Dyna-Die: Towards Full Kinematic Incremental Forming

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ABSTRACT: This article focuses on the realization of a simple and kinematic tool setup for incremental sheet metal forming. It allows achieving a similar geometrical accuracy like a full specific support, but minimizes the tool setup and increases the process flexibility at the same time. In incremental sheet metal forming different process variants are in use. The simplest one is the single point incremental forming process which works with a single forming tool and does not require any support. The partially supported incremental forming process uses a simple tool setup for a static support of the sheet when forming only in local areas. In the fully supported incremental forming process a specific die is used which includes the geometry of the part to be manufactured. Here, a good geometrical accuracy can be achieved, but expensive and specific tools are needed for the support. In the full kinematic incremental forming process both the forming tool and the supporting tool move synchronously in three axes. This process is very flexible regarding the part geometry and promises a good accuracy. However, the mechanical setup is very complex and requests a specialized machine. The setup described in this article includes a kinematic support which can be mounted on a conventional milling machine. The presented dynamic support consists of an exchangeable support tool, which is fixed on a rotating plate. During the incremental forming process the dynamic support moves synchronously with the forming tool. This way, a flexible forming with simple tools and low costs is realized. The parts manufactured by the Dyna-Die have been compared to parts which were produced using a full and a partial static support as well as without any support. The discussion of the results completes this contribution.

Key words: incremental forming, sheet metal forming, kinematic, dynamic die

1 INTRODUCTION

In recent years the interest in small batch production processes has increased significantly. In this context a special focus should be placed on incremental sheet metal forming (ISF). This forming process can be conducted in a conventional milling machine by mounting the forming tool in the spindle while the sheet metal is fixed with a clamp. Since the spindle can be moved in three ore more independent axes complex part geometries can be realized. Within this process sheet metals are formed stepwise with only a localized plastification. Consequently, universal tools can be used to achieve different geometrical shapes. For conventional forming techniques like deep drawing or stamping tools are predefined by the shape of the desired part and can only be used for this special purpose. Compared to them, the main economic advantage of ISF arises: a low-priced and flexible production of sheet metals for small series and prototypes.

Although the first attempts for producing parts with sheet metal forming are mentioned in the patent of Leszack [1] in 1967, the initial process development started since the late 1990s [2]. Up to now, several variants of ISF have been investigated to proof their feasibility for producing parts with a wide range of materials [3]. Single point incremental forming (SPIF) can be performed easily without any die so that no additional tooling costs arise. However, without any supporting die it is not able to produce parts with sharp edges and the resulting deviations between the produced and the desired geometry are quite high. To reduce the deviations, two different types of static dies are commonly in use. While partial dies support only a local region of the sheet metal, specific dies have to contain the final shape of the desired part geometry. Partially supported dies consist of a simple and cheap construction, but comparing both types, the specific dies allow a production of parts with higher precision. On the other hand, full specific dies can only be used for one production task. With the motivation of improving the process flexibility and the geometrical accuracy at the same time the use of a second moving tool seems to be promising.

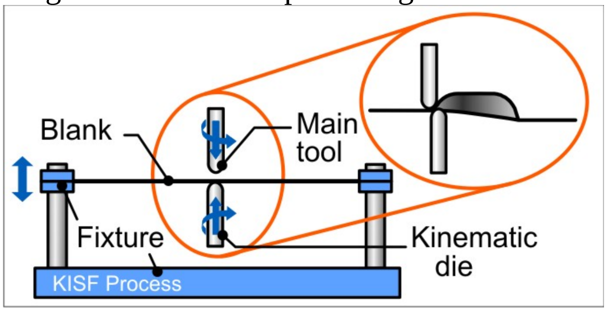

Fig. 1: Theoretical setup for kinematic ISF

Meier et al. [4] presented one possibility to realize this full kinematic variation of incremental sheet metal forming (KISF) by the use of two robots. Another possibility is shown by Maidagan et al. [5] where a tricept robot as a master tool is combined with a moving XYZ-table for the supporting slave tool.

In this article, the authors present a simple method to upgrade a conventional milling machine with a dynamic die (Dyna-Die). Taking into account that the forming mechanisms for ISF are not completely clarified at present the construction of a specialized machine is quite complex. The setup showed in the following article does not require high investment costs and allows the production of simple parts in order to investigate and design the KISF process. To show the capability of the presented solution, experiments are conducted by using different types of supports. This is followed by an analysis of the geometrical accuracy for each part.

2 EXPERIMENTAL SETUP

2.1 *Setup requirements*

With the aim of approaching the described KISF process a second moving tool has to be implemented into the previously used experimental setup. In addition, the second tool has to move mechanically independent from the first one to have the possibility of synchronization. Taking into account that the whole available space in the milling machine in Z-direction is needed to perform the ISF with static supports, the movement of the second tool should be reduced to the XY-plane. Furthermore, inexpensive parts have to be used for this setup to guarantee a low cost upgrade.

2.2 *Realized setup*

The realized dynamic die is shown in detail in Fig. **2**. The additional tool movement is achieved by a rotating table. As a matter of course, only rotational symmetric parts can be produced. In the presented case the second tool is realized as a cone which is mounted on the rotating plate. The produced conical parts have a diameter of 168 mm at the top and a height of 40 mm, the flange angel is 60°. During forming the contact zone between both tools moves from the cone`s top down to the plate. The cone tool can be mounted at four different radii, so different part diameter can be achieved. Since, the second tool is exchangeable other part geometries can be produced. The shown setup includes an additional unspecific support in the center of the plate which can also be removed. In further investigations it will be possible to investigate if this feature is necessary for the evolution and the design of KISF for non-symmetric parts.

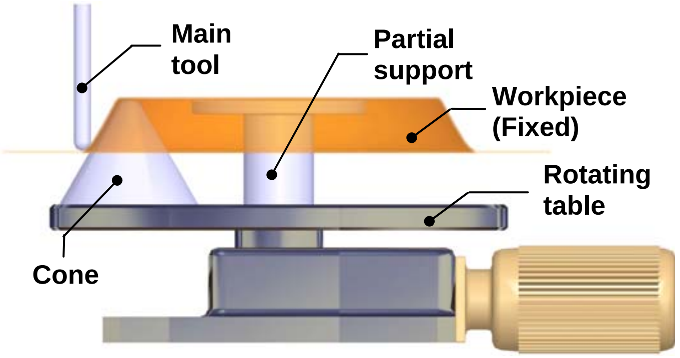

Fig. 2: Experimental setup – Dyna-Die

3 EXPERIMENTAL PROCEDURE

The focus of this analysis is on the achievable accuracy of the Dyna-Die, which represents a very simple and cheap method of a two point, full kinematic ISF process variant. The parts manufactured by the Dyna-Die are therefore compared to three other common ISF process variants, which are:

- SPIF, which works without a supporting tool
- ISF with partial support
- ISF with full specific support

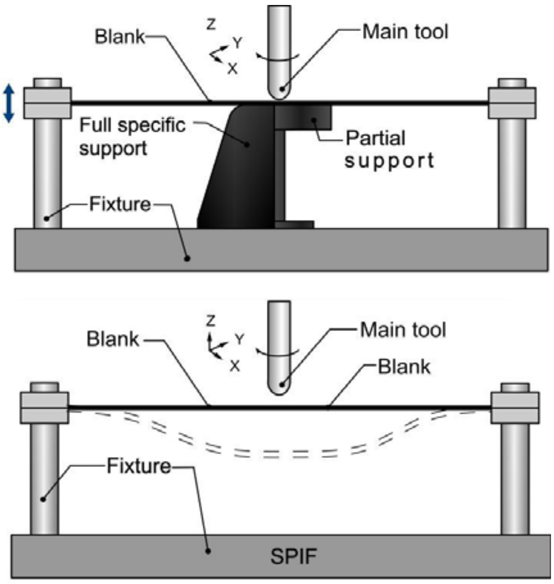

Fig. 3: ISF process variants

All experiments presented in this text use Al 99.5 (semi-rigid). This material allows a high strain and can be formed with comparably low forming forces.
A pin-shaped tool with a diameter of 10 mm has been used due to the smallest radius in the part of 6 mm.

3.1 *Preparation*

The experiments have been carried out on a conventional 3-axes CNC milling machine. In this case, the NC machining suite, which is included in CATIA V5 R17, has been used to generate the unidirectional tool path. The authors preferred a unidirectional tool path without any correction methods. This way, the deviation of the different processes is not influenced by optimized tool paths.

3.2 *Procedure*

During forming the sheet has been fixed on a frame which moves downwards by gravity and the tool motion respectively. The sheet is coated with oil as lubrication on both sides. The velocity of both tools is approximately 2200 mm/min. The speed of the upper tool, which is moved by the milling machine, has been adjusted manually during the process in order to achieve a synchronous motion of both tools. While the rotational speed of the table with the support tool keeps constant, the speed of the forming tool, which moves along the circumference of the part, has to increase due to its conical shape. After becoming familiar with the setup, sufficient synchronicity could be achieved.

3.3 *Accuracy measurements*

The accuracy of the manufactured parts has been measured with the help of an optical measurement system (ATOS) by GOM. This way, STL files of the manufactured parts have been created, which could be imported into the CAD system in order to compare them with the reference model. For the deviation analysis again CATIA V5 R17 has been used. The measured STL model has been orientated close to the reference CAD model by a best-fit procedure, which is included in CATIA.

4 RESULTS AND DISCUSSION

4.1 *Accuracy*

The accuracy achieved with the Dyna-Die is similar to ISF using a full specific support. The deviation is in the range of aproximately 1.2 mm (in total). The process variants with partial support and no support showed less accurate results. No correction strategies have been considered in the tool paths.
Fig. 4 shows a comparison between the results of the parts manufactured by the described process variants. The deviation depicted in the figure is scaled by factor ten. Graph a) in the figure represents the deviation of the part manufactured by the Dyna-Die. Compared to graph b), which shows the part manufactured with a full specific support, the deviation is in a similar range, but in the opposite direction at the flange area. The full specific support does not allow a negative deviation and the manufacturing of parts which are smaller than the used die. In contrast, the Dyna-Die provides the possibility to change the relative position between both tools. In b), an increased deviation in the part’s center is observed. This could be caused by the influence of the bending at the edge of the part. A similar bending effect could not be recognized by the use of the Dyna-Die.
A partial support like used in c) leads to an increased deviation. Here, an even stronger bending effect has been observed which is caused by less support of the sheet during the forming process.
In d), no support has been used during the

incremental forming process. This causes strong evasive movements of the sheet and leads to high geometrical deviations of the manufactured part.
The authors are aware of the fact that correction methods in the tool path generation will improve the part accuracy. Therefore, further experiments are necessary.
It was found out that the Dyna-Die in the current state is not as reliable as a full specific support setup because some of the parts showed cracks. This is probably caused by the lack of synchrony in the motion of the upper and lower tool as the speed of the forming tool has been adjusted manually.

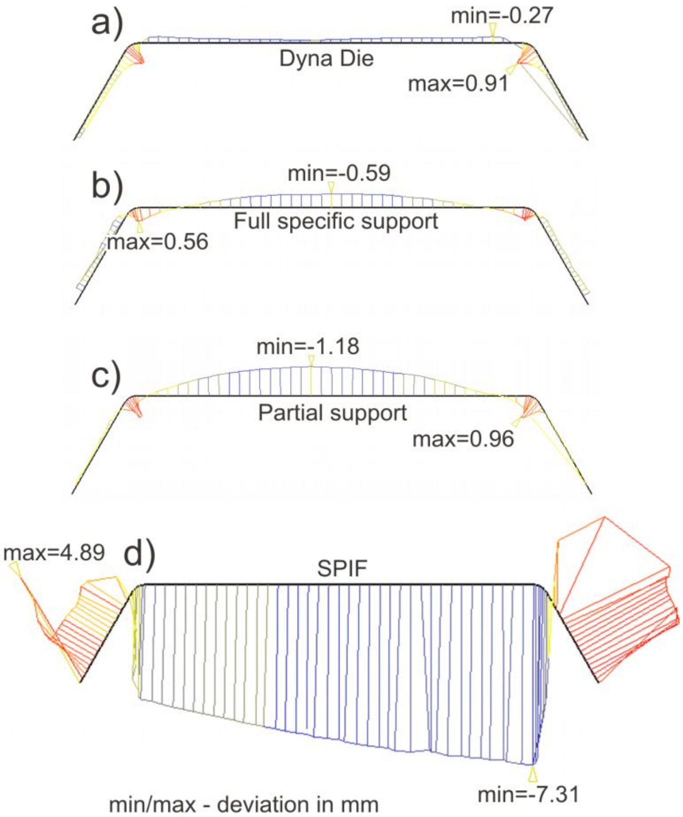

Fig. 4: Comparison of accuracy for different ISF process variants

The results of a fully supported manufacturing process were only slightly better than the parts produced by the Dyna-Die. The partially supported process delivered worse results. In order to have similar manufacturing conditions, no correction method has been used in the tool path.

4.2 *Surface quality*

The rotating tool of the Dyna-Die has left marks (scratches) on the surface of the sheet although lubrication has been used. Compared to the other ISF process variants used in the experiments, the surface quality on the lower side of the sheet has been clearly worse.

5 CONCLUSIONS

The Dyna-Die presented in this paper, involves a simple tool setup, which can be used as an upgrade for a conventional milling machine. It allows the production of rotationally symmetric parts in a full kinematical way as both the forming tool and the support are moving during the forming process. The experiments have shown that the described kinematic ISF process is capable of producing parts in an equal quality and accuracy as the ISF with a full static support. With some small modifications concerning the synchronous motion of both tools this simple and cheap setup allows fundamental research in full kinematic ISF before focusing on the manufacturing of more complex parts. The authors assume that tool path correction methods, like e.g. surface reconstruction, and optimized process strategies, will improve the accuracy of the manufactured parts.

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