TOOL PATH GENERATION IN SPIF, SINGLE POINT INCREMENTAL FORMING PROCESS

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ABSTRACT: In Incremental sheet metal forming process, one important step is to produce tool path. To generate an accurate tool path is one of the main Challenge of Incremental sheet metal forming process. Various factors should be considered prior to generation of the tool path i.e. Mechanical properties of sheet metal, the holding mechanism, tool speed, feed rate and tool size. In this work Investigation studies have been carried out to find the different tool path strategies and their effect on process accuracy. Tool path for variety of generic shapes have been generated as a demonstration example and used to determine process accuracy capabilities for the generated tool path, simulation under to strategies have been carried out using ABAQUS.

Key words: Sheet metal, single point incremental forming, SPIF, Tool path Generation.

The incremental forming

INTRODUCTION

Incremental Forming distinguishes itself by the use of simple tools mounted on CNC machines or robots with the aim of permanently deforming the sheet metal under work, avoiding complex and expensive stationary / moving dies and press systems.

In order to form the sheet metal into the desired shape, a suited tool, mounted on the machine end, is moved accordingly to a predefined path. Some strategies have been developed, differentiating among themselves for the equipment and for the procedure; they are:

- single point Incremental forming, where the sheet is deformed only by the tool, and no support is present;
- double point Incremental forming, where the sheet is deformed by means of a tool and a local support;
- Incremental forming with die, where the tool deforms the sheet against a regular die.

All these strategies can be applied both on CNC machines and robots. The Incremental Forming strategy adopted in this work uses a die, permitting to achieve the best results in terms of geometrical and superficial quality of the product.

Anyway, it must be stated that it is not mandatory to use expensive materials for the die, as high strength steels, because the working loads and the area of deformation are relatively small; in contrast, polymeric materials, thermosetting resins, hardwood or any other material satisfying stiffness and surface finishing requirements can be used, allowing an overall cost reduction.

The main components of the incremental Forming with die forming rig are as shown in figure 1 (a & b) :

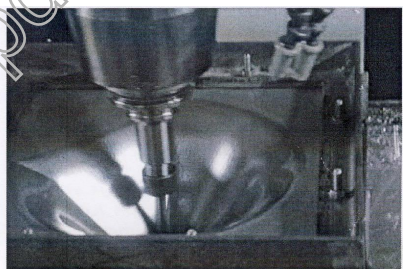


Figure 1a: Incremental forming process

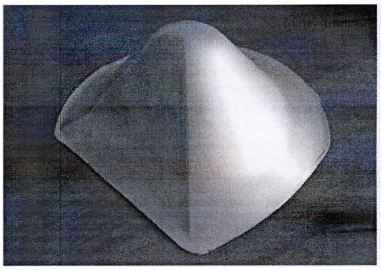


Figure 1b: The Geometry carried out by means of incremental forming.

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- The die, which copies the part geometry;
- The blank holder (fixed or mobile), that keeps the sheet in the correct position during the process.

When the die has a positive (convex) geometry, the blank holder should be moved by hydraulic actuator in order to firmly maintain the sheet in the proper working position; in the case of negative (concave) geometry, the blank holder can be fixed.

The die, is mounted on the faceplate table of the operating machine, and the moving punch deforms the sheet until it meets the die. The punch shape must be optimized in function of the required geometry and finishing. Usually it has a cylindrical shape with a spherical head; the sphere size is an important process parameter, in fact tools with large radius allow better material flow and reduced working time, but smaller radii are often necessary to satisfy the geometrical characteristics of the part to be formed (the radius of the sphere must be equal or less than the minimum curvature radius present in the object).

Tool path

The path followed by the tool is generated by a CAM software, starting from the CAD model of the object or of the die.

For positive die geometry, the punch deforms the sheet starting from the centre and moving towards the boundary, whereas for concave die geometry, both outer-to-inner and inner-to-outer paths can be used. In the first case, the punch progressively deforms the blank with a spiral movement from the top going towards the maximum depth (direct forming, Fig. 2a), while in the second case, the punch is firstly moved down to the maximum drawing depth, then a spiral trajectory in upwards direction completes the process (inverse forming, Fig. 2b).

This last approach assures a better material flow from the boundary and limited thinning risks, but it can be used only with limited die depths because it need higher lateral forces than the first approach.

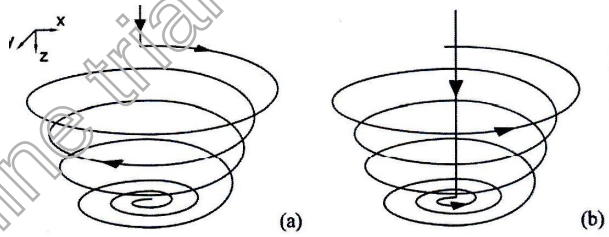


Figure 2: (a) Inverse (b) Hybrid

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In this work, a hybrid solution was tested, where the punch is progressively moved downwards up to the bottom of the die (as in direct negative forming) but contemporary it follows a inner-to-outer spiral (as in inverse negative forming)

An example of tool path generated is shown to figure 3.

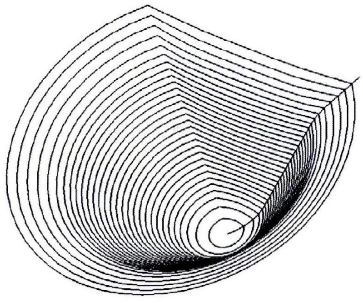


Figure 3: An example of toolpath

Tool path strategies

Due to the elastic-plastic properties of the sheet metal, the tool path of a given shape will vary from the final shape as shown in Fig. 4. This is obvious at the beginning of the process where there is evidence of both elastic and plastic deformation. The final shape of the formed part has been found to be dependent upon a number of factors including the tool-path, the material properties of the sheet metal, the tool material, tool speed and the tool feed rates

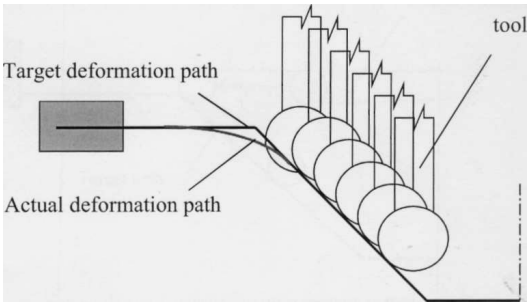


Figure 4: Target and actual ISF tool path different

Tool path strategies to improve this have been developed for the selected case studies. Fig. 5 shows the various possible tool path solutions to correct the difference in the targeted and actual deformation paths.

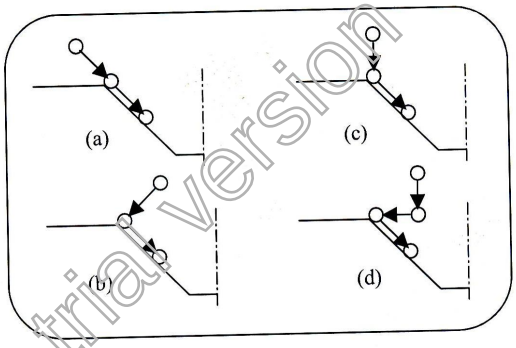


Figure 5: Possible solutions to allow starting point inaccuracy

Option (d) was seen to be the most effective toolpath over the variation in the toolpath. Fig. 6 shows how this variation overcomes this problem.

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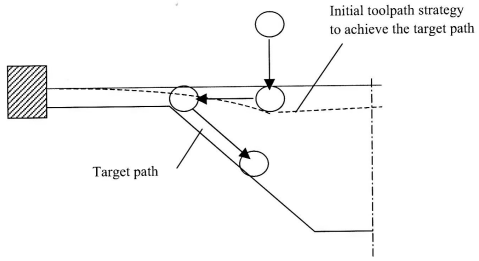


Figure 6: Initial deformation approach strategy

Maximum slope achievable using ISF

The incremental deformation of the sheet metal is limited by the amount of depth to which the sheet metal can be deformed. This can be verified by determining the limiting angle a as shown in Fig.7.

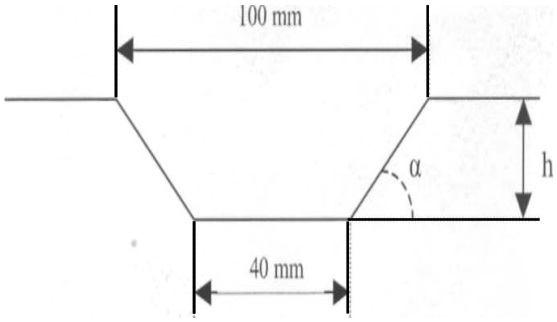


Figure 7: Dimensions of the cone

In order to compare different parts with various forming angles, the thickness of the sheet metal must be uniform for all parts. The only parameter that must change is the angle. The part chosen is a cone with dimension 100 mm for the top diameter, 40 mm for the bottom diameter. The tool has a diameter of 17.5 mm. The rectangular holder was used for this experiment.

Table 1: Achieve angle of deformation

Angle [α]	Height [h] [mm]	Feed ratio [ΔX/ ΔZ]	Pass / fail
45	30	2/2	Pass
56.31	45	2/3	Pass
63.43	60	2/4	Pass
71.57	90	0.5/1.5	Pass

Forming strategies

Simulation tests were carried out with two forming strategies (strategy "A" and "B" with constant step depth) to experimentally verifies the forming on a truncated cone.

By strategy "A" (see Figure 8) the slave tool is following the master tool but all the time in the flat zone of the part.

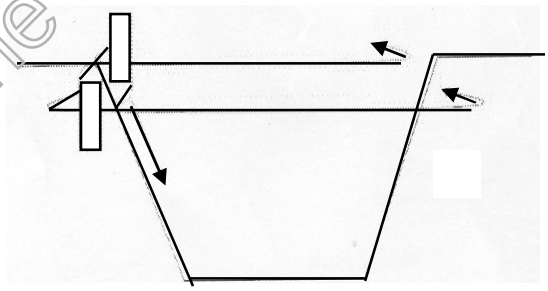


Figure 8: Strategy A

By strategy "B" (see Figure 9) the slave tool has a constant path on the outer contour and supports the master tool right on the opposite side of the sheet.

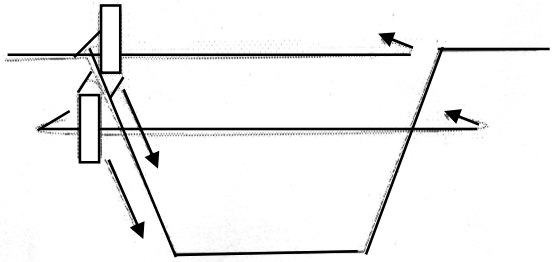


Figure 9: Strategy B

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Control can handle simultaneously interpolated 28 axes and four spindles. Four execution channels allow four different machining operations to run in synchronization. We only used six axis, three for the forming (master) tool and three for the supporting (slave) tool. A precise calibration assures that the movements of both machines are according to the same origin, and that they move along the same axes.

The master tool movement is programmed using CATIA CAM software intended for surface milling. The slave tool path generation is solved with a C++ program. The output of the program can be in CATIA file format (for visual validation) or in NC-CODE.

Strategy "B"
In order to support the master tool with the slave tool a predefined gap is needed between the two hemispherical tools. Figure 10 shows the master-slave configuration for strategy "B".

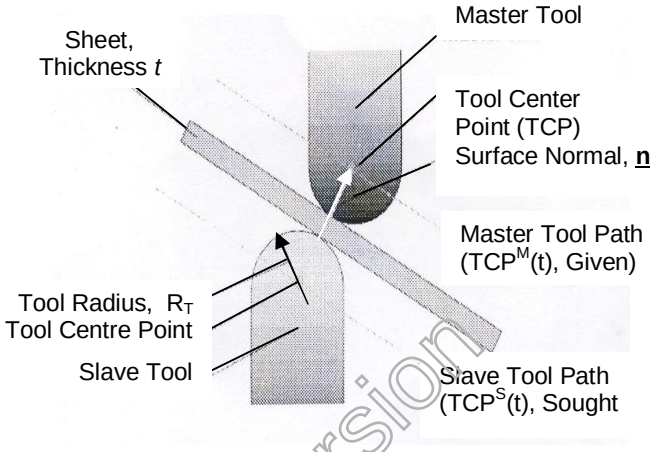


Figure 10: Master-slave configuration for strategy "B"

The simplified formula (1) for strategy "B" is the following

$$TCP^S = TCP^M + (2R_T + t)\frac{n}{n} \qquad (1)$$

Where **t** is calculated with the so-called sine-law
$t_1 = t_0.\sin(90° - \alpha)$ (2)

Volume constancy leads to this relationship (2) between initial (to) and actual (ti) sheet thickness by a given wall angle a.

Strategy "A"
Strategy "A" is the same as strategy "B" for the first level of the forming, but after the first level the calculation is different. Figure 11 shows the master and the slave tool paths in strategy "A"

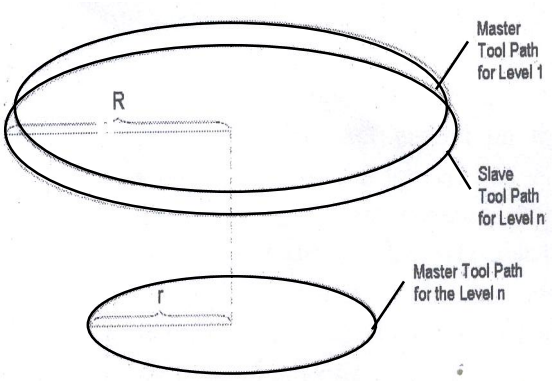


Figure 11: Master and slave tool paths in strategy "A"

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The simplified formula for strategy "A" is the following

$$TCP^S = \left[\left(TCP \times^M, TCP_Y{}^M \right), \left(\frac{R}{r} \right), TCP_Z{}^S \right] \quad (3)$$

TCP^S is given here with coordinates and TCP_Z is calculated only once, at the first level.

It is worth mentioned that both strategies can be used with multistage forming to reach higher formability.

CONCLUSIONS

The presented tool path generator program has a simple graphical user interface and is able to generate slave tool paths for arbitrary freeform surfaces based on the master tool path calculation of a well known industrial CAM software.

In this paper, the incremental deformation theory of plasticity has been implemented in ABAQUS using a behaviour law implemented in a specific user function (VUMAT). The model has been tested on a cup forming process. The results are compared with those obtained with the classical flow rule theory. We found that the numerical errors are acceptable while a reduction of CPU time was observed.

An integration of the tool path definition created by CATIA in ABAQUS has also been developed using Visual Basic and Python scripts and the maximal velocity of the tool is then controlled.

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