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SINGLE POINT INCREMENTAL FORMING OF LARGE-SIZE COMPONENTS

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ABSTRACT

In recent years, due to a number of comparative advantages, incremental forming technique (IFT) has been increasingly employed in metal forming industry as an alternative to conventional methods, particularly for individual and small batch production of part with complex geometry of materials hard to deform.

Present paper investigates the possibility of application of single point incremental forming (SPIF) technology for manufacturing a bus escape hatch. Similar to other large-sized components, this sheet metal part (dimensions 842x658x46mm) is not favourable with standpoint of SPIF technology because of amplified spring back and pillow effect. These effects as well successful processing of large sized components by SPIF depend very much of the toll trajectory. As a rule, it requires complex tool path, which in turn increases forming time. In current study, the focus was paid on adequate selection of the tool's kinematic parameters with the aim to attain final part with satisfactory accuracy. Comparing dimensions of CAD model and the final part elastic spingback was determined in reference points.

Key words: *Incremental forming, sheet metal, large-size workpiece*

1.0 INTRODUCTION

Modern sheet metal forming industry is being faced up with different challenges and requirements. To meet increasing demands for customized and new products of various shapes and materials, production in small quantities at low cost, etc., a few flexible, innovative, and rapid manufacturing methods have been introduced recently. Single Point Incremental Forming (SPIF) is one of them.

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Basically, SPIF technology is a combination of sheet metal forming and machining operations. During incremental forming rotating and moving tool or punch acts (presses) on small area of the sheet plate clamped into a frame with goal to avoid sliding. The tool path is programmed in advance and, as a rule, CNC milling machine is used for processing. The final shape is formed gradually as a result of a series of localized deformation induced by the tool. Since only local deformation appears forming load in SPIF is considerably smaller compared to classical sheet metal forming processes like deep drawing, and is not dependent on the size of the product [1], [2], [3]. In addition, the punch geometry is simpler, wear is less, and noise reduction is significant. This technology allows higher forming limit of material as well and forming of asymmetric parts [2, 4, 5]. However, the main disadvantages of SPIF technology are related to low dimensional and shape accuracy and relatively long processing time. [6].

In order to achieve high geometrical and shape accuracy tool path trajectory has to be different from the one corresponding to the CAD profile [7]. Programming of the punch trajectory is very complex task since different phenomena should be taken into account: material elastic springback, removal of the part from the clamping device, sheet bending, trimming after processing, "pillow effect" [7] etc. CAx techniques are very often employed for analysis and design of SPIF process, but in industrial applications even numerical simulations are not effective enough because of their computational time, modeling complexity and accuracy [7].

Many authors investigate the possibility of tool path modification in order to increase geometrical accuracy [7, 8, 9]. Most of the studies are carried out for small-size component while there is a lack of information regarding large size components. Matsubara [9] presents an example where SPIF technology is successfully applied for shaping large size sheet plate (1400x700x500mm). In terms of workpiece size, it was concluded that SPIF technology has no limitation, i.e. maximum size of product is limited only by the scale of the forming machine.

This study deals with manufacturing of the escape hatch for buses from sheet plate using SPIF technology. The workpiece falls into the category of large size components (dimensions 842x658x46mm). Object of investigation was to determine elastic springback after the production, as difference between dimensions of CAD model and the final part.

2.0 PROCESS OVERVIEW

2.1. Types of incremental sheet forming

The most commonly used types of incremental sheet forming are shown on Fig.1. There are two main categories: Single Point Incremental Forming and Two Point Incremental Forming.

Single Point Incremental Forming (SPIF) without a backing plate is the simplest form of incremental sheet forming (Fig.1-a). The sheet plate is clamped into a steady frame. Since there is no backing plate beneath the sheet plate the process is more flexible because pieces of different shapes can be made. The size of the workpiece is limited by the size of the sheet metal and the size of the frame. The size limitation is present at every other type of incremental forming. The basic idea of the process is that the positive die has to be raised from under the sheet metal after each lap of the tool path. By using a backing plate beneath the sheet plate the accuracy of the workpiece is highly improved (Fig.1-b). Although the backing plate limits the shape of the wokrpiece it is still a flexible form of incremental forming. By using a backing plate the tool path has to be programmed from outside to inside. The tool path starts from the biggest diameter of the part and by every vertical step it gets smaller. Using a partial male die (Fig.1-e) has to be from inside to outside. The tool path starts form the smallest diameter of the part and by every vertical step it gets bigger.

During Two Point Incremental Forming (TWIF) the sheet metal is always in contact with the tool from the top and an auxiliary tool from the bottom. Auxiliary tool can be a full male die (Fig1-c), full female die (Fig.1-d) or even another moving tool (Fig.1-f). Two point incremental forming is used for increasing the final workpiece accuracy; however the flexibility of the process is decreased.

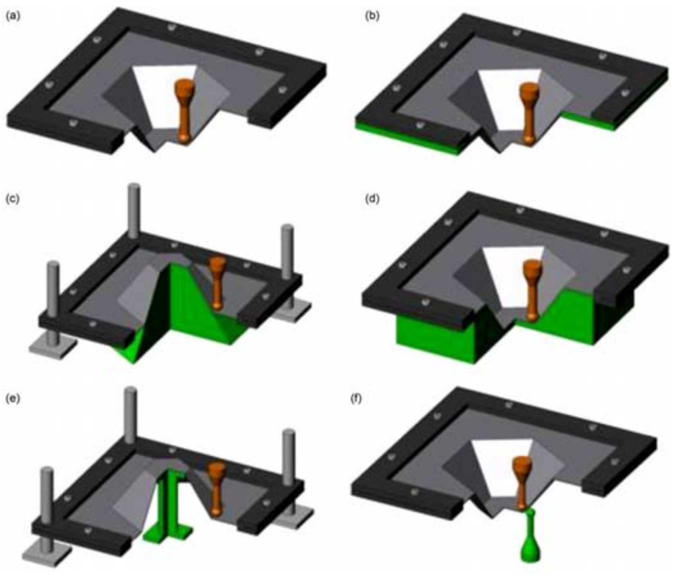


Fig. 1 - *Types of incremental forming*
a. – Single point incremental forming without a backing plate
b. – Single point incremental forming with a backing plate
c. – Two point incremental forming over a full male die
d. - Two point incremental forming into a full female die
e. - Single point incremental forming with a partial die
f. - Two point incremental forming with two moving tools [10]

2.2. Tool paths

At incremental sheet metal forming the tool paths can be 2,5 dimensional and 3 dimensional. 2,5 dimensional tool paths are 3D contours which are divided to increments only by the Z axis.
First the tool makes its moves in the horizontal (X and Y axis) plane, than a vertical pitch is made (Z axis) and the tool moves again in the horizontal plane (Fig. 2). 3 dimensional tool paths are significantly more complex because the increments are divided not only by the Z axis but at the same time by the X and Y axis as well (Fig. 3). From 3 dimensional tool paths, the most commonly, engineers use the spiral tool path.
In order to obtain successful processing of large size parts, it is necessary to select adequate tool trajectory. There are two trajectory types:
- “profile milling” or contour path: tool moves only along the contour of the part (Fig. 4)
- “pocket milling”: tool moves in the part as if it was milled from a whole material (Fig. 5)
Vertical pitch has a big influence on the accuracy of the final part. By increasing the vertical pitch the formability of the material decreases as well as the surface quality [9].

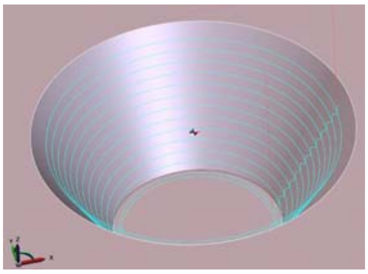


Fig. 2 - 2,5 dimensional tool path

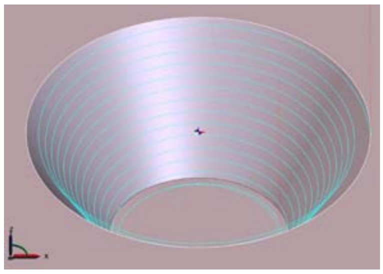


Fig. 3 - 3 dimensional tool path (helical)

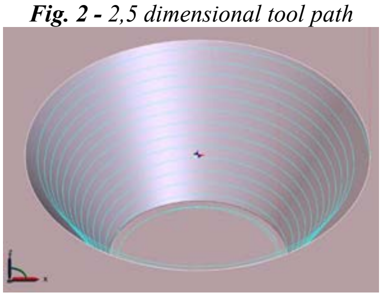


Fig. 4 - "profile milling" or contour path

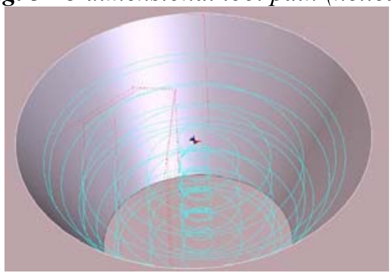
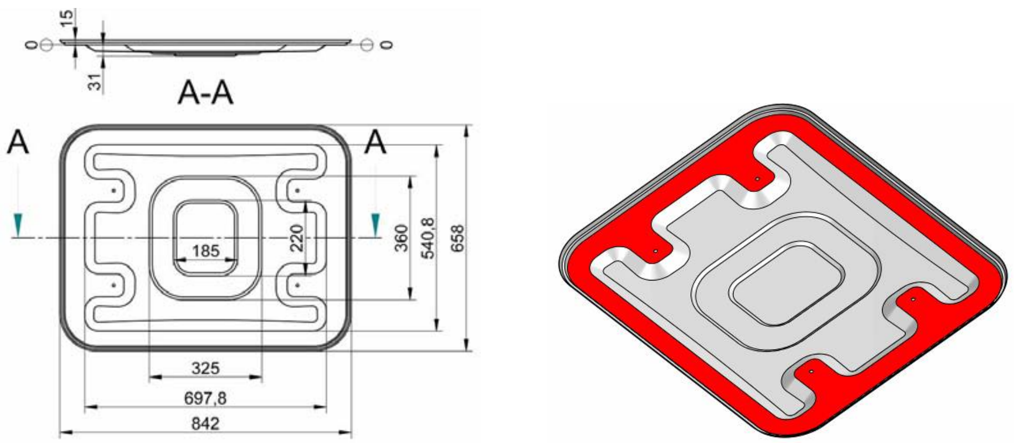


Fig. 5 - "pocket milling"

3.0 EXPERIMENTAL INVESTIGATION

Experimental part of this paper considers manufacturing of escape hatch using incremental forming technology. Drawing of the escape hatch is presented in figure 6a and 3D CAD model is presented in figure 6b. Model was used as input information for the machine programming.



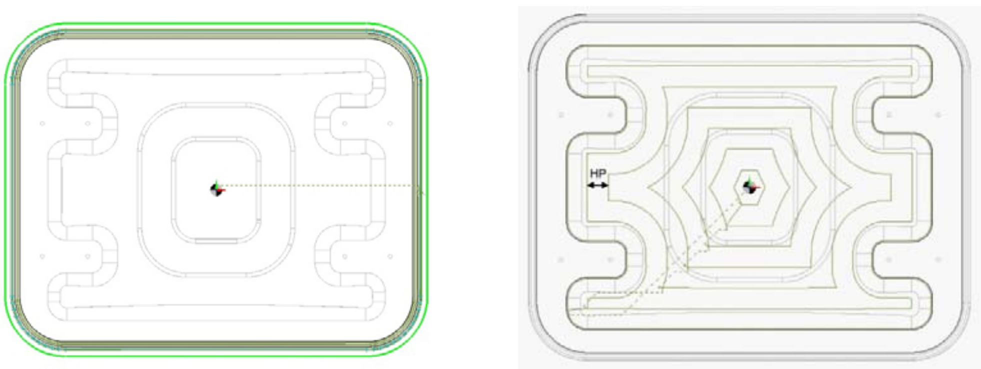
a) Drawing of escape hatch

b) 3D model of escape hatch

Fig. 6 - Escape hatch

During the production of escape hatch it was necessary that zero plane (figure 6a) remains as smooth as possible. Reason for that lies in fact that on this plane some other parts need to be attached. Because of that, manufacturing of escape hatch was divided on production of the feature which is 15mm above the zero plane and feature which is 31mm under the zero plane, figure 6a. This was necessary because of the elastic sprinback which would make impossible to obtain flat zero plain. The first feature was formed using support post. Tool path was programed to be profile milling with spiral tool path, 0,5mm vertical pitch and 4m/min feed rate, figure 7a. After that the sheet metal was turned by 180 degrees around horizontal plane and second feature was formed with impression using profile milling (figure 7b). Feed rate was 10m/min, vertical pitch was 0.3mm. For manufacturing of both features angular speed of die was 1000rpm. Production time was around two hours.

For impression wooden backing plate with 19mm thickness was used, figure 8. Wood is chosen because it is cheaper and easier to mill with regard to steel. Production of escape hatch is presented in figure 9.



a) Top view of the part formed with "profile milling"

b) Top view of the part formed with a "pocket milling"

Fig. 7 - *Forming with impression*

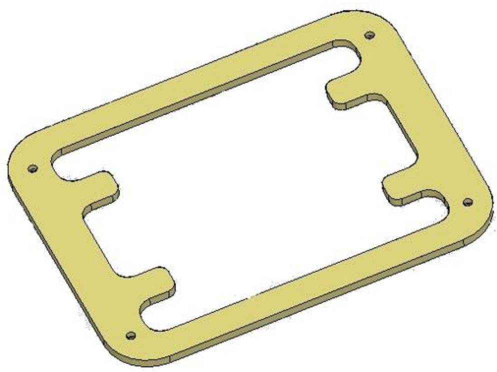


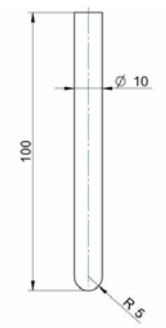
Fig. 8 - *Wooden backing plate*

Fig. 9 – *Production of escape hatch*

For production of escape hatch sheet metal DC01 (C 0146) material was used. Thickness of used sheet metal was 0,8mm. Initial dimensions of sheet plate were 862x678mm. CNC vertical milling center Haas VF-3YT was used for forming process. Machine with main characteristics is presented in figure 10. Tool used in experiment was cylinder ϕ10x100mm with spherical shaped had, figure 11. Tool material was tool steel EN X210Cr12 hardened to 60HRC.

X travel	1016 mm
Y travel	660 mm
Z travel	635 mm
Max speed	8 100 rpm
Rapid feed rate	18 m/min
Max forming feed rate	12,7 m/min

Fig. 10 *- Picture of the Haas VF-3 YT CNC vertical milling center with main characteristics*



a) The shame of the tool

b) Picture of the tools used for deformation

Fig. 11 - *Tools used for incremental forming*

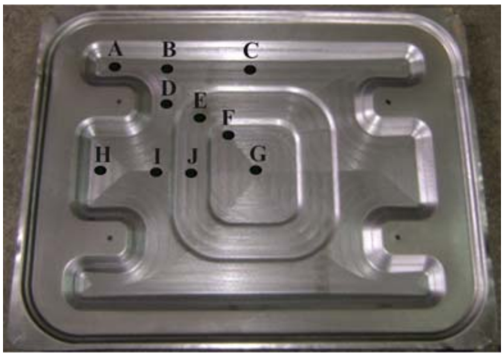


Fig. 12 – *Measurement points*

The escape hatch obtained by incremental forming is presented in Fig. 12. After the forming process measurements were made to determine the value of elastic springback. Fig. 12 shows the measuring points. Measurements were made in the Z (vertical) direction using standard measurement tools. The results of the measurements can be seen in Table 1. Table 1 also contains comparison of final part measurements and CAD dimensions.

Table 1. *Results of the finale part measurement and comparison with CAD dimensions*

Measurement points	CAD measure [mm]	Final part measure [mm]	Difference [mm]
A	16,1	15,9	0,2
B	18,4	18,1	0,3
C	19,3	18,9	0,4
D	19,1	18,9	0,2
E	24,5	24,0	0,5
F	30,6	29,0	1,6
G	31,0	28,2	2,8
H	17,7	17,0	0,7
I	18,6	17,9	0,7
J	24,8	23,0	1,8

4.0 CONCLUSION

Current paper presents manufacturing of large – size sheet metal component (bus escape hatch) by single point incremental forming. Process was performed on CNC vertical milling center. Main technological parameters are given and tool and die were designed and made.
Final product was investigated in terms of accuracy i.e. amount of elastic spring – back at different locations of the escape hatch. This analysis shows that largest deviations between real and CAD

model takes place in the middle of the component (point G, figure 12) and with the distancing from center towards part periphery this deviation decreases.

As the production time for one component is quite long (app. 2 hours) presented process would not be suitable for large batch size production. In such case deep – drawing is optimal production method. In further work deeper analysis of large size part production by SPIF is planned. Special attention will be focused on the influence of difference process parameters on the component quality and production time. Also, simulation of this process by FE method will be performed.

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INKREMENTALNO DEFORMISANJE VELIKIH DELOVA

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REZIME

U poslednjih nekoliko godina inkrementalno deformisanje se sve više koristi u industriji obrade deformisanjem kao alternativa konvencionalnim postupcima. Ova tehnologija je naročito primenjiva u slučajevima pojedinačne i maloserijske proizvodnje delova komplikovane geometrije. U ovom radu je prikazano istraživanje mogućnosti primene inkrementalnog deformisanja (SPIF) za izradu poklopca velikih dimenzija. Dimenzije poklopca su 842x658x46mm. Problem koji se javlja pri obradi velikih delova inkrementalnim deformisanjem je elastično vraćanje.
Uspešna izrada velikih delova u mnogome zavisi i od trajektorije alata. Često je potrebno da trajektorija bude kompleksna što znatno povećava vreme obrade. U ovom radu je fokus stavljen na određivanje adekvatnih kinematskih karakteristika procesa kako bi se dobio deo sa što većom tačnošću. Upoređivanjem CAD dimenzija i dimenzija gotovog dela u referentnim tačkama je utvrđena veličina elastičnog vraćanja.
Ključne reči: *Inkrementalno deformisanje, lim, delovi velikih dimenzija*