A new approach for toolpath programming in Incremental Sheet Forming

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ABSTRACT: Because of involved means and process implementation, toolpath generation is a key topic linked to incremental sheet forming. Process characteristics ask for specifically dedicated toolpaths. This paper firstly evaluates the impact of toolpath type and of other programming parameters on process implementation through an experimental campaign performed on a parallel kinematics machine tool. Then, a new approach to perform Intelligent CAM programmed toolpaths is proposed. This innovative toolpath programming concept is based on toolpath optimization thanks to real time tool force evaluation made into CNC controller. A feasibility study is finally achieved in a conclusive way.

Key words: Toolpath optimization, Incremental Sheet forming, Intelligent CAM programming, Forming force Control, CNC data

1 INTRODUCTION

Incremental sheet forming is a recently emerging process to manufacture sheet metal parts that is well suited for small batch production or prototyping [1, 2]. As the process implementation consists in making the tool performing computer generated toolpaths on z-levels that decrease under a determinate step, toolpath generation becomes a key topic linked to incremental sheet forming, regarding both on productivity and conformity.

Until recently, most of the research was focused on sheet metal formability using this process [3-6] and most authors employ standard CAM generated milling toolpaths. However, Kopac et al. considered in [7] the working direction effects in single point forming. Attanasio proved in [8] that it is better to program constant scallop height toolpaths than constant axial increment toolpaths. To optimize parts accuracy, Ambrogio et al. propose to program “vitiated trajectories”, which are deliberately wrong but lead to acceptable parts once the forming constraints are relaxed [9, 10]. Another solution is proposed by Hirt in [11] where the toolpaths are adapted after having measured the first produced part.

It could be beneficial to study works about toolpath optimization for milling applications, which have already been widely studied, to propose new optimization ways for incremental sheet forming [12-14].

Hence, the first objective of this paper is to evaluate the effects of incremental sheet forming toolpaths on the implementation of incremental sheet forming process, especially regarding to productivity and conformity. The study focuses not only on trajectory parameters but also on the toolpath shape itself. Related works highlighted the fact that the choice of forming trajectory has an effect on the process performances, for example [2].

Then, the second aim of this work is to propose a new approach to generate intelligent forming toolpath. This approach is called ICAM (Intelligent Computer Aided Manufacturing) programming. It is based on real time tool force evaluation performed without any additional equipment. According to the estimated force, forming toolpaths are compensated on-line to reduce loads and maintain sheet metal integrity.

2 TOOLPATHS EFFECTS ON PROCESS IMPLEMENTATION: FIRST RESULTS

2.1 Experimental setup

An experimental study of single point incremental forming was performed to evaluate the effects of the process parameters when producing an entire shape (Fig. 1).

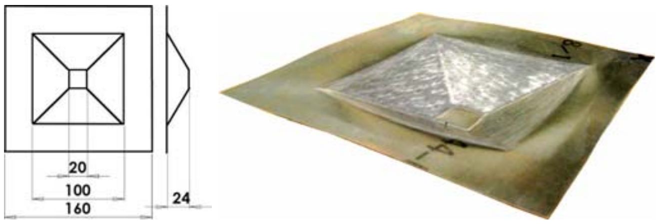

Fig. 1. Test Part

Three parameters were studied: feedrate, axial increment and forming strategy (1-2-3). Strategies 1 and 2 are contour parallel and Strategy 3 is a spiral toolpath. Strategy 1 consists in z-level contouring; after each level the axial increment is taken plainly along z-axis. In Strategy 2, the axial increment is obtained gradually along one side of the square shape. In Strategy 3, a quarter of the axial increment is taken along each side of the square. The objective of this work is not to propose new forming strategies but to underscore the effects of toolpaths shape on the process implementation, in particular on productivity, conformity and cost issues.
Other parameters were the same for all experiments. Sheets were made of aluminum alloy (5086) and had a 0.6 mm thickness. Forming tool radius was 10 mm..

2.2 Results

According to the experimental results given in Table 1, feedrate has no influence on forming force. Forming times are linked to feedrate and axial increment combination. Forming strategy has an effect on forces and on final part accuracy. Among the tested toolpaths, Strategy 1 offers here the best compromise. Nevertheless, coupled effects are also observed, so that process implementation depends on a proper combination of all toolpaths parameters.
As a consequence, CAM software generated toolpaths cannot be directly used for incremental sheet forming applications because their parameters are optimized for another manufacturing process. It is a fact that most authors are using such strategies and obtain interesting results. But any productivity or quality improvement will need to optimize these CAM milling orientated toolpaths according to the stakes conveyed by the forming process.

Table 1. Experimental Results

Strategy	Axial Inc. (mm)	Feedrate (m/min)	Forming Force (N)	Forming Time (min)	Depth Error (mm)
1	0.5	0.5	637	23	0.18
		1.5	647	8	0.24
	1.0	0.5	890	12	0.05
		1.5	855	4	0.05
2	0.5	0.5	564	29	0.21
		1.5	545	10	0.24
	1.0	0.5	690	15	0.07
		1.5	671	5	0.18
3	0.5	0.5	598	23	0.55
		1.5	578	7	0.52
	1.0	0.5	746	12	0.79
		1.5	726	4	0.70

3 INTELLIGENT CAM PROGRAMMING TOOLPATH GENERATION

Because of the elastic springback, it difficult to predict sheet metal position after tool release. Forming toolpaths programming is consequently quite complicated. Moreover, in two points incremental forming, if toolpaths are not well adapted, sheet metal can be gripped between die and tool, what can affect the part and damage the forming device. As a result, CAM milling toolpaths are not suitable anymore.
It is also necessary to control and adjust toolpaths according to what is really going on the machine tool. Forming loads stand besides for a performing parameter for controlling process implementation, as shown by Duflou in [15]. On this point, Filice et al. proposed in [16] an interesting method to control on-line the implementation of single point incremental sheet forming. However, this approach is based on 3d dynamometer acquisition prediction models, what penalize its efficiency in a flexible production environment.
In a previous work, a new method to optimize NC machining processes by controlling the force between tool and manufactured part has been proposed by the authors [17]. Its major objective is to integrate process constraints in toolpaths programming and control. In practice, this approach, called ICAM (Intelligent Computer Aided Programming), consists in decoupling toolpath generation between the CAM software and the CNC.

Basic toolpaths are generated by CAM software and sent to CNC. Then, during the running of the program, these toolpaths are optimized by the NC controller according to real time process data. No additional equipment is necessary neither to acquire tool force data nor to perform adaptative force control. Therefore, high flexibility and high efficiency are insured.

In this paper, ICAM approach is implemented for incremental sheet forming applications. The developed method divides into two levels. The first one consists in collecting tool forces directly from CNC data. In the second level, machine tool is driven not only by the CAM software generated G-code file, but also by the force estimation obtained in real-time in the first level.

3.1 Tool force collection

The objective is not to perform process monitoring operations, but to dispose of an assistance tool dedicated to toolpath optimisation during process implementation.

Proposed approach consists in acquiring forming loads directly from CNC data, without any additional equipment. On a practical point of view, forming load estimation divides into three steps. Step 1 lies in catching servomotor torques generated by machine tool dynamics during the axis displacement, without any process effort. For that, torques values are acquired while the NC program is executed without the sheet metal. Indeed, recent CNC controllers let the user access axis torques while running a NC program. Step 2 is performed in forming conditions. Torques values are acquired during the manufacturing of the part. Measured values contain both forming and dynamics contributions. During Step 3, forming loads are calculated from estimated forming torques and from the geometrical transformation model of the machine tool.

As a result, it is possible to estimate instantaneous forming loads from CNC data.

3.2 Toolpath adaptation

Second level of the method consists in adapting toolpaths according to the results of forming force estimations. The major objective is to prevent any sheet metal damage caused by a too high forming force. Two approaches were identified to implement it: to modify the forming tool jog or to call a subroutine that clears the tool (Fig. 2).

For the first one, tool jog parameter is modified “real-time” into the CNC. A difficulty conveyed by this optimization lies into its duration. Final part accuracy can be affected by the jog variations. This way of adapting toolpaths is rather dedicated to positive forming applications where a too high forming force is often due to an wrong position of forming die.

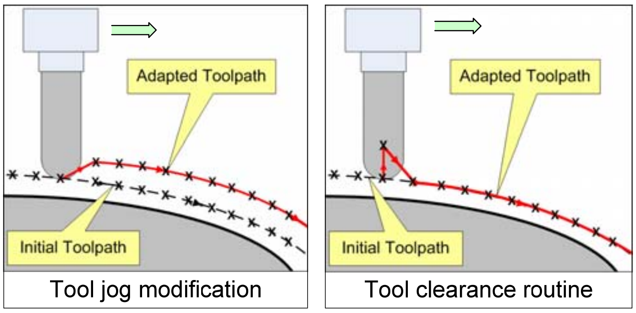

Fig. 2 Toolpath adaptations

Another way to prevent the sheet metal from damaging is to call a tool clearance routine (Fig. 2). This routine generates a retract movement along tool axis, so that it is possible to limit the tool load even in five-axis trajectories. On a practical point of view, as soon as tool force overtakes a preset value, forming NC program calls the clearance subroutine. Retraction value is defined by user before running the NC program. As toolpath modification is only local, this approach is efficient for local tool overloads. This solution suits also to single incremental forming applications.

3.3 Feasibility study

A feasibility study was performed to validate first level of the method. Machine tool used was the five axis parallel kinematics parallel machine of the laboratory. Servomotor torques where acquired by CNC controller (Siemens 840D). The interest of using a parallel kinematics machine tool is to prove the efficiency of ICAM approach with unusual machine architectures.

The experiment was performed in single point forming and consisted in carrying out a 100 mm diameter toolpath with a 2 mm z-increment on a 0.6 mm sheet metal. Forming forces were calculated from servomotor acquisitions according to ICAM approach. Results are on Fig. 3 and showed a good concordance between Kistler dynamometer data and the ones from CNC.

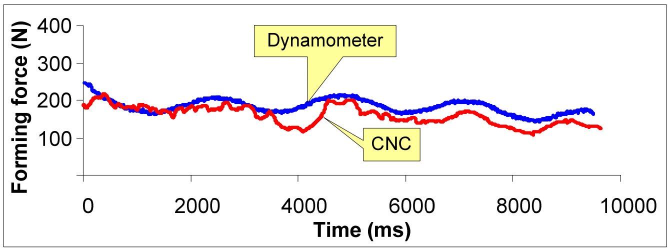

Fig. 3. Results of a validation test

This validation test consequently highlighted the efficiency of ICAM approach. Indeed, its objective is not to perform process monitoring but to get forming force evaluations with the view to adapt toolpath if necessary.

4 CONCLUSION

Toolpath generation is one key topic linked to incremental sheet forming. It is also necessary to develop specific toolpath generation to improve its efficiency.

In this paper, an experimental study highlighted the effect of the forming strategy and other programming parameters on the efficiency of the process. Its results show that rough milling CAM software toolpaths are not sufficient anymore to properly implement incremental sheet forming.

Hence, the implementation of Intelligent CAM programmed toolpaths for incremental sheet forming is presented. This new approach enables to adapt manufacturing toolpaths during the machining of a part regarding to process data. Toolpath optimization is carried out into the CNC controller. No additional equipment is necessary to collect data or drive the machine tool, what insures its flexibility and its efficiency. A feasibility study was finally achieved in a conclusive way.

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