AN OVERVIEW ON INCREMENTAL SHEET FORMING, A METHOD FOR RAPID MANUFACTURING OF HOLLOW METAL PARTS

Alexandru C. FILIP¹ and Ion NEAGOE¹

ABSTRACT: During the last decade, incremental forming is an innovative processing method which has been strongly investigated. Its potential as a flexible manufacturing method was noticed. This paper aims to present a comparative study of the recent worldwide developments in the field of incremental sheet forming (ISF), as a flexible method for manufacturing hollow metal parts. There are pointed out its particularities for rapid manufacturing and small quantity production. The advantages and the weak points of the method are classified and some future strategies of improvement are drawn up. The paper includes the results of some research done by the authors on sheet manufacturing by spinning, seen as an ISF process.

KEY WORDS: incremental forming, metal spinning, rapid manufacturing, AISF, sheet metal.

1 INTRODUCTION

In the manufacturing world of today, the demand of highly customized products is increasing every day. Even if the mass production is still used, the small quantity batches are more and more required. The key words of manufacturing are: flexibility, product customization, customer orientation, high quality, low production cost.

The specialists all over the world must find quick answers to these new challenges, introducing new sustainable technologies which can assure the survival and development of their companies.

In sheet metal forming, the manufacturing processes evolution towards a more flexible production has made big steps in the last period of time. Introducing the numerical control for stamping and bending has strongly increased their rate of flexibility. On the other hand, the deep drawing process remained a little behind, due to the requirement of dedicated punch and die, mainly for asymmetric shaped sheet parts.

Probably, an important step was done by the hydroforming process, which eliminated one of the dedicated tools and, thus, increasing the process flexibility with lower rates of the cost.

Another step was the idea of replacing the conventional tools with the so-called multi-point tools. The principle is to use of a set of discrete punches whose height is adjustable and creates a reconfigurable tool, according to any shape of the part to be formed. The flexibility is increased, but setup and accuracy are still today issues to be solved.

Another important milestone is considered to be the incremental forming process. It is a relatively new forming process which doesn’t require dedicated punches and dies for the deep drawing of hollow parts. This fact makes it the most flexible forming process known so far.

The process of incremental forming can be used both for bulk and sheet forming. However, considering the academic research and the industry interest, the process was mostly studied for manufacturing sheet hollow parts, especially for asymmetric shapes. Thus, the process is usually named Incremental Sheet Forming (ISF), or Asymmetric Incremental Sheet Forming (AISF).

The most important advantages of ISF can be pointed out easily as following:

- a high rate of flexibility among the deep drawing methods – to manufacture a new part, one needs only to load the new NC program in the NC equipment of the machine and a few technological parameters adjustment;
- the set-up costs can be, practically, zero, as usually, a hammer-type rounded universal tool is used for most of the parts;
- no need for dedicated machine-tools – usually, a milling machine is suitable to carry out the process of forming;
- a low cost method for rapid manufacturing of new parts or remaking the old parts whose conventional dies are not available;
- a higher rate of formability than the classical deep drawing process, due a more advantageous stress state created by using the localized deformation.

¹Transilvania University of Brasov, Manufacturing Engineering Department, str. Mihai Viteazul no. 5, 500174-Brasov, România, tel./fax +40.268.421318. E-mail: filipal@unitbv.ro; neagoe_ion@unitbv.ro
Like all other manufacturing methods, ISF has its weak points. The main problems to be improved are:
- a low productivity rate which leads to a long manufacturing time – usually ISF needs several minutes comparative to seconds in the case of conventional deep drawing process;
- a not sufficient accuracy of the part’s shape, usually demanded in such cases – the springback is much stronger and it needs a well compensation to achieve the required precision;
- not enough theoretical knowledge of ISF – even if FEM was used to understand the process, there is still room for some research to clarify the mathematical model which explains the deformation process.

By analyzing the technical literature in the field in the last decade, this paper aims to give a comprehensive image on the incremental sheet forming process, emphasizing its applicability for rapid prototyping of new parts and rapid manufacturing of small quantity parts. It also gives a critical eye on the process, pointing out the future directions of research, as foreseen by the authors of this paper.

The authors of the present paper consider that in the field of incremental sheet forming some clarifications on the terminology can be made. In the next section, these facts are presented.

2 ISF TERMINOLOGY

The name incremental forming can be used, more generally, for the processes which form the part by creating localized deformations, moved progressively on a certain path to cover the entire surface of the product.

Considering the previous definition of the process, it must be accepted that manufacturing methods like metal spinning or cold rolling are also incremental forming processes. Thus, a classification is required, depending on the shape of the part:
- metal spinning, used mostly for axi-symmetric shapes;
- incremental forming, named usually asymmetric single-point incremental forming (AISF), used for non symmetric shapes.

Both of the two methods were explored with more interest in the last decade, due to the growing demands of customized products and small sized production in the field of sheet metal forming.

For both of the two methods the main tool is a universal one. It can be a hammer-type rounded tool or a roller. Metal spinning is done on machine-tools similar to common lathes, usually called spinning machines or even spinning lathes. AISF is done on NC milling machines by adapting their table for sheet clamping.

Depending on the processing strategy, AISF can be performed in several ways. As shown in section 4, there are SPIF, TPIF and multipoint ISF (MPIF). Some specialists noticed also two possible directions of forming, downwards and backwards, usually naming them negative and, respectively, positive incremental forming.

Beyond the terminology used in industry or academic research for this class of forming processes, its strong development is foreseen in the future of customized production.

3 ISF BY METAL SPINNING

Metal spinning is a manufacturing process known since the Middle Age. It is mainly used for axi-symmetric parts and, until the numerical control was introduced, it required high working skills. The process was carried out on a common lathe, figure 1. The blank sheet is clamped with a tail stock facing a profiled mandrel. By handling a rod-type tool with a rounded head, the craftsman forms the hollow part following a progressive strategy.

The next stages were the creation of spinning machines with hydraulic copying device and, nowadays, with NC equipment. Practically, any shape of axi-symmetric hollow parts, made of metal sheet, can be manufactured on the latter type of machines. For example, figure 2 presents the strategy for manufacturing a cone by a multi-pass path.

![Figure 1. Metal spinning on a common lathe](image-url)
Depending on the shape and dimensions of the part, a certain manufacturing strategy is applied. If the part has a small relative height, it can be processes in one single pass.

If it is higher, it needs a multi-pass path, which can be linear or curved.

The main issue about metal spinning is creating a technological database with the values of the main parameters used in the process such as the feed rate, the decreasing rate angle and the angle at the first pass, the radius of the roller and the spacing between two successive passes.

Some own research of the authors introduced new math models of the process and CAD simulators to speed up the set-up time for a certain kind of part and to minimize the risk of failure due to a wrong chose of the parameters’ values.

Further research is required to extend the technological database and the range of shapes which can be tested on the CAD simulators.

4 ASYMMETRIC ISF

Asymmetric incremental sheet forming is considered an innovative manufacturing process with a high flexibility and a great potential to be used on a large scale basis in the industry.

Incremental sheet forming (ISF) was first introduced by Roux and Leszak by registering USA patents on a new dieless method of forming.

The principle is relatively simple, figure 3: the sheet is clamped with a blankholder on a main plate and a hammer-type rounded tool is moved towards a certain path, with a certain depth feed rate and progressively deforms the sheet, giving it a hollow shape.

This type of mechanics of forming, “borrowed” from the milling process, eliminates the specific punch and die, used normally in a conventional deep drawing process and gives a high flexibility at low set-up costs.

The parameters which influence the process are considered to be:

- the shape of the path followed by the tool;
- the speed of the tool along the path;
- the depth feed rate;
- the radius of the forming tool;
- the presence or absence of any back support of the sheet during the deformation process.

The main advantage of the ISF – flexibility at low costs – was noticed. Recent research have foreseen some industry opportunities such as automotive body prototypes, aerospace housings and panels, maintenance of old and vintage cars, housings for lighting, medical prosthetics and, generally, all cases where rapid manufacturing is required.

All researchers accepted so far a classification of ISF in two major groups:

- Single Point Incremental Forming (SPIF), fig. 3, when there is no back support on the other side of the sheet facing with the forming tool;
- Two Point Incremental Forming (TPIF), figure 4, when there is a back support of the sheet, like a simple universal plate (a) or a conventional specific punch (b).

Analyzing the mechanics of forming of the two methods, one can easily notice that SPIF, figure 3, is a negative incremental process, named also dieless forming, because it doesn’t require any die. TPIF, figure 4, is a positive incremental process which requires a supporting punch.

The process of deformation at ISF is complex. The stress state, is formed on a localized forming zone and is in permanent movement according to the tool movement along its designated path. The radius of the tool directly influences the contact area.
with the sheet, directly generating the processing force.

The stress and strain states are similar to conventional deep drawing for SPIF and a little different for TPIF. However, the localized character of the deformation makes the difference and allows values of the deformation degree greater then in conventional deep drawing.

The main challenge was to create a suitable theoretical model able to predict with enough accuracy the stress and strain states which directly lead to a correct prediction of the final shape and dimensions of the part. Another challenge, still not solved today, was to answer why the forming with a localized deformation allows much greater rates of stretching, beyond the conventional forming limit curves, used in classical deep drawing.

Theoretical models were introduced the accuracy of the parts was analyzed and FEM models were tested.

Recent researches have revealed and modeled the mechanism of deformation in ISF and established mathematical equations with the process parameters involved: stress and strain, wall thickness, radius of the tool, forming force.

One other issue was the strategy of tool movement. As in milling processes, during ISF, the path of the tool directly influences the manufacturing time and the part’s accuracy. Several researches proposed some improved strategies to optimize the tool path according to the accuracy and shape of the part.

Between the two major types of ISF, SPIF and TPIF, there must be pointed out some differences which can influence their applicability in a certain case and the accuracy of the part:

- in SPIF the forming is made, usually, from the outer to the inner area of the sheet, compared to TPIF, where it is reversed;
- while SPIF does not need any dedicated tool, in some cases, TPIF needs a specific tool, according to the part’s final shape;
- in SPIF the instability of the process and springback are more intense, while TPIF is more stable and springback has smaller values;

Besides the use of one forming tool, some research was carried out to design a strategy of using several tools simultaneously. The process, figure 5, named multipoint incremental forming, is more complex and needs dedicated machine tools, able to control the movement of the forming tools. This process is suitable for large scale products to increase the production productivity and to decrease the springback effects.

Despite all these researches, the mechanics of deformation is still not clearly understood because of its complexity determined by the localized deformation which moves progressively on the sheet during the process.

There is still needed a simple effective model to explain the influence of major process parameters and their interaction and to give a better control to the springback which directly affects the part’s accuracy. Some recent research made important steps to achieve the previous goals.

One interesting direction of research noticed is that of joining ISF with other known forming processes. For example present a new hybrid process, where ISF is combined with stretching. In the first stage of the process, figure 6, stretching is used to process the major shape of a certain part and in the second stage, ISF is used to process local concave shapes such as pockets or grooves. This strategy assures a decrease of the whole processing.
time and a better accuracy of the local shapes, because of the backward forming in their case.

A new direction for ISF is foreseen by some researchers, the one of using robotized arms instead of the usual forming tool driven by a milling machine. This process, already named robot-based ISF or roboforming, gain terrain as it appears to increase the part’s accuracy.

5 CONCLUSIONS

Looking back to the sections previously presented, it can be surely stated that incremental sheet forming – ISF – is, probably, the answer to the challenge of increasing flexibility in the field of sheet forming.

The process answers well to the flexible production’s main requirement – manufacturing small or single sized lots with low costs and a short switching time.

The achievements made in the last decade are significant. The process is passing to a new level, that of an industrially suitable technology.

Most of the last researches, focused on improving accuracy of the part, were successful and new strategies of processing occurred, solving one of the weak points – the uncontrolled springback of the material.

Future developments must improve the design of the CAM module which controls the tool movement, able to assure the suitable forming strategy according to any kind of hollow shape. The tool movement can be optimized to compensate the springback by processing data of part’s geometry, on-line measured during the process of forming.

6 REFERENCES


7 NOTATION

The following symbols are used in this paper:
ISF = Incremental Sheet Forming
AISF = Asymmetric Incremental Sheet Forming
SPIF = Single Point Incremental Forming
TPIF = Two Point Incremental Forming
MPIF = Multipoint Incremental Forming.