New solutions in Incremental Sheet Forming

Theses Booklet

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Introduction

In recent years, a new kind of plastic deformation method, called incremental sheet forming (ISF) has become increasingly echoed in the scientific literature.
The ISF process is similar to metal spinning, its origin goes back to a patent granted in 1967, but the realisation of it started (because of absence of technological conditions) only in the 90's. Opposite to metal spinning, where the sheet metal is formed to an axial symmetric object by spinned on a lathe and pressed continually with a tool, in ISF the sheet is clamped down with a frame and formed with a spherical head forming tool.

In contrary to conventional plastic deformation processes the final shape of the part is not determined by specific dies, rather by the three-dimensional movement of a forming tool, for which an appropriate tool path has to be calculated, based on the part geometry. This movement can be carried out by a CNC milling machine or by an industrial robot.
The design, manufacture and later on the storage/disposal costs of a traditional stamping tool are significant higher than in ISF which allows higher formability and is environmentally more friendly.
Of course, this relative slow process is only profitable with small series and Rapid Prototypes but the applicability of it has a wide range in the field of automotive industry, aircraft industry, architecture engineering and medical aids manufacturing.

In the past years, the research - in connection with ISF – has focused on the boundaries, on the modelling of the process, on the improvement of the geometric accuracy of the parts, on the applicability of new materials, and on the tool path optimisation.
Figure 1 shows the main variants (Single Point – and Two Point Incremental Forming, SPIF and TPIF respectively) of this process.

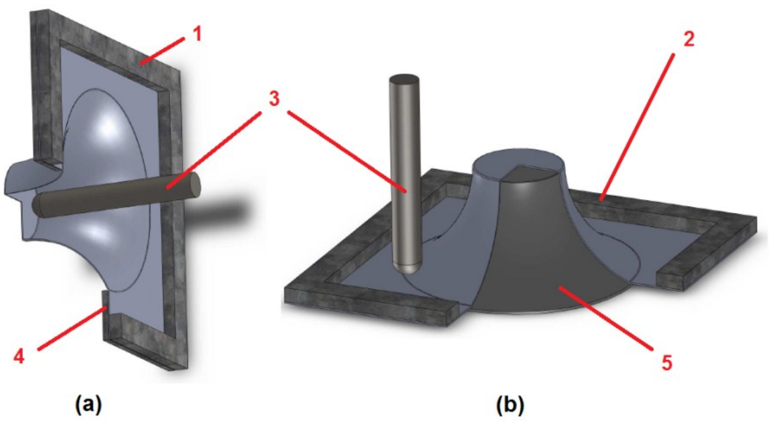


Figure 1. Illustration of (a) vertical SPIF, (b) horizontal TPIF with 1: stationary blank holder (BH), 2: moving BH, 3: forming tool, 4: backing- /faceplate, 5: stationary/moving, full/partial die

A special TPIF variant is the two-sided Incremental Sheet Forming or fully kinematic ISF (with supporting tool), in which two main forming strategies can be realised („A: with peripheral support" and „B: with local support").

In the case of strategy "A" the second tool acts as a backing plate, moving synchronised with the forming tool, but it does not leave the first contour level of the supporting tool path. In the case of strategy "B" the second tool moves synchronised with the forming tool, but ensuring continuous local support at each tool path level (see Figure 2).

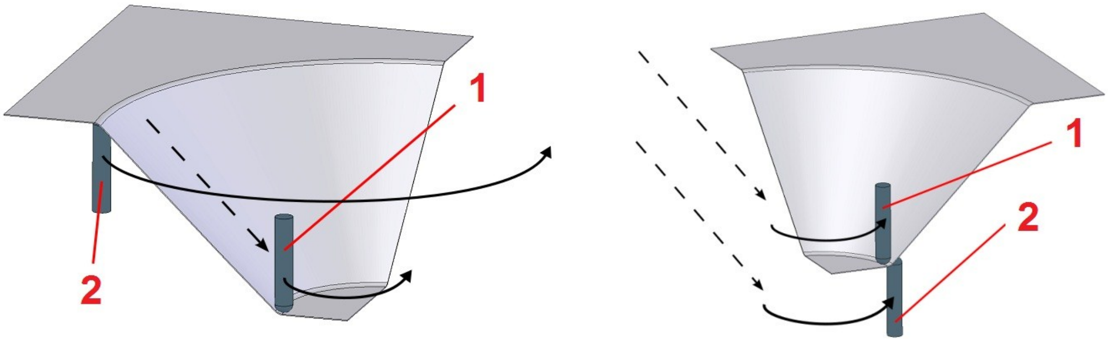


Figure 2. Illustration of forming strategy „A" and „B" with
1: forming tool, 2: supporting tool

Aim of the thesis

My goals are the analysis and improvement of this new kind of plastic deformation process, furthermore the modelling, development and testing of new measurement methods for ISF which can make the sheet forming more accurate and effective.

It this process it is important to determine indirectly or directly the sheet thinning to prevent fracture of the sheet. It is significant to use direct measurement methods in case of anisotropic, material failure affected sheets. The question remains what type of direct measurement method is suitable for sheet thinning and how to intervene in the machining process. A further question is the adequate tool path definition and application in terms of part quality and the implementation of an adaptive control.

Since, according to the literature and based on experiences, the numerical simulation of the previous processes are time consuming, therefore I attempt to test and compare new process strategies mainly with forming experiments.

Furthermore, my goal is the adaptation of heat-assisted ISF to thermoplastic polymer sheets.

Investigated materials and applied test methods

In the investigation, aluminium (Al1050), PVC and PE-HWST sheets were used. Tensile tests were performed to determine the characteristics of some sheets. Design of experiments (DoE) and ANOVA analysis have been used in the research work.

Experiments were carried out in the research centre of Tecnalia (prior name: FATRONIK), at BME MOGI - Department of Mechatronics, Optics and Information Engineering and in the CIM Research Laboratory of the Institute for Computer Science and Control, Hungarian Academy of Sciences (MTA SZTAKI CIM Lab.).

Applied equipment

- Rieckhoff type 2.5D CNC milling machine
- Prototype of a TSISF system
- Mitsubishi RM-501 type manipulator
- KUKA KR6 type industrial robot
- FANUC S430iF type industrial robot

Force measurements were carried out with a JR3 type Multi-axis force and torque sensor cell. Some sample parts are scanned with GOM's systems, sheet thickness measurements have been validated with a Mitutoyo SLIM Type Linear Gage.

The integration of the Hall sensor (AD22151 type IC - for thickness measurements) into the ISF process was carried out with the help of a self-made calibration device based on a micrometre screw. Preliminary simulations and the design of the sheet thickness measurement device alpha prototype were carried out with a FEM program. Heat-assisted Single Point Incremental forming experiments were performed with an AOYUE-852A type rework station. To determine the temperature distribution of the sample sheets a Testo 875 type thermo camera was used.

Applied programs

CAD and CAM programs: SolidWorks, SolidCAM

Robot motion simulation program for kinematic examinations: IRBCAM

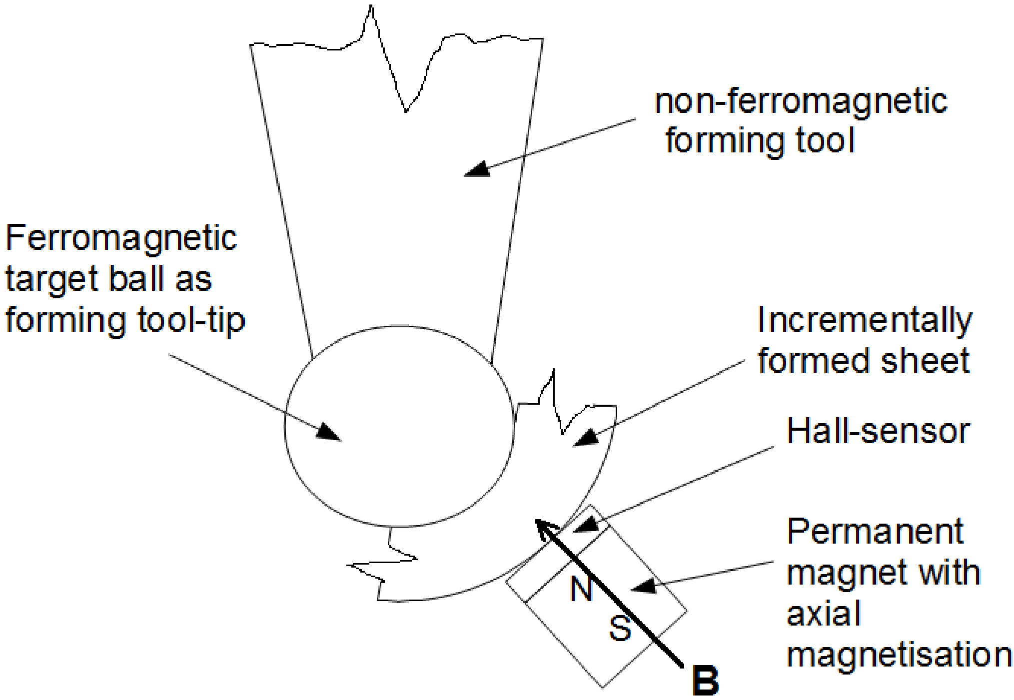
Real-time CNC and robot control program: Linuxcnc 2 (prior name: EMC2)

FEM simulation program: ANSYS Workbench v11

Theses

Thesis I

In case Single Point Incremental Forming (SPIF) is applied on a non-ferromagnetic sheet, the following configuration and measurement method is suitable to measure on-line the sheet thickness in the small plastic zone:

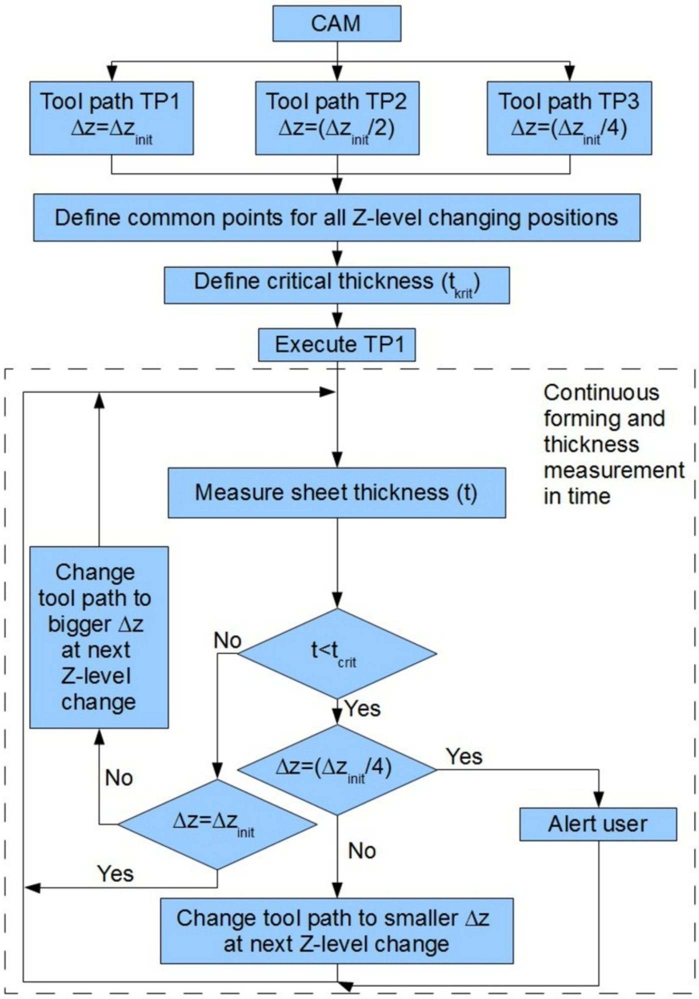


This is proved by results of SPIF experiments carried out on aluminium (Al 1050) sheets with 0.5 mm initial thickness and variable wall angle geometry. (In the figure "B" stands for the magnetic B filed.)

Related publications: [PC-Paniti2011], [PJ-Paniti2012], [PB-Paniti2014], [PJ-Paniti2014c], [PC-Paniti2014]

Thesis II

Single Point Incremental Forming (SPIF) can be realised with the combination of pre-calculated tool paths on the same geometry. The tool path control, for changing tool paths on-line with different incremental depths, is capable to bypass fracture due to localised thinning up to the sheet's forming limit. The tool path control is defined with the following block diagram:



This is proved by results of SPIF experiments carried out on aluminium (Al 1050) sheets with 0.5 mm initial thickness and variable wall angle geometry.

Related publications: [PB-Paniti2014], [PJ-Paniti2014c], [PC-Paniti2014]

Thesis III

Opposite to the conventional two robot/machine tool (forming machine) concepts of Two Sided Incremental Sheet Forming (TSISF), the optimal supporting force/position in the case of TSISF can be realised with one, at least 4-DOF machine and with a linear actuator equipped C-frame support, where the optimal supporting force is achieved with the force control of the tools. The forming tool on the forming machine is eccentric and the force control is based on one-component force cells mounted on the mentioned devices (forming machine and linear actuator). Tool path calculation for the simplified TSISF system can be realised with the following approach:

In case when the eccentric tool (mounted on the forming machine) is acting as forming tool, while the supporting tool on the linear actuator is force controlled:

1. Calculate generic tool path GTP(X, Y, Z, I, J, K) of the part as in SPIF (I, J, K values are coordinates of the contact point).
2. Calculate supporting points with $S = F + (2R_T + t)\frac{n}{|n|}$.
3. Replace Z coordinates in *S* from GTP for eccentric tool path.
4. Calculate rotational angle γ of the last joint based on the following coordinates: TCP_X^F, TCP_Y^F, TCP_X^S, TCP_Y^S.
5. Solve inverse kinematics problem.
6. Replace the joint position value of the last joint to γ.

In case when the eccentric tool (mounted on the forming machine) is acting as supporting tool, the Z-coordinate of it is force controlled and the linear actuator is acting as forming tool:

1. Calculate generic tool path GTP(X, Y, Z, I, J, K) of the part as in SPIF (I, J, K values are coordinates of the contact point).
2. Recalculate Z for linear actuator, based on starting position of the actuator.
3. Calculate supporting points with $S = F + (2R_T + t)\frac{n}{|n|}$.
4. Calculate rotational angle γ of the last joint based on the following coordinates: TCP_X^F, TCP_Y^F, TCP_X^S, TCP_Y^S.
5. Solve inverse kinematics problem.
6. Replace the joint position value of the last joint to γ.

Where

$$S = \begin{bmatrix} TCP_X^S \\ TCP_Y^S \\ TCP_Z^S \end{bmatrix}, \quad F = \begin{bmatrix} TCP_X^F \\ TCP_Y^F \\ TCP_Z^F \end{bmatrix} \text{ and } \quad \underline{n} = \begin{bmatrix} n_X \\ n_Y \\ n_Z \end{bmatrix}.$$

Related publications: [PP-Paniti2012], [PB-Paniti2014], [PJ-Paniti2014b], [PC-Paniti2014]

Thesis IV

Two Sided Incremental Sheet Forming (TSISF) strategy with local support results higher formability than TSISF strategy with peripheral support.

Results of TSISF experiments carried out on aluminium (Al 1050) sheets with 0.6 mm initial thickness are confirming this.

In case of simple axial-symmetric test parts a tool path of TSISF strategy with peripheral support for the first supporting contour can be realised with the following equation:

$$S = \begin{bmatrix} TCP_X^F \frac{R}{r} \\ TCP_Y^F \frac{R}{r} \\ TCP_Z^S \end{bmatrix} \tag{2.3}$$

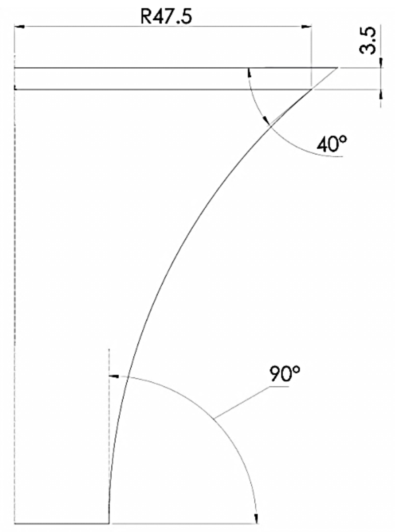
where TCP_Z^S is calculated only for the first level of the forming, the parameter r is the radius of the last tool path contour of the forming tool, while R is the radius of the first tool path contour of the supporting tool.

Related publications: [PJ-Tisza2010], [PJ-Paniti2010], [PJ-Paniti2014b]

Thesis V

The increasing value of the axial reaction force of Heat-assisted Single Point Incremental Forming (Heat-assisted SPIF) with 5 mm thick PE-HWST* sheets does not exceed 1000 N in the incremental forming period, in case the sheet is heated up to 70°C.

Heat-assisted SPIF of thermoplastic polymers can be carried out with a hot air gun, positioned coaxial to the opposite side of the sheet with a C-frame. The experimental equipment can be replaced with two synchronised robots/machine tools where one of them is moving the hot air gun.



Reaction force measurements of Heat-assisted SPIF experiments (bi-directional, z-level milling tool path with tool diameter: 15 mm, incremental depth: 0.5 mm, speed: 3000 mm/min, air temperature: 110 °C, air flow rate: 20 L/min, nozzle diameter: 8.4 mm) of 5 mm thick extruded PE-HWST sheets, carried out with the above geometry are confirming this.
*(PE-HWST density: 0.947 g/cm^3, crystallite melting range: 126°C - 130°C, modulus: 900 MPa, tensile strength: 22 MPa, Shore hardness D: 64)

Related publications: [PC-Paniti2007], [PC-Nacsa2011], [PJ-Paniti2014a]

Author's publications

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[PB-Paniti2014] Paniti, I. (2014). New Solutions in Online Sheet Thickness Measurements in Incremental Sheet Forming. In Applied Information Science, Engineering and Technology, Springer International Publishing, pp. 157-177.

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