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SINGLE POINT INCREMENTAL FORMING – COMPARISON BETWEEN TECHNOLOGICAL EQUIPMENT BY AN OVERALL PROCESSING TIME POINT OF VIEW

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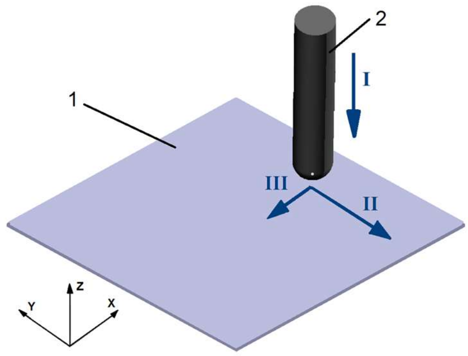
Abstract: *Single point incremental forming (SPIF) can be unfolded on various technological equipment. CNC milling machines and industrial robots are usually chosen for this purpose, both having advantages and drawbacks. The most obvious advantage of the industrial robots relies upon their superior kinematic, due the superior number of axes, especially when compared with 3-axis CNC milling machines. However, most of the parts manufactured by means of SPIF have simple shapes, which usually do not require more than 3-axis equipment for processing. Thus, it is arguable if using industrial robots for SPIF process could be justified by an economic point of view. The approach presented in this paper compares, by means of simulation, three processing strategies used for manufacturing a simple truncated cone shaped part, using a 3 axis CNC milling machine and an industrial robot. Moreover, the kinematic of the industrial robot is further improved by using a special positioning unit, which add two supplementary axis to the equipment. In order to run the simulation process, kinematic models for both equipment were developed. The processing regime (speed and feeds) was kept the same for all three simulated strategies. The main goal of the proposed approach was to test if the use of an equipment with superior kinematic (industrial robot) adds any advantages to the process, when manufacturing simple parts.*

Key words: *single point incremental forming, CNC milling machine-tool, industrial robot, kinematic.*

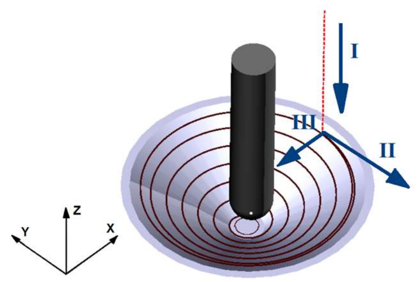
1. INTRODUCTION

Single point incremental forming (SPIF) is a rather unconventional process which allow the user to manufacture a sheet metal part in a flexible way, without the need of using a die [1−2]. The workpiece (1), a sheet metal plate, is moved on XY axes, against the punch (2), which executes an incremental movement on Z axis (Fig. 1,*a*). This combination of motions can be unfolded on many technological equipment, but CNC machine-tools and industrial robots are the most targeted for the task [1−7]. CNC machine-tools and industrial robots can perform coordinated motions, which involve high accuracy, using closed control feedback feed drives on each axis.

Recently, the use of industrial robots for operations which require continuous path control (milling) instead of operations which require only point-to-point control (assembly) has increased significantly [8]. Continuous path control requires a high amount of computing power, when generating the programming code, to avoid singularity points. Only recently, the commercially available CAM software solutions were able to make use of the latest advancements in computing technology and provided modules for robot continuous path control, and consequently for robot milling [8].



a



b

Fig. 1. Incremental forming: *a* – workpiece; *b* – part.

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However, most of the robot milling applications targeted sculptured parts, such as artworks or statues, instead of parts specific for machine building industry. This fact could be explained by taking into consideration that the achievable accuracy for parts machined by robot milling is still low, when compared with the one achievable on CNC machine tools. However, for the process studied in this research, SPIF, the accuracy requirements are not so high. Moreover, SPIF is not a milling (cutting) process, but a forming one, even if it uses milling CAM software packages for generating the processing toolpaths.

Most of the researchers [1–7] are assimilating the punch with a ball mill and the SPIF process with a finishing milling operation, facts which allow the use of a milling CAM software for SPIF, an approach which was also used in this paper. There are also several shortcomings of this approach, the most important ones being the reduced accuracy achievable by using the generated toolpaths and the impossibility of making a realistic simulation of the process. The CAM simulation engines will show the removing of the workpiece material (cutting process), while, in reality, the material is only redistributed (forming process).

In the approach presented here, a commercially available CAM software package for milling will be used to generate the toolpaths for processing a part by SPIF, using two different technological equipment. The overall machining time, based upon the length of the toolpaths will be compared.

2. MODULAR DIE

A literature survey shows that, in most cases, tools have a simplified construction, being made of fixed components, without any modularization. More precisely, the main components of tool system are: active plate 1, workpiece 2 and the retaining plate 3, Fig. 2.

For the targeted research, a modular die was designed, which is made of the U-shaped profiles shown in Fig. 3. Six U-shaped sections 3 are placed on the machine table. These are attached to the machine table 4 by means of the fasteners 5.

The metal sheets to be processed are fastened between the U-profiles and the rectangular plates 1 by means of removable assemblies 6 (screws and nuts).

As can be seen from Fig. 3, the great advantage of this modular die is an easy reconfiguration procedure which includes rapid changes in shape and size.

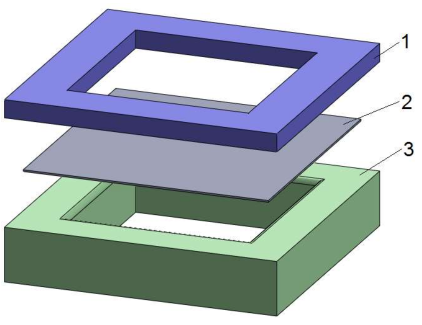


Fig. 2. Forming tool system.

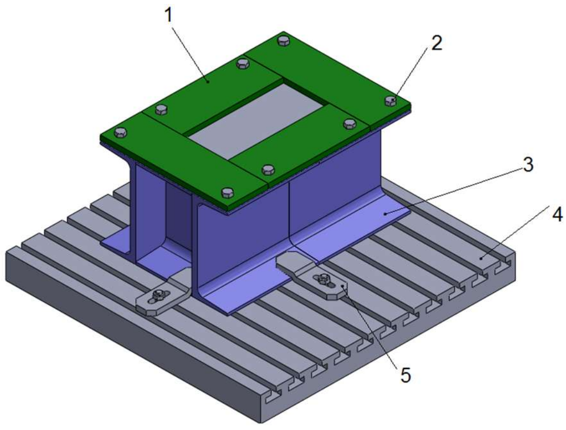


Fig. 3. Modular die.

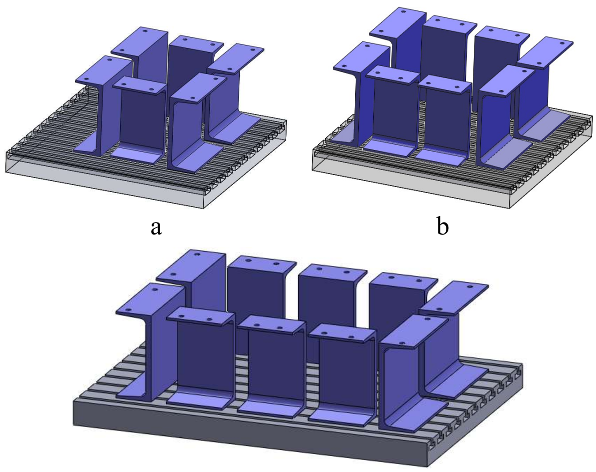
This is achieved by simply adding or removing U profile sections. A wide variety of die types and sizes can be obtained, regardless of the part shape and size. Hence, this emphasize yet another significant advantage of incremental forming, the use of modular dies, which leads to a very small cost for manufacturing forming tools. Only the following costs are included here:

- price of U-shaped blanks;
- price of the metal plates for fastening the sheet metal blank;
- price of cutting the U profile sections and fastening plates in different sizes;
- cost of machining the fastening holes.

Fig. 4 shows some constructive alternatives of modular active plates. Thus, Fig. 4.a depicts the positioning of the profiles for the modular die with six U-profiles presented in Fig. 3.

Another variant is shown in Fig. 4.b, where it can be seen that eight U-shaped profiles were used. Thus, one can notice that the addition on width of only two U profiles leads to the doubling of the actual working spece, and hence it leads to a double dimension of the processed part.

In Fig. 4.c the number of U-profiles has been supplemented with two more so that a working space three times higher than in the situation shown in Fig. 4,*a* is obtained and it can be observed the use of a total of ten U profiles.



a b

c

Fig. 4. Modular active plates: *a* – 6 U-profiles; *b* – 8 U-profiles; *c* – 6 U-profiles.

3. SIMULATION

One of the main goals of this research was to compare the results of using two technological equipment, when processing a part by means of SPIF by an overall processing time point of view.

A Haas Mini Mill CNC three axis milling machine and a KR 210 R2700 extra industrial robot were considered as technological equipment. The reason for this selection relies on the fact that the above mentioned equipment are available in the research facilities of Lucian Blaga University of Sibiu, the home organization of two of the authors of this paper.

The overall dimensions for Haas Mini Mill are presented in Fig. 5, while for KR 210 R2700 extra robot the dimensions are presented in Fig. 6 and Table 1.

Kinematic models for both equipment were developed [11−13]. In order to fully take advantage of the kinematic capabilities of the industrial robot, the two-axis positioning unit, DKP-400 (Fig. 7), also manufactured by KUKA company was taken into consideration. It is here to mention the fact that DKP-400 unit is not available at Lucian Blaga University of Sibiu, but a replacement for it is in the design process.

A simple truncated cone-shaped sheet metal part was used for the comparison. The overall dimensions of the part and its 3D model of it are presented in Fig. 8

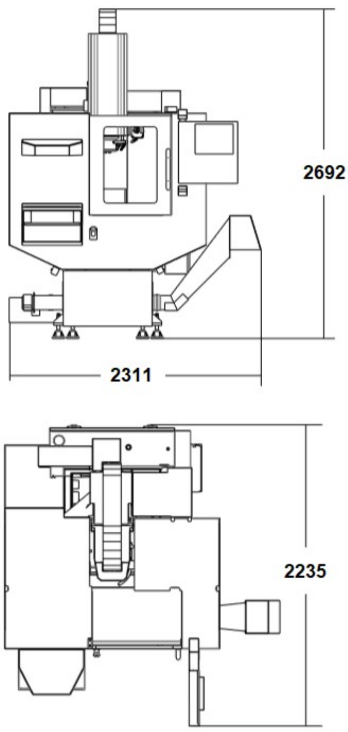


Fig. 5. Overall dimensions of Haas Mini Mill CNC machine-tool [9].

Table 1

Dimensions KR 210 R2700 extra industrial robot [10]

A [mm]	B [mm]	C [mm]	D [mm]	E [mm]	F [mm]	G [mm]	H [mm]
3.026	3.451	2.696	1.874	822	1.732	1.200	1.150

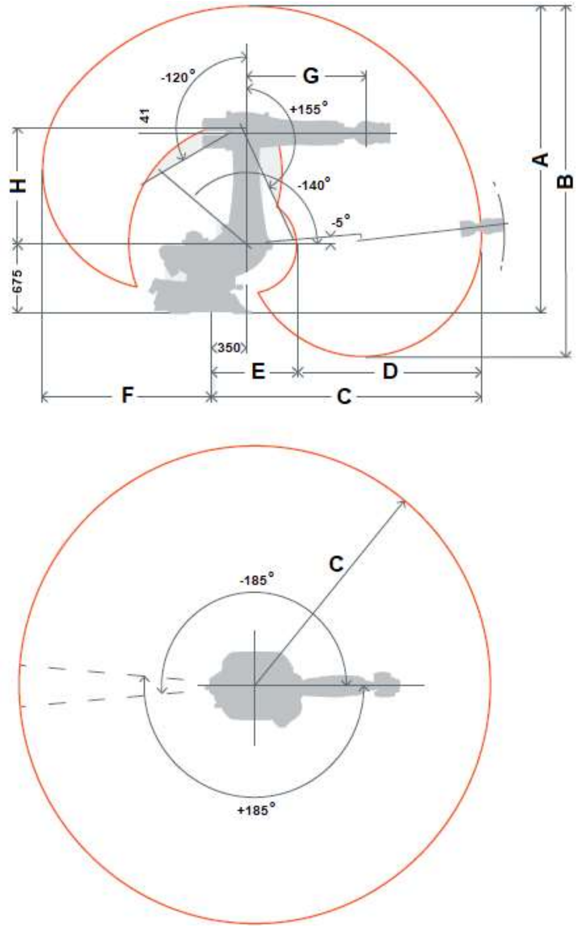


Fig. 6. Overall dimensions and workspace of KR 210 R2700 extra industrial robot [10].

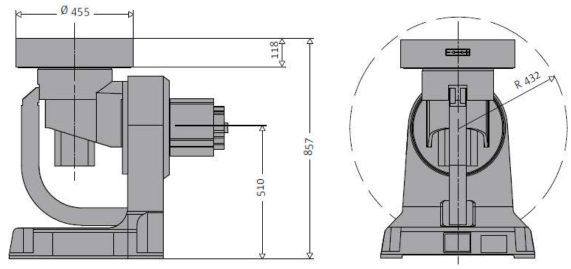


Fig. 7. Overall dimensions and workspace DKP-400, two-axis positioning unit [10].

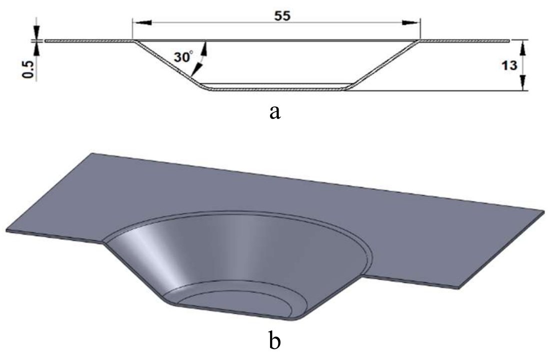


Fig. 8. The processed part: *a* – dimensions; *b* – 3D model.

Three machining strategies were chosen for testing the overall machining time for the CNC milling machine-tool and the industrial robot. The simulation was unfolded by means of a commercially available CAM software solution, SprutCAM [14].

Strategy 1 (Fig. 9):

- 3 axis spiral toolpath on Haas CNC milling machine;
- a cylindrical punch with hemispherical head of 10 millimeters diameters was used (seen by the CAM software package as a ball mill);
- the spiral step was set as 4 mm;
- the spindle speed was set at 300 rpm;
- the working feed was set at 150 mm/min.

Strategy 2 (Fig. 10):

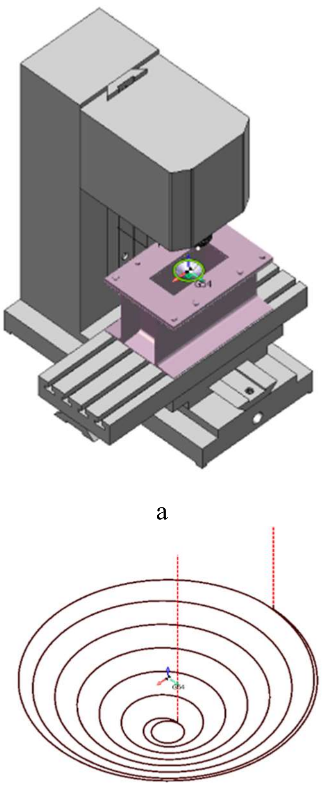
- 3 axis spiral toolpath on Kuka KR 210 R2700 extra robot;
- the spiral step was chosen 4 mm;
- similar cutting regime as above.

The tool axis was kept fixed, parallel to Z-axis and the DKP-400 unit was kept fixed. In this way, the machining process was similar to one unfolded on the Haas CNC milling machine, by a kinematic point of view.

Strategy 3 (Fig. 11):

- 5 axis spiral toolpath on KR 210 R2700 extra industrial robot;
- the spiral step was chosen 4 mm;
- similar cutting regime as mentioned in strategies 1 and 2.

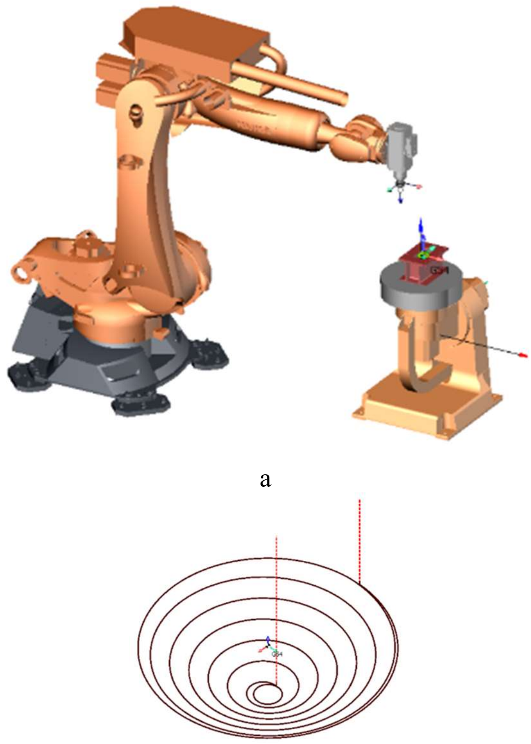
The tool axis was set to be always perpendicular on the part surface, and the DKP-400 unit was set free to rotate around its vertical axis.



a

b

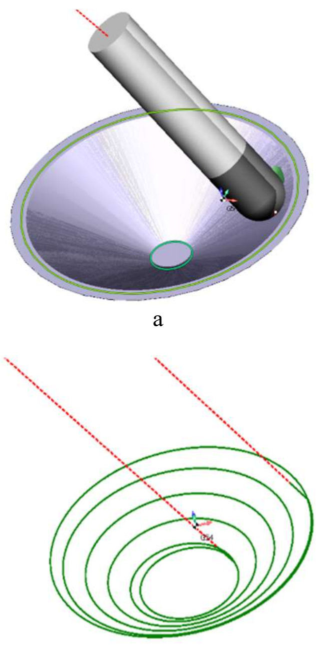
Fig. 9. Strategy 1: *a* – kinematic model of Haas Mini Mill CNC machine-tool; *b* – spiral processing toolpath.



a

b

Fig. 10. Strategy 2: *a* – kinematic model Kuka KR 210 R2700 extra industrial robot; *b* – spiral processing toolpath.



a

b

Fig. 11. Strategy 3: *a* – tool perpendicular on the part walls; *b* – spiral processing toolpath.

Figures from 12 to 15 presents a comparison between strategy 2 and strategy 3, by using simulation screenshots. From figures 12 and 13, which present different position of the tool during the process, using strategy 2 it can be noticed that the value on A6 rotational axis shows very small differences between figures (-113.698 compared to -114.074) while supplementary axis E2 is kept at 0.

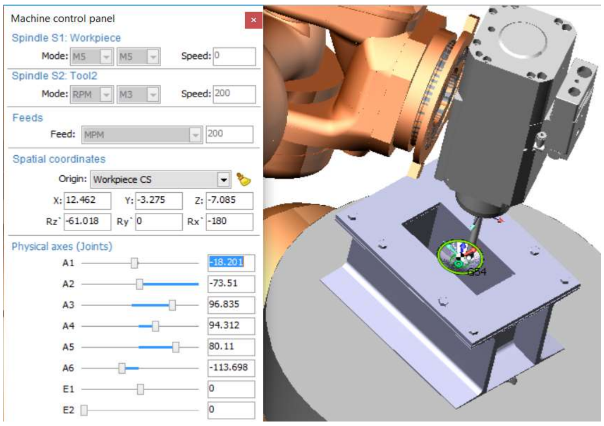


Fig. 12. Strategy 2 – first screenshot.

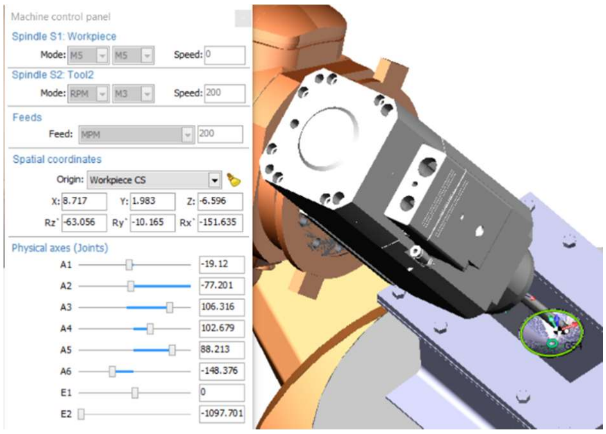


Fig. 13. Strategy 3 – first screenshot.

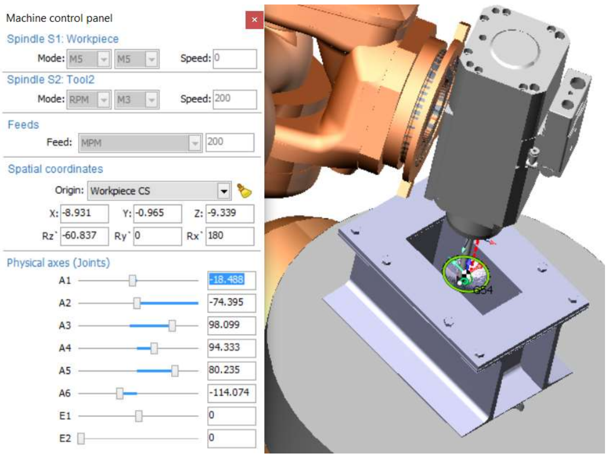


Fig. 13. Strategy 2 – second screenshot.

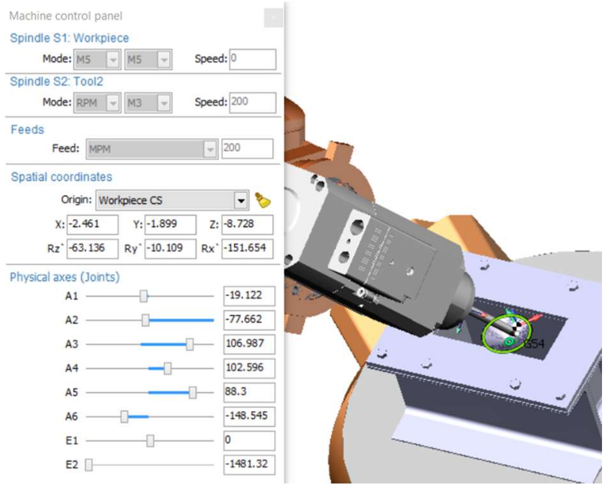


Fig. 14. Strategy 3 – second screenshot.

From figures 14 and 15, which present different position of the tool during the process, using strategy 3, it can be noticed that the value on A6 rotational axis shows the same small differences between figures (-148.037 compared to -148.545) while big differences can be noticed at supplementary axis E2 (-374.516 compared to -1481.32).

Consequently, the tool unit is kept perpendicular on the part surface by combining slight orientation changes on A6 with large movements on supplementary axis E2.

The spindle speed and working feed were kept the same for all tested strategies. The overall processing time for the three strategies are presented in Table 2.

It is here noticeable that for strategy 2 there are slight changes in the overall processing time depending on the initial position of supplementary axis E2. E2 axis is kept fixed during this strategy but its initial position can be set by the operator. However, these slight changes do not significantly influence the overall machining time for strategy 2.

A dramatic decrease of the overall machining time can be noticed when processing the part using strategy 3, a multi-axis approach.

A reduction of 91 seconds appeared when using strategy 3 instead of strategy 1. If one considers the total amount during strategy one as 100% of the overall machining time, the processing time during strategy 3 represents only around 67% from it.

Table 2

Overall processing time for the tested strategies

Strategy	1	2	3
Type	3-axis on CNC machine-tool	3-axis on industrial robot	5-axis on industrial robot
Overall processing time	4 min. 39 sec.	4 min. 49 sec.	3 min. 8 sec.

A 33% reduction of the overall machining time could dramatically increase the productivity of the process with significant influence upon reducing the manufacturing costs.

4. CONCLUSIONS

The work presented here starts with the introduction of a newly developed modular tool system which increases the flexibility of the SPIF process by allowing the user to change the size of the working space and consequently the size of the processed part.

In the second part of this research, a comparison between using a CNC milling machine-tool and an industrial robot as technological equipment, by means of simulation was made.

A previous stage of the work involved the development of kinematic models of the above-mentioned equipment.

A commercially available CAM software package, normally used for cutting operations (milling and turning), SputCAM, was used both for building the kinematic models and running the simulation.

The simulation results have shown that when using simple toolpaths, with fixed tool axis, there are no significant differences between using 3-axis CNC machine tools and industrial robots, with regards of the overall processing time.

On the other hand, when taking advantages of all kinematic capabilities of the industrial robot, together with the 2-axis positioning unit, the overall processing time was reduced significantly. The amount of processing time reduction was around 33%, showing that the use of technological equipment with superior kinematic capabilities can be justified by an economic point of view, considering the significant increase of the process productivity.

It is also important to mention that without the use of the DKP-400 2-axis positioning unit, the 5-axis processing strategy did not work, because the CAM software package was not able to find a solution to generate the toolpath without driving the structure of the industrial robot into singularity points. Adding two supplementary axes (of DKP-400 unit) solved the problem.

It can be stated that, even for simple parts, the use of technological equipment with superior kinematic can dramatically reduce the overall processing time, a fact which could justify the price difference between a 3-axis milling machine and a 6-axis industrial robot with similar or even larger (in this particular case) overall dimensions.

Of course, the CNC machine-tools still has a superior rigidity, which means that its manufacturing accuracy is higher, but one has to keep in mind that the accuracy requirements for the parts processed by means of SPIF are usually lower.

Further research will be performed on three main directions:

- designing and manufacturing a custom made 2-axis positioning unit, able to perform in a similar way as DKP-400;
- validating the simulation results by a thoroughly conducted experimental program;
- developing a set of accurate tools for assessing the economic impact of unfolding the SPIF process on various technological equipment.

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REFERENCES

[1] J. Jeswiet, F. Micari, G. Hirt, A. Bramley, J. Duflou, J. Allwood, J., *Asymmetric single point incremental forming of sheet metal*, CIRP Annals of Manufacturing Technology, 2005, 54, 623–650.

[2] A.K. Behera, R.A. de Sousa, G. Ingarao, V. Oleksik,, *Single point incremental forming: An assessment of the progress and technology trends from 2005 to 2015*, Journal of Manufacturing Processes, 2017, 27, 37–62.

[3] S. Gatea, H. Ou,; G. McCartney, *Review on the influence of process parameters in incremental sheet forming*, International Journal of Advanced Manufacturing Technology, 2016, 87, 479-499.

[4] F. Micari, G. Ambrogio, L. Filice, *Shape and dimensional accuracy in single point incremental forming: state of the art and future trends*. International Journal of Materials Processing Technology, 2007, 191, 390–395.

[5] M. Skjoedt, M. H. Hancock, N. Bay, *Creating Helical Tool Paths for Single Point Incremental Forming*, Key Engineering Materials, 2007, 344, 583–590.

[6] R. Malhotra, N.V. Reddy, J.A. Cao, *Automatic 3D spiral toolpath generation for single point incremental forming*. Journal of Manufacturing Science, E-T ASME. 2010.

[7] H. Zhu, Z. Liu, J. Fu, *Spiral tool-path generation with constant scallop height for sheet metal CNC incremental forming*, International Journal of Advanced Manufacturing Technology, 2011, 54, 911-919.

[8] Y. Chen, F. Dong, *Robot machining: recent development and future research issues*, International Journal of Advanced Manufacturing Technology, 66, 2013, 1489–1497.

[9] Haas CNC INC, company website, https://www.haascnc.com, accessed: 2018-09-12.

[10] KUKA AG, company website, https://www.kuka.com/en-us/services/downloads/, accessed: 2018-09-12.

[11] R.E. Breaz, O. Bologa, A.L. Chicea, S.G. Racz, *Using Serial Industrial Robots in CNC Milling Procesess*, Buletinul Institutului Politehnic din Iași, Secția Construcții de Mașini, LXI (LXV)/3, 2015, 21-28.

[12] R.E. Breaz, S.G. Racz, O. Bologa, M. Tera, *Considerations regarding CAM techniques for robot milling*, Academic Journal of Manufacturing Engineering, Volume 15 / 2017 Issue 3, 23-28.

[13] A. L. Chicea. R.E. Breaz, O. Bologa, *Building 3D Geometric and Kinematic Models of Five-Axis Machine-Tools for Manufacturing Prosthetic Devices*, Applied Mechanics and Materials, Vols. 809-810, 2015, 1004-1009.

[14] SprutCAM user manual, Sprut Technology Ltd., https://www.sprutcam.com/files/documentation/SprutCAM11/eng/index.html, accessed: 2018-09-12.