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STUDIES ON THE PRODUCTION OF PARTS BY MEANS OF INCREMENTAL FORMING ON CNC LATHES

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Abstract: *The incremental forming process is a manufacturing process used for obtain parts in small or unique batches without the need to use a special die. There is different technological equipment used to perform incremental forming applications such as CNC (Computer Numerically Control) machine tools, such as milling processing centers, or industrial robots. Thus, parts with simple geometry of different shapes can be obtained. The paper presents a study for the realization of a complex part in two stages. The first stage is that of obtaining a truncated cone type part on a three-axis milling center. The second stage of manufacturing involves an additional incremental forming, which due to the shape of the part cannot be done on the same machine, which is why a new set of tools was created that allows parts to be processed on a CNC lathe machine.*

Key words: *Single point incremental forming, milling machine, lathe machine, CNC.*

1. INTRODUCTION

Cold plastic forming processes, together with machining processes, are the most widespread and widely used methods of generating the shape of finished parts in the field of mechanical engineering.

The two main groups of machining processes have thus divided their field, and an implicit distribution of the need to use one or the other has been established: cutting operations for the production of small and medium-sized parts under high precision conditions, and cold-forming operations for the production of large parts and complex shapes. This distribution was mainly influenced by the automotive industry, where the representative parts for the two types of manufacturing processes can be find: engine components made by machining operations and body parts made thought for cold plastic forming.

The incremental forming process, which appeared relatively recently, is not yet very well represented in the literature, especially with regard to forming conditions for certain categories of materials, despite its many advantages and potential industrial applications. In addition, although the published research is relevant, often the results obtained are limited or contradictory [1], making further research in this area necessary.

The idea of incremental forming of sheet-type blanks using a tool with singular contact (sometimes wrongly called "single point contact" - the contact area being actually a surface which depends on the punch's shape), was patented by Leszak [2] long before it was even feasible from a technical point of view [1].

The incremental forming process is a manufacturing process intended to obtain parts in small or unique batches without the need to use a special die, thus being particularly advantageous from an economic point of view [3].

In the context of this approach, the theoretical researches have targeted the development of models that would allow the analysis through the finite element method of the behavior of this type of blanks, in order to examine the formability limits of a metallic materials. But this research intends to use bimetallic sheets whose forming limits, although they can be studied individually for each sheet, it is not possible to determine the forming limit for bimetallic sheet as a whole.

Another major research direction referred to the manner of generating the shape of parts obtained through the incremental forming process, from the point of view of trajectory types and of manufacturing strategies. Thus, it has been noticed that the specialty literature grants little attention to the type of trajectories employed, the researches being oriented almost exclusively on using simple trajectory, such as level curves, obtained by intersecting the part's contour with planes parallel to the horizontal plane.

Single point incremental forming (SPIF) has been studied during the last years. But despite this, the pieces obtained are mostly pieces with simple geometry, such as: cone truncated with different angles of inclination of the walls, hemispherical pieces, truncated pyramid, etc. [4, 5].

The manufacturing process consists of a system that contains a punch with a hemispherical head 1 that forms a metal sheet blank 2 that is fixed between a retaining plate 3 and a active plate 4. By describing a specific trajectory in the horizontal plane, the final shape of the

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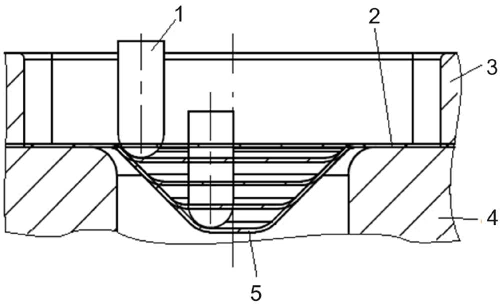

Fig. 1. The process for the incremental forming of metal sheets.

part 5 is obtained (for example, in this case, the movement is made on a circular trajectory), while its depth is obtained by movements on the vertical axis. These movements will be repeated until the final shape of the part Fig. 1.

As a result of describing a circular trajectory in each vertical plane, a conical piece will result. To obtain this piece, four vertical processing steps can be observed.

2. EXPERIMENTAL RESEARCHES REGARDING THE INCREMENTAL FORMING PROCESS OF DOUBLE LAYER SHEET

However, industrial-scale application of the process is limited, although recent research has tried to improve this situation. Firstly, there is still no unanimous opinion on the optimal technological equipment for the process. Some authors consider that CNC machine tools such as milling centers are the most suitable [5,6], while others have investigated the possibility of using serial and parallel industrial robots [4], [7–9]. Another important aspect to be taken into account is that there is not enough data on the size of the technological resistance forces occurring in the process. Thus, there is a reticence to use the process in order to avoid damage to expensive equipment due to the occurrence of forces in the process exceeding the permissible limits [4].

Although the fields of use of numerical control machines are so varied, there are no machines in the industry that are intended for incremental forming.

The state of art in this field is reminiscent of only a few specialized machines that are used only for research purposes. For this reason, in general, only numerically controlled milling machines or industrial robots are used to carry out experimental researches.

2.1. Single point incremental forming of double layer metal sheet

Multi-layer sheets offer the great advantage of accumulating the mechanical properties that are advantageous to each individual metal, but at the same time it allows to eliminate some of the defects that each material assumes separately. All these properties must be preserved under the condition that the mass of the piece must be reduced as much as possible. There are cases where certain properties are required on the outside of the part, while very different properties are required on the inside of the part.

The experiments started from the use of two metal sheets, more precisely an aluminum layer AA6016 (thickness 0.8 mm) and a layer of deep-drawing steel DC04 (thickness 0.6 mm).

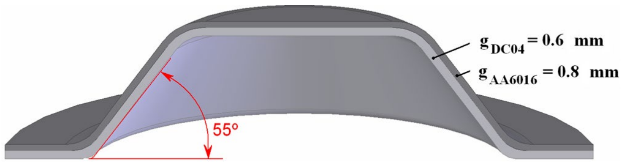

Fig. 2. Cone frustum part.

The preliminary experimental researches have shown that, in order to process the parts made of double layer sheet blank by incremental forming, it is necessary for the contact between punch and blank to take place on the aluminium layer of the sheet. When the blank was oriented so that the contact occurs on the steel sheet, this led repeatedly to a fracturing of the processed parts (in one or both layers).

Using these two materials, it is intended to obtain a cone fostrum type part with a wall angle of 55 degrees, as we can see in Fig. 2.

2.2. Tools system use for manufacturing by SPIF of a cone part

The numerical control was initially applied to machine tools for machining, but today it is increasingly widespread in the field of forming machining and laser, plasma, oxy-acetylene flame or water jet cutting machines.

The experimental researches regarding the incremental forming process of double layer sheet have targeted the realizing of parts with complex shapes, in conditions of high dimensional precision. Therefore, there was chosen as technological equipment for the experimental researches the numerical controlled milling center Haas MiniMill, from the endowment of the laboratories of the Department Industrial Machines and Equipments of the Faculty of Engineering of Sibiu, presented in Fig. 4. Tooling system used in processing consists, as can be seen in Fig. 3, of the punch 1 mounted in the tool holder 2, the metal sheets 3, the active plate 4, the retaining plate 5, the plate 6 mounted on the base plate 7.

Due to the fact that in the first stage manufacturing of part need only simple movements of the punch we can use three-axis CNC milling center HAAS MiniMill (Fig. 4).

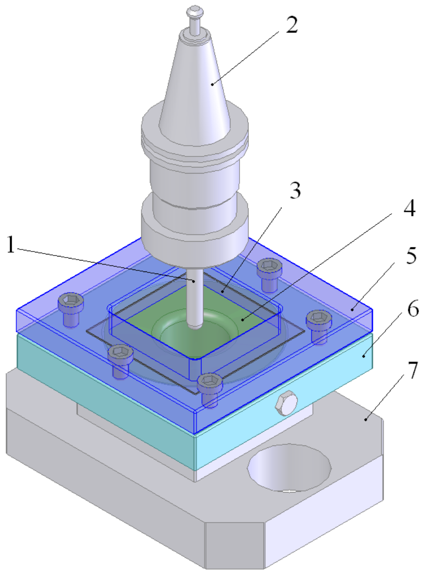

Fig. 3. Tool system used for SPIF.

Fig. 4. HAAS MiniMILL milling center [10].

Fig. 5. Tool system fixed on HAAS MiniMILL milling center.

In Fig. 5 one can see the tool system mounted on the machine table and prepared for incremental forming.

This system is fixed on the table of the Haas MiniMILL milling center as shown in Fig. 5.

2.3. Trajectories used for obtaining cone type parts by SPIF

In order to obtain the final form of the part, a two-step strategy was used.

The first stage involves the production of a truncated cone part by incremental forming on a three-axis CNC milling machine.

The milling machine shown in Fig. 4 has three axes which are detailed in Fig. 6.

Thus:

- the *Z*-axis is the main spindle axis,
- the *X*-axis is the longest axis of the machine (and in this case is parallel to the machine door),
- the *Y* axis perpendicular to the *X* and *Z* axes.

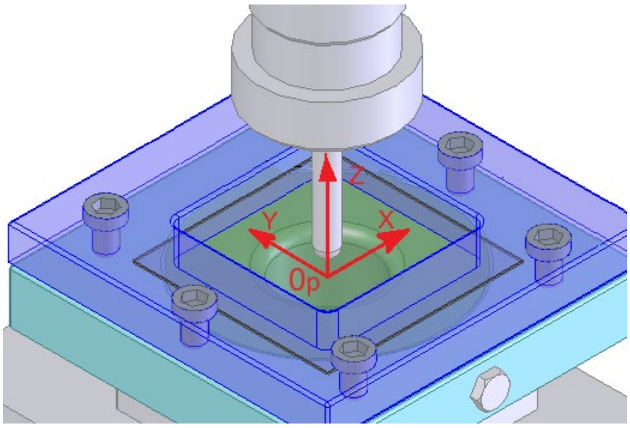

Fig. 6. Tool system fixed on HAAS MiniMILL milling center.

Due to the complexity of the part shape, a second incremental forming of the part is required, but the milling machine does not allow tilting of the punch nor the machine table, which is why it was decided to continue the incremental forming on a CNC lathe machine, this being the only way to obtain the shape of the final part.

2.3. Trajectories used for obtaining cone type parts by SPIF

Thus, Fig. 7 shows the trajectories of the punch for generating the cone shape parts, the obtaining of which involved the following steps:

1 – fast approach (represented by dotted line) above the starting point of processing;

2 – technological feed on the Z axis at the Z1 level is - 2 mm (represented with a solid line);

3 – description circular trajectory with technological advance with the diameter of $D1 = 36$ mm;

4 – repeating steps 1 and 2 for diameters $D2$, $D3$, $D4$, $D5$, $D6$, $D7$ for processing depths of $Z2 = -2$ mm, $Z3 = -4$ mm, $Z4 = -6$ mm, $Z5 = -8$ mm, $Z6 = -10$ mm, $Z7 = -12$ mm.

The technological feed was set at a value of 240 mm/min. During processing, the punch exhibits a rotational movement. The use of this rotational movement is intended to reduce the frictional forces between the punch and the part.

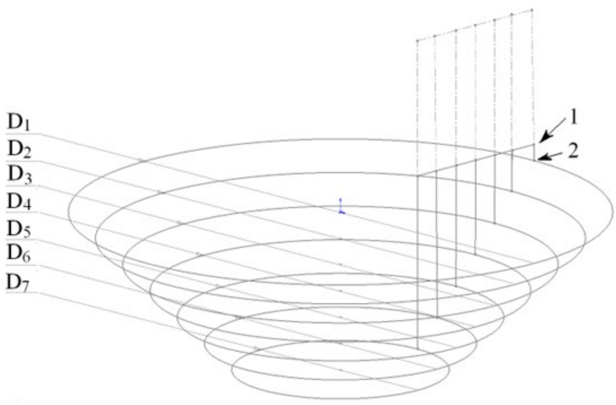

Fig. 7. The trajectories of the punch necessary for the manufacturing of the part.

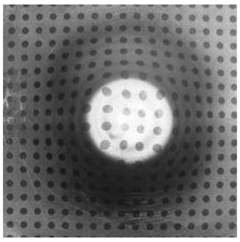

Fig. 8. Cone frustum part.

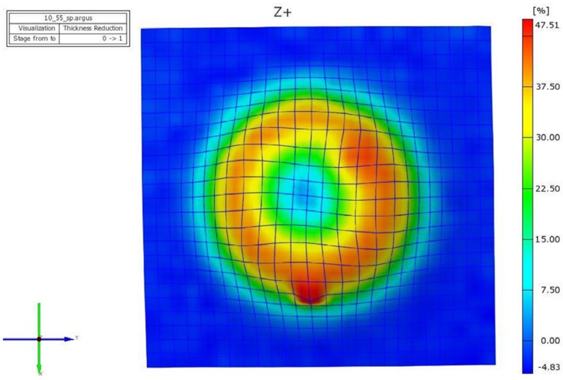

Fig. 9. Thickness reduction.

After the manufacturing, there were determined experimentally the thickness reduction and strains in the parts realized through incremental forming in order to evaluating the plastic forming behavior of the double layer sheet.

The measurements were carried out using the ARGUS optical deformation measurement system. The measurement is carried out for the DC04 steel to which the 2/3 mm point grid was applied (Fig. 8). All the data presented in this paragraph indicate the behavior of the DC04 material, which at the time of the incremental forming process was positioned between the active plate and the aluminium sheet.

Also thickness reduction was measured using the ARGUS optical deformation measurement system, on the steel surface of the part. Maximum thickness reduction appears in the area with the minimum diameter of the part (Fig. 9).

On the area with the 55-degree inclination of the walls, it is observed that there is a very small thickness reduction of the metal sheet, so material allows an additional incremental forming.

3. RESEARCHES REGARDING THE INCREMENTAL FORMING PROCESS OF A COMPLEX PART

The second part of the machining consists of an additional operation of incremental forming of the previously obtained truncated cone type part. Starting from this part, we want to obtain the finished part of the complex shape shown in Fig. 10.

Experimental layout for second incremental forming contains:

- incremental forming of complex part
- tools system use for processing the final part was adapted for incremental forming on CNC lathe machine;

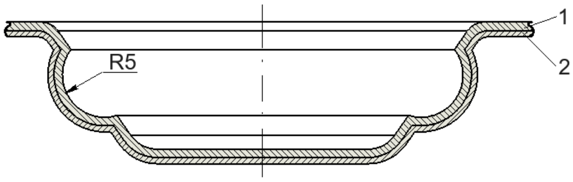

Fig. 10. Complex shape part.

- trajectories of the punch have to be developed due to the fact that because there are neither technological equipment nor software packages intended for incremental forming.

3.1. Incremental forming of double layer metal sheet complex part

The complex part has a radius of 5mm in the wall area. So, the second step of the processing consists of an additional incremental forming operation of the previously obtained truncated cone piece, where the positioning of the two layers of sheet metal is kept the same. Thus, the DC04 deep-drawing steel sheet is positioned on the outside, (marked 2 in Fig. 10), while the aluminum sheet is in contact with the punch (pointed with 1 in Fig. 10).

3.2. Tools system use for manufacturing by SPIF of a complex part

The tooling system used in machining contains the same essential parts as the one used in the first stage of incremental forming in Fig. 3. The difference is the design of a new tool set that can be mounted in the ST15Y CNC lathe machine (Fig. 11).

Thus, in Fig. 12, the truncated cone type piece is fixed between the active plate, the holding plate 3, the base plate 1 is designed so that it can be mounted in the chuck of the CNC lathe machine.

Fig. 11. ST15Y Lathe machine [10].

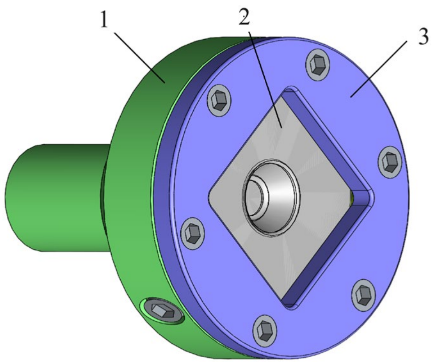

Fig. 12. The die used on lathe machine.

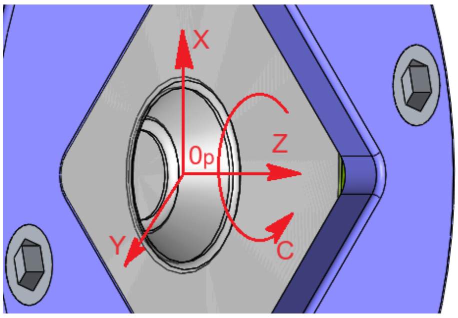

Fig. 13. Axes use for incremental forming on lathe machine.

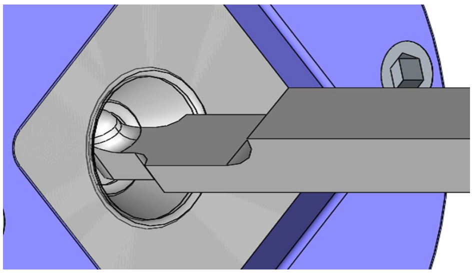

Fig. 14. Incremental forming tools used for incremental forming, including the punch.

As is well known, if we talk about turning the spindles of CNC machines are different (Fig.13), thus:

- the Z axis is a translation axis, more precisely the axis of the main spindle is in this case horizontal;
- the X axis is vertical;
- the Y axis is perpendicular to the above-mentioned axes;
- the C axis is an axis of rotation about the Z axis.

A spherical punch (10 millimeters in diameter) has also been designed in order to allow access to the working area Fig 14. The clamping part of the punch is identical to that of a lathe tool so that it can be clamped in the turret.

3.3. Trajectories used for obtaining complex part by SPIF

The manufacturing process for making the complex part involves additional incremental forming on the CNC lathe machine. Because of the shape of the final part, the manufacturing process required the part to be formed in two major steps:

I. The first step is similar, in terms of its role in the machining process, to the roughing process used in machining metallic materials and involves the following work steps:

a. first of all, the punch performs a rapid approach movement until it approaches the area to be machined. The rapid approach movement is symbolized by the dotted line in Fig. 15. During this operation no rotational movement of the workpiece is required;

b. the punch performs a feed movement in a direction perpendicular to the part wall and at a depth of 1 millimeter;

c. the punch describes a rotational movement around the circumference of the workpiece (this movement is performed by rotating the part);

d. the punch advances a new step along the depth (perpendicular to the workpiece wall);

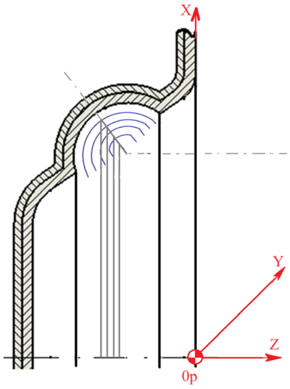

Fig. 15. The movement of the punch on four different steps on Z axis.

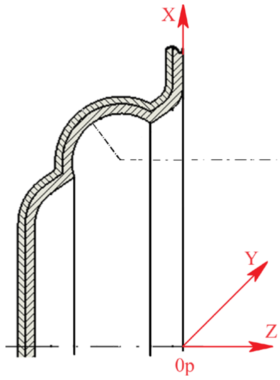

Fig. 16. The rapid retraction of the punch.

e. the punch describes a new rotational movement around the entire circumference of the part (this movement is performed, as in step d, also by rotating the workpiece);

f. these movements of advancing along the depth and moving along the circumference are repeated until the finished part is obtained;

g. after the four steps in depth the ten millimeters diameter punch is removed from the working area, with rapid retraction following the path indicated by the dotted line in Fig. 16.

II. The second step of forming is similar to the finishing process of turning and is carried out in order to increase the dimensional and shape accuracy of the workpiece.

So, in this case the manufacturing process consists of moving the punch along the trajectory of the part simultaneously with the rotation of the workpiece on the axis. The trajectory required in this case can also be seen in Fig. 17.

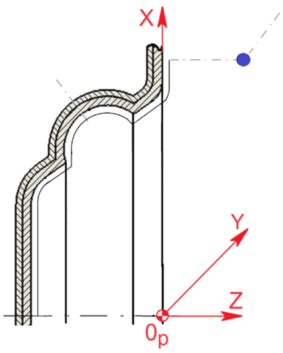

Fig. 17. The final trajectory of the punch used in order to improve the precision of the part.

4. CONCLUSIONS

The paper present first of a short state of art of manufacturing processes used in automotive industry.

Based on this, there is a growing need to develop small series and even one-off parts in the case of parts machined using the plastic forming process. Thus, the incremental sheet forming process is described and some possible types of equipment on which it could be implemented are mentioned.

Then the paper describes the steps required to obtain a complex part through SPIF.

The paper describes the steps needed in order to obtain the part:

- the first step involves obtaining a simple shaped piece, namely a truncated cone with a wall inclination of 55 degrees. The first step involves obtaining a simple shaped part, namely a truncated cone with a wall inclination of 55 degrees. In order to obtain this piece, the experimental research steps are detailed. The paper mention and describe all the necessary processing steps, such as:
  - tools system uses for incremental forming manufacturing of a cone part;
  - technological equipment used for experiments;
  - HAAS milling machine were use in order to obtain the cone part;
  - thickness reduction was measured;
  - from here it was determined if the area where the additional manufacturing is needed allows the second stage of processing.
- the second step introduce a second incremental forming in order to obtain the complex part. Thus, the paper further describes:
  - tools system uses for processing the final part was adapted for incremental forming on CNC lathes;
  - trajectories of the punch were developed due to the fact that because there are neither technological equipment nor software packages intended for incremental forming.

Further experimental researches will be the processing of the part of complex shape on the CNC lathe and analysis of the shape and dimensional accuracy of the part.

REFERENCES

[1] K.P., Jackson, J.M., Allwood, M., Landert, *Incremental forming of sandwich panels*, Journal of Materials Processing Technology, vol. 204, pp. 290-303, 2008.

[2] E., Leszak, *Apparatus and Process for Incremental Dieless Forming*, USA patent no. US3342051A1, published 19.09.1967.

[3] A.E. Ragab, *Analyzing SPIF Product Characteristics Using Full Factorial Design-Integrated PCA Approach*, Processes 2023, 11, 1254.

[4] M.O. Popp, G.P. Rusu, V. Oleksik, C. Biris, *Influence of vertical step on forces and dimensional accuracy of SPIF parts – a numerical investigation*, IOP Conference Series: Materials Science and Engineering, v. 968, pp. 012-020, 2020.

[5] T. Trzepieciński, M. Szpunar, A. Dzierwa, K. Żaba, *Investigation of Surface Roughness in Incremental Stheet Forming of Conical Drawpieces from Pure Titanium Sheets*, Materials. 2022.

[6] M. Ilyas, G. Hussain, H. Rashid, M. Alkahtani, *Influence of Forming Parameters on the Mechanical Behavior of a Thin Aluminum Sheet Processed through Single Point Incremental Forming*, Metals. 2020; 10(11):1461.

[7] V. Oleksik, D. Dobrota, S.G. Racz, G.P. Rusu, M.O. Popp, E. Avrigean, *Experimental Reasearch on the behaviour of Metal Active Gas Tailor Weleded Blanks during Single Point Incremental Forming Parts*, Metals, 2021.

[8] M.O. Popp, GP. Rusu, S.G. Racz, V. Oleksik, *Common defects of parts manufactured through single point incremental forming*, MATEC Web of Conference, v. 343, 2021.

[9] H. Meier, O. Dewald, J. Zhang, *Development of a Robot-Based Sheet Metal Forming Process*. Steel Res. Int. 2005, 76, 167–170.

[10] Haas CNC INC, company website, https://www.haascnc.com, accessed: 2023-05-05.