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CONSIDERATIONS REGARDING THE INCREMENTAL FORMING PROCESS IN MANUFACTURIG

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Abstract: *The incremental deformation process of the sheet metal blanks allows the realization, without the use of dies with a high degree of complexity, of a wide variety of parts, mostly for automotive (car body parts) and bio-medical industry (prosthetic devices). The process has great flexibility and could represent a manufacturing solution when small batches or even prototypes of complex sheet metal parts must be manufactured. However, many technological aspects of the process are still to be researched and improved, to determine manufacturing companies to implement it on wide-scale, industrial basis. The paper gave an overview, based upon both a literature review and some results obtained by the authors of the present work, over the main aspects of incremental forming process as manufacturing solution for sheet metal parts. The main methods, tools and technological equipment used within the process are presented. The study focuses on the flexible approach regarding single point incremental forming, which involves the use of 3 axis CNC machine-tools, using hemispherical punches instead of cylindrical mills, combined with low-price dies for processing the parts. To further increase the flexibility by using flexible tools that can be easily adapted to new types of parts, a new modular tool assembly was proposed.*

Key words: *CNC milling machine, sheet metal forming, single point incremental forming, modular tool.*

1. INTRODUCTION

At present, the processes for cold plastic forming are widely used at the industrial level, especially in the field of automotive industry.

Cold plastic forming uses forming tools with different shapes and sizes to produce parts for the automotive industry, based on the negative shape of the part. The main disadvantage of this approach is that it does not allow the rapid change of the part's shape as the market is constantly expecting new car models.

The most used manufacturing process by cold plastic deformation is deep-drawing. Considering the current industry orientation towards small and unique series production, there are several major drawbacks of the deep-drawing process.

Of these, the most important one is the high complexity of the forming tools. A consequence resulting from this is a long time of production of the forming tools, as well as a high cost of these tools.

The incremental deformation process of the sheet metal blanks allows the realization, without the use of dies with a high degree of complexity, of a wide variety of parts. Single Point Incremental Forming (SPIF) is a sheet metal forming technique wherein a sheet is formed using a single, small tool as opposed to a large die [1].

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2. SINGLE POINT INCREMENTAL FORMING PROCESS (SPIF)

Per the principle of single point incremental forming, in a first step, the tool executes a two-axis motion in the plane (*XOY*) along a predefined trajectory. Then, in the second phase, the tool executes a movement on the third axis (z). These two steps are repeated until the final shape of the part is obtained.

In Fig. 1 the SPIF process is presented, where 1 represent the blankholder, 2 – metal sheet, 3 – tool (punch), 4 – backing plate. The downward progression of the tool is noted with 5 [2]. Both blankholder and backingplate are stationary during the entire process.

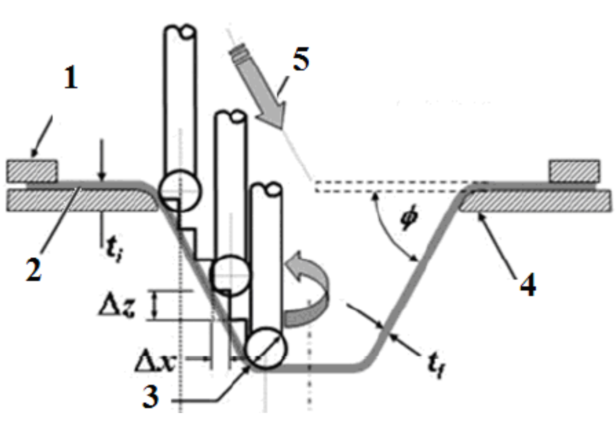

Fig. 1. Single point incremental forming process [2].

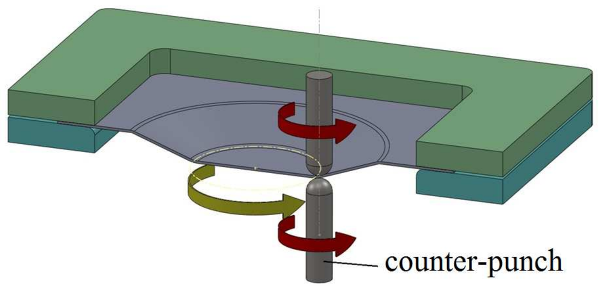

Fig. 2. TPIF with counter-punch.

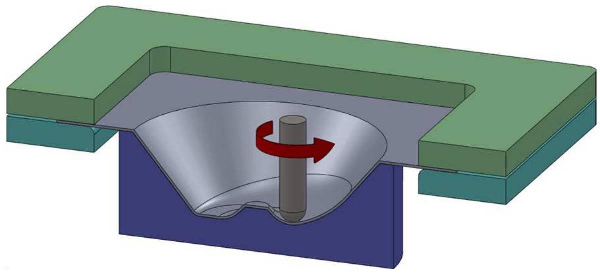

Fig. 4. TPIF with full die.

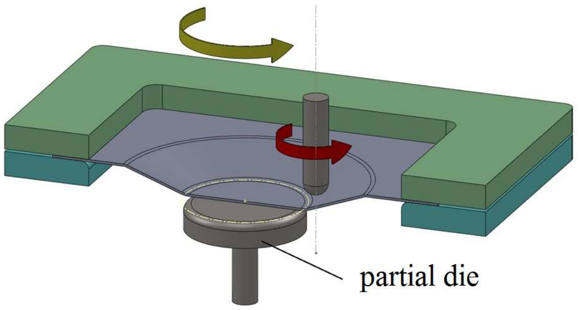

Fig. 3. TPIF with partial die.

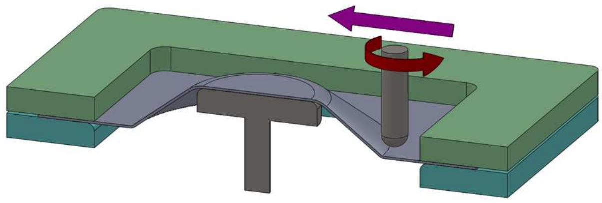

Fig. 5. TPIF with partial die.

3. TWO POINT INCREMENTAL FORMING (TPIF)

The basic idea of the incremental two-point deformation process is to use, in addition to the previously used punch, a supporting element positioned under the blank. This deformation model involves the use of a second punch, placed under the blank, which is often called "counter-punch" (Fig. 2). The counter-punch describes the same trajectory as the first punch.

Due to the similarity between the trajectories of the punch and the counter-punch some authors consider this to be also a SPIF process [4].

3.1. Two point incremental forming with partial die

The partial die, presented in Fig. 3, serves as a support for the core areas of the blank, thereby improving the geometric accuracy of the part [5].

The partial mold supports certain essential areas during processing. For this type of incremental forming, the punch describes the trajectories on the outside of the part.

The geometry of the partial die is simplified relative to the geometry of the parts, because it is designed to process many types of geometrically similar parts.

3.2. Two point incremental forming with full die

However, the incremental forming with the lower total die, although falling within the category of incremental forming process due to the "incremental" character of the punch motion, can no longer fall into the category of dieless forming processing.

This type of incremental forming is most often used to obtain large complex components such as car body parts.

The major advantage of this process is that it allows a high geometric geometry of the parts to be obtained, and this is due to the fact that the blank is forced between the tool and the total die (Fig. 4) [6].

Thus, one must mention the higher cost of this process, first the material required for the mold parts (steel, aluminum, rubber, plastic, wood or foam), and secondly the manufacturing costs.

The low flexibility resulting from the use of the lower die for each piece type is also a major drawback.

3.3. Two point incremental forming with partial positive die

As mentioned above, there are certain shapes of parts that cannot be processed without using a die. In such cases, a support element called a partial die may be used (Fig. 5).

The difference with the above case is merely the positioning of the partial die, which in this case is located above the blank. With this method, caved shapes can be processed.

3.4. Two point incremental forming with full positive die

Two point incremental forming with full positive die is also used to process complex geometry parts such as the parts needed by the automotive industry, it is necessary to use dedicated dies to achieve the required precision.

Even if a dedicated die is used, the incremental forming does not deviate from the basic purpose of the process, due to the fact that for the complete mold it is possible to use inexpensive materials such as rubber or wood.

Using this method, one can combine the advantages of the classic deep-drawing process with incremental forming.

Thus, the process consists in moving the total vertical die and at the same time realizing the incremental displacements of the punch, obtaining the geometrical details of the piece.

Finished parts are especially those that involve certain bending radii of the piece, which is processed by incremental deformation (Fig. 6).

Thus, finally, a high accuracy of the part can be achieved [4].

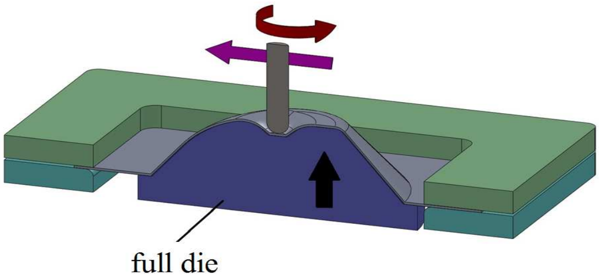

Fig. 6. TPIF with partial die.

3.5. Multi-stage two point incremental forming with partial die

Another strategy to obtain larger wall angles is to redirect the distribution of the material to the walls of the workpiece.

Several authors have adopted multi-stage strategies for this purpose. Successive trajectories, which correspond to those with large angles of the wall, are processed by means of a multi-stage processing method.

Thus, in order to overcome this limitation some researchers have successfully applied forming strategies in several stages (using the so-called "pre-forming").

The process is used by Bambach which develops the forming equipment shown in Fig. 7, where the columns 2 mounted on the base plate 1 allow the active plate 3 and the blank holder 4 to move vertically. The active plate and the blank holder fix the blank 5. The incremental forming is achieved by moving the punch 6 on the area of the outer wall of the workpiece. The material is fixed in the central area and the partial die 7 [7].

The first stage of the forming process consists in lowering the subassembly consisting of the active plate and the blankholder (Fig. 1,*a*), and represent the first forming of the sheet in which the active tool is only the partial die (movement I).

The next processing step is incremental forming and it is achieved by moving the punch to the conventional contour trajectories. This stage is also called the "pre-forming" stage (Fig. 8).

The following deformation steps aim to gradually increase the wall angle (Fig. 9). The punch executes the movements starting, this time from the bottom and continuing vertically, but upwards. Movements III' and III" are lifting movements, followed by displacements in the plane where the tool performs the same displacement movements on the contour.

The lifting step is followed by the lowering step, which increases the angle of the wall so that at the end the angle of the finished piece can reach 81° (Fig. 10).

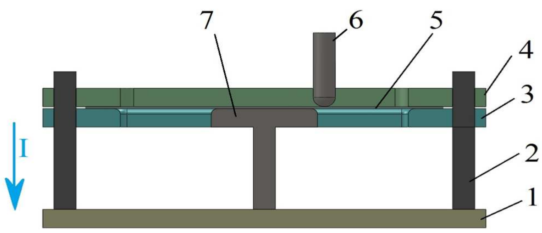

Fig. 7. First step of multi-stage TPIF.

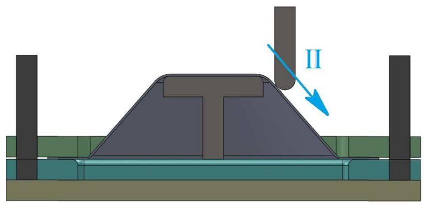

Fig. 8. Second step of multi-stage TPIF.

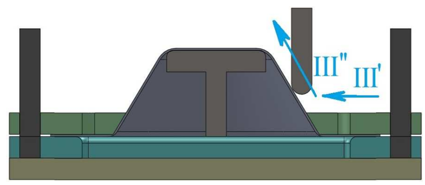

Fig. 9. Third step of multi-stage TPIF.

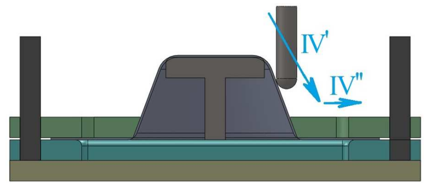

Fig. 10. Fourth step of multi-stage TPIF.

4. TYPES OF TOOLS USED IN THE SINGLE POINT INCREMENTAL FORMING PROCESS

SPIF is a process with real potential to be used by the industry, if we consider the possibility of quick manufacturing of unique parts, requiring only a CNC machine tool as technological equipment (which is common equipment of industrial companies) and a simplified die.

The most frequently used dies are presented in Fig. 11 [2]. The parts obtained on this dies are limited dimensionally by the blankholder and by the backing plate.

Similar tools are used of Henrad [9] and presented in Fig. 11, where 1 is the blankholder, 2 – part, 3 – backing plate, 4 – top plate, 5 – support columns, 6 – base plate.

Another clamping system of the blanks on the numerical control machine tool is used by Camara,

The system proposed of Camara it is composed of static frame (Fig. 12,*a*) fixed on the machine working table.

The backing plate which support the sheet and minimaze springback (Fig. 12,*b*) and the blank holder (Fig. 12,*c*). The tool assembly so formed is shown in Fig. 13 [6].

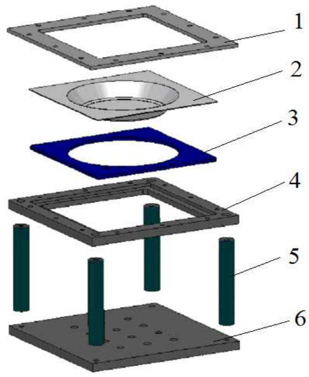

Fig. 11. Tools used for incremental forming [1].

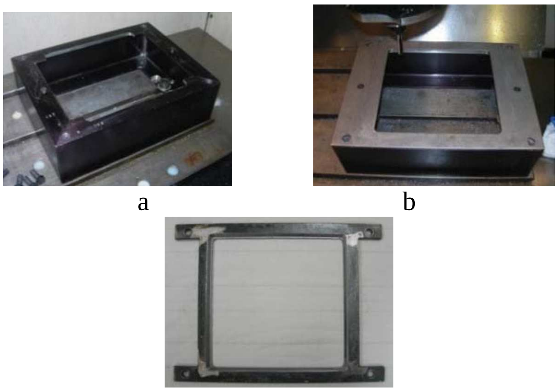

Fig. 12. SPIF clamping system [6].

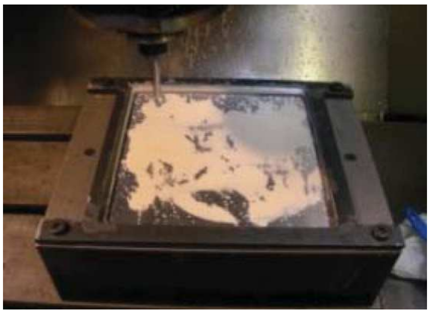

Fig. 13. Modular blank holder [6].

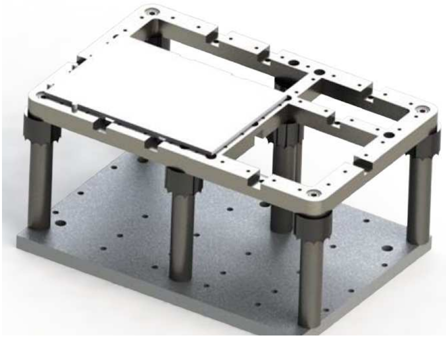

Fig. 14. Modular blank holder [1].

Adams [1] uses a modular blank holder system that allows the use of different blank sizes but unfolding of the single point incremental forming process is similar (Fig. 14).

The modularity of the blank holder system consists only of the possibility to use three sizes of semi-finished products.

5. THE EXPERIMENTAL LAYOUT USED FOR SINGLE POINT INCREMENTAL FORMING

Analyzing all technological aspects described above, some advantages of SPIF can be emphasized, such as:

- high flexibility due to the fact that various geometries of parts can be obtained using the same die;
- the simple construction leads to lower prices of dies;
- it does not require complex machining equipment (a standard numerical controlled milling machine-tool can be used).

Consequently, experimental researches have been unfolded by the authors in order to further support the industrial implementation of SPIF.

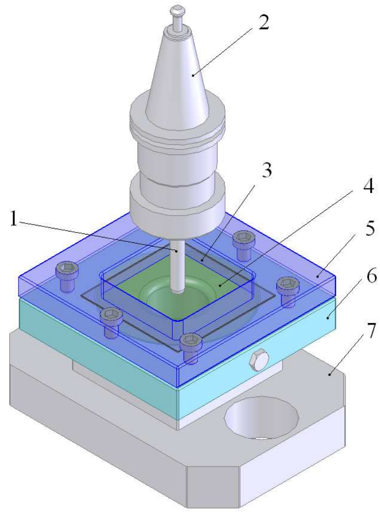

Fig. 15. The tools used in SPIF process.

Therefore, it was opted for using a forming die with a set of exchangeable die plates, which, when used in SPIF, allow a detailed research of their behavior during forming, by means of the realizing of several typo-dimensions part.

The tools used in SPIF process are presented in Fig. 15, consisting of the following elements: 1 – punch, 2 – punch holder; 3 – metal sheet; 4 – die; 5 – blank-holder; 6 – die holder; 7 – base plate.

To obtain manufacturing trajectories, as complex as possible, and consequently, in order to process parts with complex shapes, the die is intended to be exchangeable and has different shapes on the inside: circular (Fig. 16,*a*) and oval (Fig. 16,*b*).

The punches used in the SPIF process are easy to replace using the machine-tool automatic tool changer and standardized ISO tool-holders. The punches employed here have a hemispherical shape at the top, with different radii.

The tool holder and three punches that were used are presented in Fig. 17.

In order to obtain parts with complex shapes, in conditions of high dimensional precision, there was chosen as

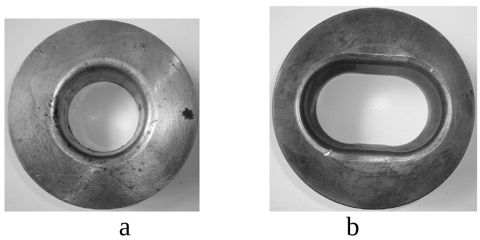

Fig. 16. The employed die plates.

Fig. 17. The punches used for the researches.

Fig. 18. The tools mounted on the machine tool table.

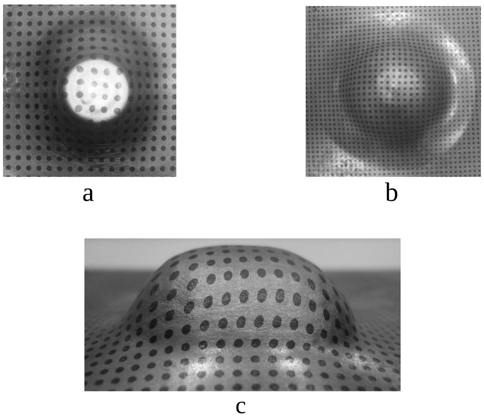

Fig. 19. Experimentally obtained parts.

technological equipment for the experimental researches the numerical controlled milling center Haas MiniMill (Fig. 18).

Using different trajectories described by the punch, different types of flange parts were obtained such as: cone frustum parts (Fig. 19,*a*), hemisphere parts (Fig. 19,*b*), complex parts (Fig. 19,*c*).

6. DESIGN OF A MODULAR TOOL FOR SPIF

The main drawback of the tool presented above is that it allows the manufacturing only small parts.

To implement modular tools, that can be easily adapted to new types of parts, a new tool assembly was designed.

As stated above, the main drawback of the process noticed also in the literature, but occurring especially in the experimental researches carried out at by the authors, is that although the manufacturing process is a flexible one, however, this flexibility is heavily influenced by the limitations that appear by using a die with a fixed shape.

Hence, the potential resulting parts are situated reduced dimensional range. Thus, to eliminate this major drawback, a tool system was designed in which both the blank holder and the active plate consist of modular elements.

As can be noticed in Fig. 20, the active plate is made up of different individual elements, which can be easily repositioned to obtain another size of the part.

The active plate can be easily modified by adding, removing or repositioning the u-shaped profiles into its structure. So, although two examples of blank holder configurations have been presented above, the variety of U-profile combinations is almost unlimited.

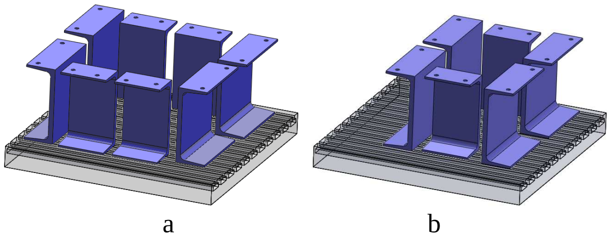

Fig. 20. The employed die plates.

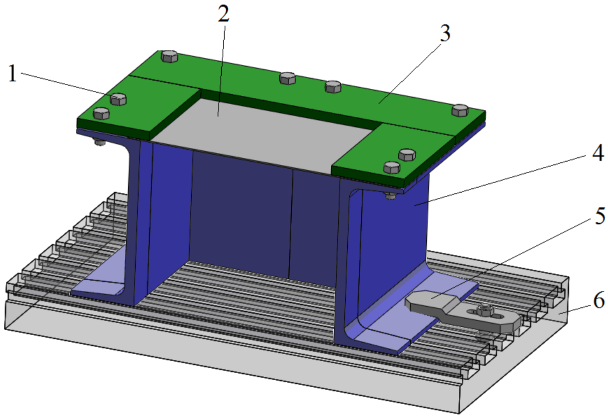

Fig. 21. The 3D model of the proposed tool assembly.

Fig. 21 shows a 3D model of the tool assembly. In this figure, it is observed that the blank 2 is fastened between the blank holder 4 (which is built by using the U profiles shown in Fig. 20) and the retaining plates 3.

The retaining plates are also made from several simple perforated plates assembled with the blank holder by means of nut screw systems.

The tool system is rigidly fixed on the CNC milling machine table 6 by means of clamp 5 (only one clamp is represented here, but usually more will be used).

For the proposed tool system, both the blank holder and the active plate are built using modular elements.

The modular character of the proposed system is shown in Fig. 22 (where eight U profiles are used), in comparison with Fig. 23 (where only six U profiles were used). Consequently, by simply adding or removing U profiles, the geometry of the retaining plate can be modified, which allows the user to also modify the working space of the punch, and finally, to modify the overall dimensions of the manufactured parts.

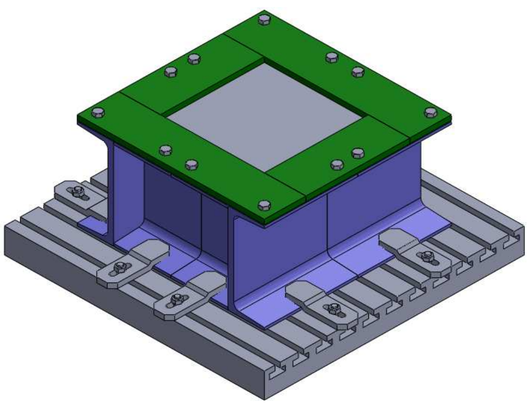

Fig. 22. The design tools made by eight U-profiles.

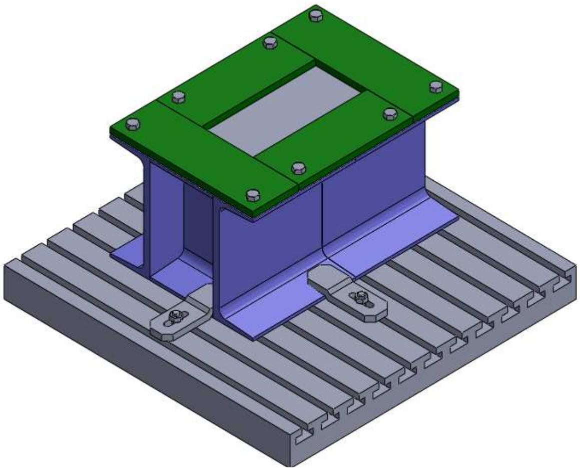

Fig. 17. The design tools made by six U-profiles.

7. CONCLUSIONS

A synthesis of the main results reported in the literature regarding the state of the art within the field of manufacturing by incremental forming was presented. The main drawbacks which hinder the industrial implementation of this promising manufacturing process were also emphasized.

The layout used by the authors for unfolding experimental research in this field was also presented, together with some manufactured parts.

The major drawback of experimental research considered by the authors was the dimensional restriction that occurs due to the use of some dies with fixed shape and dimensions. Consequently, a modular design for forming tools used within the incremental forming process was proposed. The modular design allows the user to change rapidly the overall dimensions of the tool, by adding or removing modules and consequently allows the increase or decrease of the overall dimensions of the manufactured parts.

Further experimental researches will be unfolded to test the proposed tool, with regards of its influence upon the geometric accuracy of the processed parts.

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