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Adaptation of Incremental Sheet Forming into cloud manufacturing

Imre Paniti *

Institute for Computer Science and Control, Hungarian Academy of Sciences, Kende u. 13–17, H-1111 Budapest, Hungary

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ABSTRACT

Incremental Sheet Forming (ISF) is a technology suitable for manufacturing small series and single products. Due to the high customization potential of this process, it is therefore necessary not only to implement the mechanical tools and control algorithms needed, but also to enable easy integration with product configurations executed by customers. The paper describes how ISF can be provided as flexible manufacturing service to production networks and how it can be configured by means of appropriate service descriptions. Furthermore, a new adaptive tool path control algorithm at process level is introduced to bypass fracturing due to localized thinning.

Introduction

Nowadays, one of the most promising approaches to improve the ability to react quickly to changing customer's demands is the automated or semi-automated integration of production networks at IT level. This is already applied in business operations, e.g. exchanging business documents such as orders and invoices [1]. However, the challenges of flexible, distributed manufacturing go beyond such operations, as this form of information exchange does not include product and production specific data such as designs and required process parameters. As a result, there is a need to integrate such specifications and manufacturing IT systems into the overall supply chain management infrastructure in order to enable quick reactions to changing product specifications.

A new concept of cloud manufacturing [2] introduces some aspects which could help to overcome this issue. The transfer of the XaaS (Anything-as-a-Service) concept to the production domain is one of these ideas, and this predicts the implementation of MaaS (Manufacturing-as-a-Service) based on cloud-computing concepts which are considered here. One precondition for the implementation is the availability of agile IT systems which are capable of supporting the degree of flexibility at production network level as well as at factory, process, and equipment levels. A research and development project within the EU's Seventh Framework Programme (FP7), ManuCloud, has been set up to develop a marketplace for virtual manufacturing services as well as to achieve the enhanced integration of manufacturing networks based on the dynamic interconnection of multiple factories.

"Three industries have been selected to be the initial application context for the ManuCloud concepts and technologies: The photovoltaic (PV) industry, the organic lighting (organic light emitting diodes – OLED) industry and the automotive supplies industry." [3] Demonstration scenarios and products have been prepared to show the integration and implementation of the small series production of complex customizable products and services of small to medium-sized enterprises (SMEs) [4–7].

On the automotive side, there are many possibilities of proving the benefits of this approach. However, it is even more motivating to apply the approaches to a flexible manufacturing technique. For this reason, the paper gives an overview of how Incremental Sheet Forming (ISF) could be implemented as a manufacturing service and of a new adaptive control algorithm to decrease the number of trial sheet-forming.

ISF variants and main technical parameters

Incremental Sheet Forming variants

ISF, known in early stages as "Incremental Dieless Forming" [8], is a promising process for the sheet metal and polymer industry with small series in the field of one-of-a-kind production. Rapid prototypes are already made for the automotive and aircraft industry but there are also good perspectives for the medical device industry and architectural design. These prototypes are generally made in the course of different research investigations

* Tel.: +36 1 279 6207.
E-mail addresses: imre.paniti@sztaki.mta.hu, imrepaniti@gmail.com

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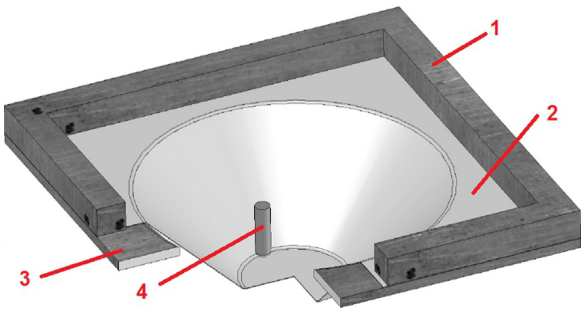

Fig. 1. Illustration of SPIF in cross sectional view, with 1: clamping frame, 2: sheet, 3: faceplate, 4: forming tool.

but there are some SMEs and research centers where parts can be ordered and then produced within days or weeks (depending on the complexity of the part). When a metal or polymer sheet is formed using ISF, the forming tool which is carried by an industrial robot or CNC machine [9] makes an indentation in the sheet and follows the tool path of the desired part.

This process step (local bending and stretching) is repeated all along the tool path until the final depth and form of the part is reached. The tool path (mostly z-level or spiral) is similar to profile milling performed using commercial or home-made CAM programs. There are different ISF variants depending on the number of contact points between the forming tool, sheet and supporting die (if used). The term Single Point Incremental Forming (SPIF) is used when the opposite side of the sheet is supported by a faceplate. Fig. 1 shows an example of SPIF.

Two Point Incremental Forming (TPIF) is used when a full or partial die supports the sheet [10]. Fig. 2 shows an example of TPIF.

A further developed variant of TPIF, where a second counter tool is synchronized with the first one, can also be used to produce the final shape [11]. The main difference between SPIF and TPIF is the forming accuracy. TPIF is more accurate but needs a partial or full support (depending on the geometry), making it more expensive.

Incremental Sheet Forming process parameters

ISF forming limits are higher than those of stamping or deep-drawing and are dependent on the following process parameters [12]:

(1) Material and initial thickness of the sheet
(2) Material and geometry of the forming tool
(3) Geometry of the part
(4) Step depth
(5) Tool path

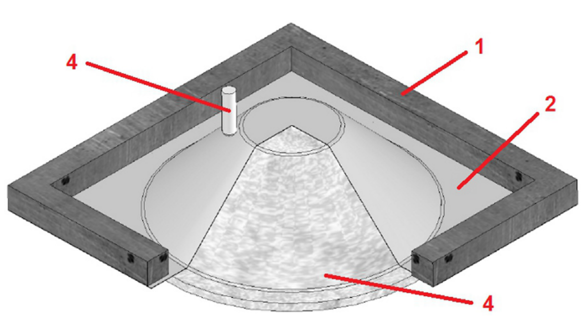

Fig. 2. Illustration of TPIF in cross sectional view, with 1: clamping frame, 2: sheet, 3: full die, 4: forming tool.

The influence of these parameters on each other and on the final product is clearly summarized in [10]. For example, sheet formability decreases with increasing step depth; this is also important when optimizing tool paths.

Tool path optimization in ISF

Tool path optimization in TPIF [13,14] and SPIF [15,16] is very important because sheet thinning [17] occurs during the forming process. Based on a geometrical model of the kinematics of ISF, the degree of thinning can be predicted with sufficient accuracy [18]. However, in the case of anisotropic materials with localized material flaws, it is better to use an on-line measurement method during forming. Some reaction force trend-based [16,19] measurement methods have been used to measure localized thinning of the sheets indirectly during forming, but only two direct methods are mentioned in literature [20,21]. The only drawback with these set-ups is that they measure the sheet thickness axially to the forming tool and not close to the deformation zone where the sheet thinning actually occurs.

SPIF experiments showed that "fracture always occurred at a previously generated shear band closest to the current position of the tool" [22]. From this, it follows that the simplest implementation of the Hall-effect sensor-based on-line thickness measurement device would be an ISF tool with an iron ball head [8]. The Hall-effect sensor and the magnet can be placed on the opposite side of the sheet. During forming, the magnet and sensor (bonded to the magnet) are carried with the forming tool. This enables an appropriate adaptive control to be used to bypass fracturing due to localized thinning.

Calibration experiments are already done for this approach and documentation of the results can be found in [23]. However, the question remains as to what type of adaptive control should be applied.

Adaptive tool path control algorithm

Separating the measurement principle from the control algorithm, two simple on-line methods can be found in [16]. In the experiments documented in [19], it was necessary to stop the machine every time forming parameters were altered (in the case mentioned, only the diameter of the forming tool). The two methods are shown below:

(A) "Tool path adaptation by modifying the tool jog" – this means a "modification of the tool height between two successive control points of the tool paths". [16]
(B) "Tool path modification by using a clearance routine" – this means "as soon as the tool load estimation overtakes a pre-set value, the forming NC program calls the clearance subroutine" which performs a retract movement along the tool axis. [16]

A drawback of these methods is that with method (A), "the final accuracy can be affected by tool jog variations if several tool path adaptations are needed during the process" [16] and with Method (B), that the user-defined movement of the tool causes local surface roughness because the tool contact and thus also the continuous forming of the sheet is changed.

In [13], experiments showed that "it is important to use a tool path with a variable step depth" and define the maximum step depth (0.2 mm) and scallop height to a low value (0.02 mm). This increases accuracy but unfortunately also the process time, thus leading to ineffective production.

A compromise can be made by using an on-line thickness measurement with a simple adaptive control algorithm, which