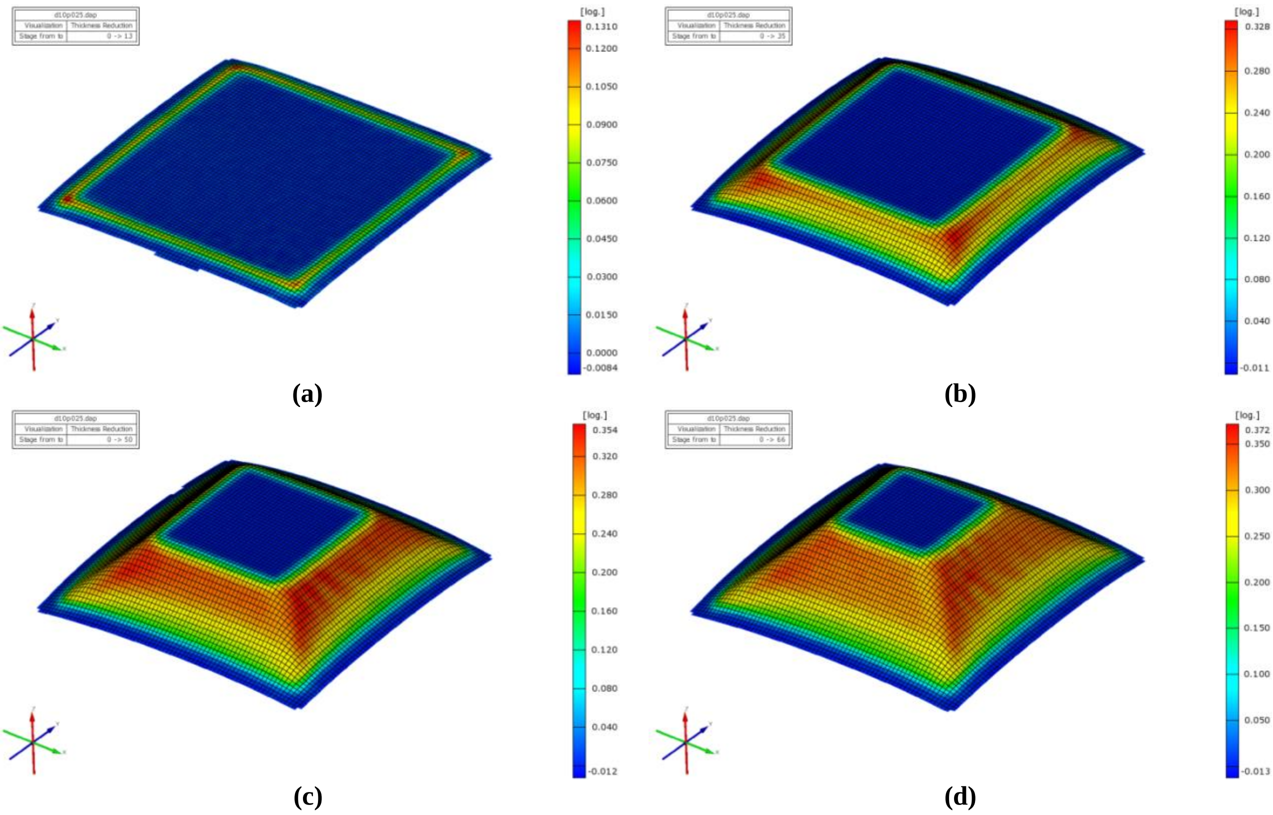
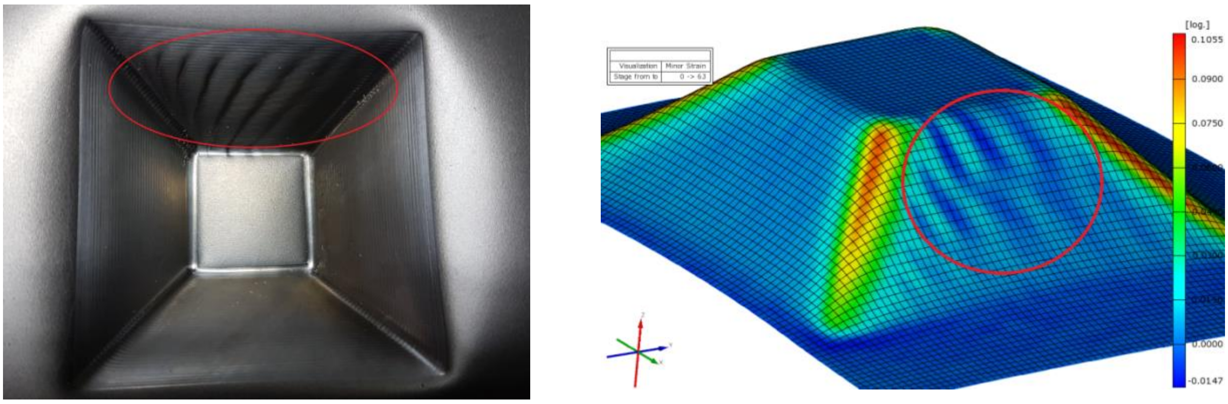


Figure 11: The thickness reduction variation on different stages for the second case (industrial robot) – (a) 25% of the final height, (b) 50% of the final height, (c) 75% of the final height, (d) the final height

The biggest advantage of this variant consists in the possibility of the evaluation of the strains, thickness reduction, precision during the forming process and eventually to correct the punch trajectory in order to improve these. The biggest disadvantage consists in the low rigidity of the industrial robot and the impossibility to induce a spindle speed to the punch. I can observe in Figure 12 the defects that can appear on the part in this variant.



(a) **(b)**

Figure 12: Defects which could occur on the second variant – (a) unevenness on the part wall; (b) – unevenness on strain map

4. Conclusions

The main conclusions that can be drawn after this analysis come from the advantages and disadvantages of the two studied equipment types.

The advantages of using CNC milling machines:

- they assure a better stiffness of the entire incremental forming process and obviously a better precision of the SPIF formed parts;
- the classical CNC programs, typical to the universal CNC milling machines can be used for generating the trajectories;
- the die can be gripped easier on the milling machine plate;
- they assure the rotation of the punch, helping the forming process, improving formability;
- higher values of the vertical step can be used if this doesn't affect the quality of the processed part;
- the CNC milling machines allow the lubrication of the forming process due to the horizontal die position.

The disadvantages of using CNC milling machines:

- they only allow the measurement of the major strain, minor strain and thickness reduction using optical methods at the end of the forming process;
- they allow the measurement of the forming forces using some special force captors but there is the risk of influences appearing among the three movement axes.

The advantages of using anthropomorphous robots:

- the vertical die positioning allows the measurement of the major strain, minor strain and thickness reduction during the entire forming process;
- high movement speed on the programmed trajectory;
- it is possible to determine the elastic springback, which directly influences the dimensional precision of the SPIF formed parts;
- the punch trajectory can be adjusted at the end of a forming process by only gripping the workpiece;

The disadvantages of using the anthropomorphous robots:

- the reduced stiffness due to their construction and the possibility of vibrations appearing during the forming process;
- serial robots can have relatively low forces compared to numerically commanded machines;
- their programming cam be more difficult due to the need of using special programs;
- the lack of lubrication and the impossibility of rotating the punch.

As a conclusion, using CNC universal milling machines is recommended when the formed parts are thicker, in a smaller number and when "on-line" error compensation is not needed. It is recommended to use industrial robots when the formed parts are made of thin sheet, on unique parts and when it is needed to compensate the springback caused errors by only gripping the workpiece once.

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