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THE EXPERIMENTAL PLANNING FOR SINGLE POINT INCREMENTAL FORMING USING *LATIN* SQUARE METHOD

BY

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Abstract. Incremental sheet forming is a new technical forming method which can provide a high accuracy of products, at short time and low production costs. Single point incremental sheet forming is a series innovative processes, flexible, which it can be obtaine various geometries without the special tool geometry. Incremental forming term is used for a variety processes, characterized by the fact that all local deformation area moves over the entire product surface. The present work is going to be focuses on the experimental planning in order to obtain a product through single point incremental sheet forming using *latin* square method.

Keywords: experimental planning; single point incremental forming; *latin* square.

1. Introduction

Single point incremental sheet forming method (Fig. 1) is an innovative forming approach method for sheet materials which it is using CNC milling machines tools, which can be applicable for prototypes production.

At single point incremental sheet forming process the blank is clamped on clamping device and the tool performs a rotational movement and also the

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approach movement (Tisza *et al*., 2013). The most important criterion to express the material plasticity limit at single point incremental sheet forming process is the maximum forming angle (Radu, 2011).

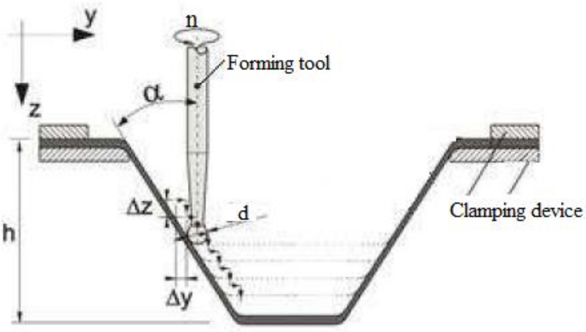

Fig. 1 – The basic principle for single point incremental sheet forming process (Tisza *et al*., 2013).

The significances of notations from Fig. 1 are the following: d – tool diameter; α – wall angle; h – workpiece height; n – rotational tool movement Δz – tool movement one Z axis; Δy – tool movement one Y axis.

The main characteristics of single point incremental sheet forming are the following:

– at single point incremental sheet forming process, we don't need a die, but we need a blank clamping device system, various tools dimensions, forming rollers, active plate etc;

– single point incremental sheet forming process requires a lot of time in comparation with conventional forming, but doesn't require high costs with equipments;

– single point incremental sheet forming process has a high flexibility, the same equipment can be used for perform various parts geometries;

– forming angle achieved is bigger than conventional forming, this thing make suitable to work with different materials which are hard for forming;

– the springback effect decreases the accuracy for conventional forming, but using single point incremental sheet forming process this disadvantage will be removed (Tisza *et al*., 2013).

Is very important to know that this process works with a biggest rapport weight/strength (Naga *et al*., 2012). To get desired final shape, single point incremental sheet forming will use a tool with hemispherical shape, where it has a trajectory predefined for deformation locally.

The blank material to get the parts through single point incremental sheet forming process is determined by technological factors and conditions for exploiting of parts. Technological factors characterized by stretching material properties, the maximum permissible deformations, or future machining operation and finishing (turning, milling, galvanization, polishing, etc.) or possibility to be assembled with another parts (soldering, welding, riveting). Ferrous and non-ferrous materials used for manufacturing the parts by single point incremental sheet forming process are standardized and delivered like thin sheets, thick plates, cover plate and strips of various sizes (Teodorescu, 1987; Iliescu, 1987).

Single point incremental sheet forming is a new process recently appeared, from this reason is not very well presented in specialty literature, regarding the deformation conditions for some types of materials, concerning the advantages which it has and potential industrial applications. More than that publications issued, presents some limited results (Jackson *et al*., 2008), which makes it necessary to continue research in this area. The studies regarding this process focus on three main directions: measuring the deformations and displacements produced on sheet, estimation the deformations using the finite element method and measure the deformation forces (Jackson *et al*., 2008).

2. *Latin* Square Method

In experimental research are using various methods like Taguchi method (Nedelcu *et al*., 2009; Dave *et al*., 2012), least squares method (Gramescu *et al*., 2014) and others. Above method takes its name from the *latin* alphabet, used for the first time when was described the plan, (http://designtheory.org/; http://www.isogenic.info/; https://onlinecourses) (Table 1). This kind of plan is recommended when test in parallel three independent variables, each with several degrees of variation. The advantage is that reducing the number of experimental conditions analyzed from K_n conditions at Kxn conditions where, n represent the number of variables considered for the study and k the modalities number of variables (http://www.statsdirect.com/; https://www.ilri.org/; http://personal).

Table 1
Presentation of Latin Square Method

	A_1	A_2	A_3
B_1	C_1	C_2	C_3
B_2	C_1	C_2	C_3
B_3	C_1	C_2	C_3

Latin square allows experiments planning to evaluate k factors effects at a number of levels variation p > 2, (http://www.statsdirect.com/; https://www.ilri.org/; http://personal). *Latin* square method provides information when the interactions effects between factors are smaller than the effects made by main factors, and experimental errors follows a normal distribution. Latin square method by order n is a matrix composed type n x n where n is a distinct symbol, each cell belonging to *latin* letters, once on line or on column, (http://www.statsdirect.com/; https://www.ilri.org/; http://personal). For example: for an factorial experiment involving three influencing (A, B, C) at three variation levels, through 3x3 *latin* square type plan, the experiences number which can be obtained the informations is only 9 (Table 2), instead of 27 according to a factorial plan complete (3^3), (http://designtheory.org/; http://www.isogenic.info/; https://onlinecourses).

Table 2
Example for Experimental Plan According 3x3 Latin Square Plan

	A_1	A_2	A_3
B_1	C_1 (1)	C_2 (2)	C_3 (3)
B_2	C_2 (4)	C_3 (5)	C_1 (6)
B_3	C_3 (7)	C_1 (8)	C_2 (9)

The terms significance from Table 2 are the following: the number from brackets is each experiment number; first matrix line is A factor for all 3 levels; the first matrix column is B factor for all 3 levels and C factor is written like *latin* square. In industrial experiments, a variable often rely on time units. The other variable may be represented by machines or operators (http://www.statsdirect.com/; https://www.ilri.org/; http://personal).

3. The Experiment Planning

For experiments tests will be used CNC machine Akira Seiki SR3 XP (Fig. 2) from Fine Mechanic and Nanotechnologies laboratory, Department of Machine Manufacturing Technology, “Gheorghe Asachi” Technical University of Iași. Some characteristics of machining center are presented in Table 3.

Table 3
Akira Seiki SR3 XP Parameters (**** Equipment Guide*)

Parameters	U.M.	Values
X/Y/Z Travel	mm	762/ 410/ 460
Table dimensions	mm	910x380
Spindle	rpm	9000
Power	HP	12
Cutting speed	m/min	36/36/30

The tool used at experimental tests is a tool with spherical peak shape (Fig. 2) from X163CrMoV12 material and the hardness is 57 HRC. The peak tool diameter is 9 mm and the length is 100 mm.

Fig. 2 – The tool which will be used at single point incremental sheet forming process.

For fixing the tool on CNC milling machine tool will choose a tool holder with collet and for fixing the sheet blank will be use the clamping device from Fig. 3, which is composed from the following elements: motherboard which is clamping on CNC milling machine tool table; support plate; 4 supports; sheet blank clamping plate and 16 fixing screws, 4 nuts. For fixing the clamping device on CNC milling machine tool will be achieved by means of clamps.

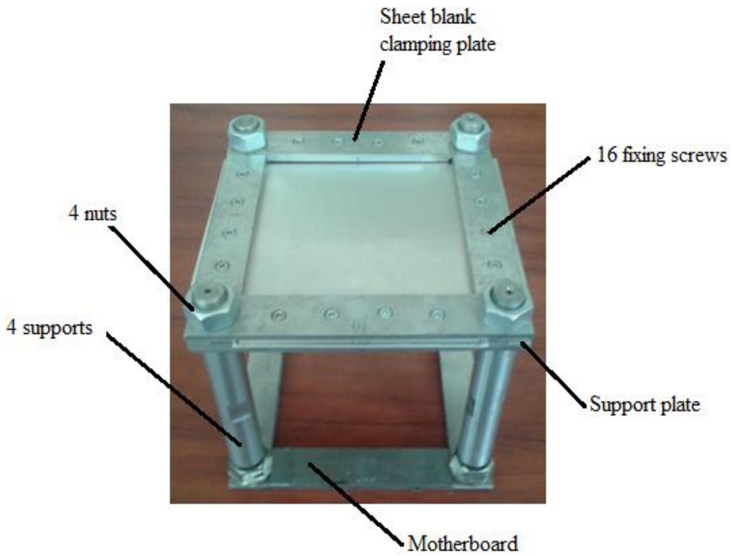

Fig. 3 – Sheet blank clamping device.

The sheet blank material is AlMg3 EN 5754 H111 with thickness 1 mm. During the experimental tests will follow 3 influence factors (A, B, C), using *latin* square method 3x3 type. This influencing factors are presented in Table 4.

Table 4
The Experimental Plan Using the Latin Square Method

		Wall angle 5º	Wall angle 10º	Wall angle 15º
Experiment 1	Speed 1500 rpm	Forming depth 0.05 mm	Forming depth 0.055 mm	Forming depth 0.06 mm
Experiment 2	Speed 3000 rpm	Forming depth 0.065 mm	Forming depth 0.07 mm	Forming depth 0.075 mm
Experiment 3	Speed 6000 rpm	Forming depth 0.08 mm	Forming depth 0.085 mm	Forming depth 0.09 mm

4. Conclusions

For single point incremental sheet forming process isn't used a die, but it is need the clamping device for fixing the sheet blank, a variety tools, forming rollers, active plates, etc. In comparison with classic forming, single point incremental sheet forming need a lot of time but doesn't require high costs with equipments.

Latin square method has the following advantages, as follows: significant reduction of experiments number to be performed is easily method to be analyzed.

Also, the method requires that the number of experiments, rows and columns to be the same and each experiment to be approximate the same in each row and column.

The blank material chosen for experimental research is very little used in specialty literature to achieve various parts and technological parameters chosen are easily to be varied on machine tool, also in software package to simulate the process.

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PLANIFICAREA EXPERIMENTULUI PENTRU AMBUTISAREA INCREMENTALĂ ÎNTR-UN SINGUR PUNCT UTILIZÂND METODA PĂTRATULUI *LATIN*

(Rezumat)

Ambutisarea incrementală este o nouă tehnică de ambutisare care poate oferi o precizie ridicată a produselor, într-un timp foarte scurt şi costuri de producţie reduse. Ambutisarea incrementală reprezintă o serie de procese inovative, flexibile, în care se pot obține diferite geometrii fară a fi necesară o geometrie specială a sculei (Tisza *et al.*, 2013). Termenul de ambutisare incrementală este utilizat pentru o varietate de procese, toate caracterizate prin faptul că zona de deformare locală se deplasează pe toată suprafața produsului. Lucrarea prezintă planificarea experimentelor în vederea obţinerii unui produs prin ambutisare incrementală într-un singur punct utilizând metoda pătratului *latin.*