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Optimization of process parameter on Surface Roughness (Ra) and Wall Thickness on SPIF using Taguchi method

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Abstract - ***Among the innovative sheet metal forming processes, Single Point Incremental Forming (SPIF) represents the simplest and the cheapest one. On the other hand, this process allows reducing set-up costs significantly and presents a very high flexibility; it is in fact, possible to create different components simply by operating on the tool path with the same tool. With the increasing demand for low-volume and customer-made products, incremental sheet metal forming (ISF), a die-less sheet metal forming process, has mostly used in industry. To response this task a fully digital integrated system from CAD modelling to finished part (CAD/CAM) for SPIF process has been developed. To determine the optimum parameter in SPIF Taguchi method of DOE with ANOVA and L9 orthogonal array was developed for different process parameter (factors) such as wall angle, feed rate, spindle speed, and step increment. The response study was performed on surface finish and wall thickness of the process.***

Key Words: *SPIF, Feed rate, orthogonal array, ANOVA etc.*

1. INTRODUCTION

Incremental forming is the process of forming sheet material into complicated shapes without the use of either male or female dies. Single point incremental forming (SPIF) is a new innovative and feasible solution for the rapid prototyping and the manufacturing of small batch sheet parts. The process is carried out at room temperature and requires a CNC machining centre, a spherical headed tool and a simple support to fix the sheet being formed. In incremental Sheet Metal Forming the blank is incrementally deformed in to a desirable shape by hemispherical or ball nose tool traveling along a prescribed path. Due to various advantages such as low cost, short lead time, good flexibility due to absence of dies and good surface finish can be achieved. With ISF approach, the deformation of the material is carried out incrementally and as a consequence, less forming loads are required comparing with the conventional processes.

Single point incremental sheet forming has four basic elements: 1) a sheet metal blank 2) a blank holder 3) a single point forming tool 4) backing plate 5) CNC motion. These basic elements are illustrated in Figure 1.F is the metal forming force, *v* is the tool feed and ω is the spindle rpm. The ISF technology is a forming approach which uses the CNC machining center, a spherical headed tool and a simple support to fix to produce a part from the sheet materials. The flexibility of the process is mainly related to the fact that SPIF does not require a dedicated die to operate as compared to other forming processes .ISF is a highly localized deformation process in which a tool, whose path is programmed to follow a particular trajectory, moves over a sheet metal and forms the desired shape. Three dimensional models of the part are designed using commercially available CAD/CAM software Feature CAM and CNC codes are generated by the same software. The codes are then fed into the CNC machine. As a result, the lead-time and cost of tooling along with the die cost can be avoided. This technique allows a relatively fast and cheap production of small series of sheet metal parts. Figure 2 gives the schematic representation of elements of ISF.

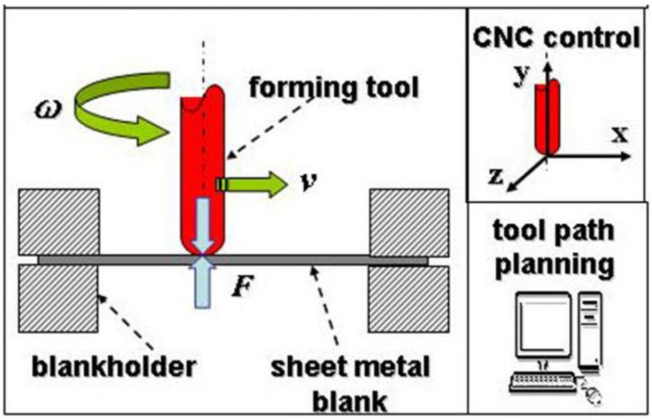

Figure 1.- Basic Elements of SPIF

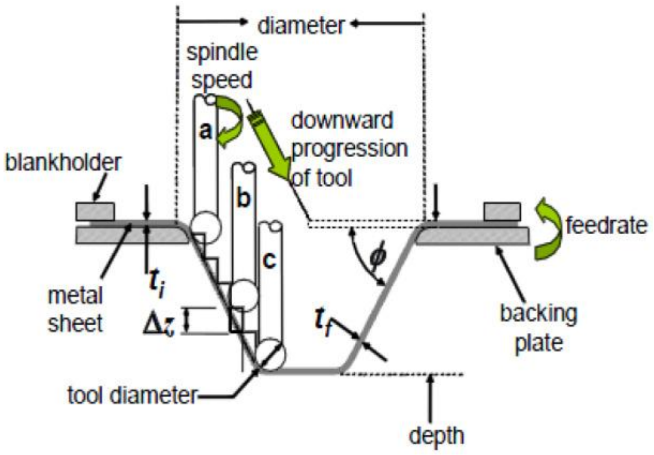

Fig. 2 ISF Process Terminology

2 METHODOLOGY

2.1 CAD/CAM design development

Conical shape was designed drawn in one operation in order to investigate incremental sheet metal forming process. CAD geometries were generated with UGNX 8.5 and tool paths are designed with UGNX 8.5 CAM as Shown in figure.

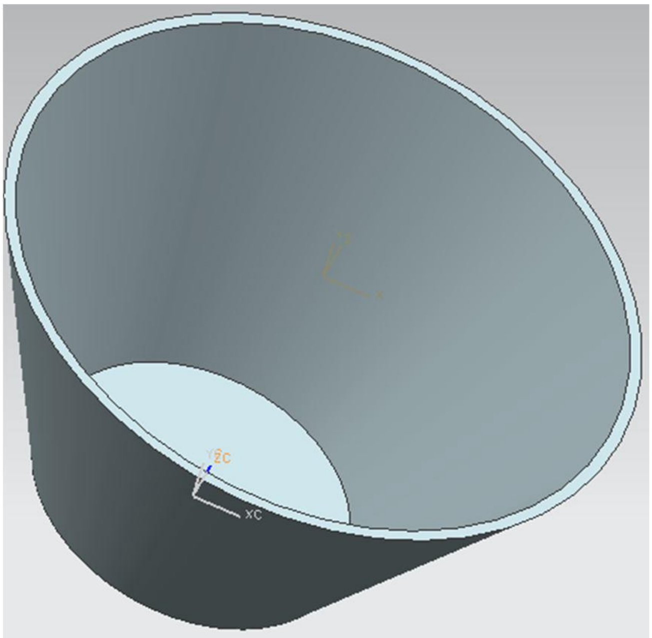

Figure - a) CAD profile in UGNX

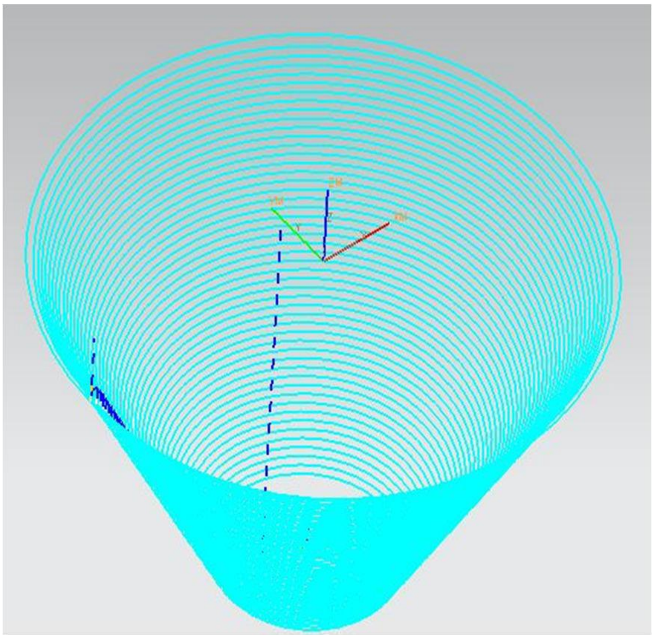

Figure - b) contour tool path in UGNX CAM

2.2 Taguchi method

Design of experiment: Taguchi method is adopted for optimizing process variables as it is simple and easy. The method is popularly known as the factorial design of experiments. This method uses a special set of arrays called orthogonal arrays. The orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values.

Table 1 - SPIF Parameter and their Levels

Factor	Level 1	Level 2	Level 3
Wall angle	55	65	45
Step increment	0.2	0.5	1
Feed rate	500	800	1200
Spindle speed	600	800	1000

Table 2 - Orthogonal Array L9

Experiment no.	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3 Results of DOE - Taguchi Method

Table 3 – Experimental Results of Taguchi Method

	Factor				Response	
Exp no	Wall Angle	Step Depth	Feed Rate	Spindle Speed	Ra	Wall thickness
1	55	0.2	500	600	3.07	0.98
2	55	0.5	800	800	3.28	0.97
3	55	1	1200	1000	4.63	0.99
4	65	0.2	800	1000	3.20	0.73
5	65	0.5	1200	600	3.87	0.77
6	65	1	500	800	4.13	0.75
7	45	0.2	1200	800	3.99	1.25
8	45	0.5	500	1000	3.45	1.25
9	45	1	800	600	5.78	1.26

3.1 Analysis of S/N Ratio

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: Target is best, Smaller is better, and Larger is better.

Smaller is better S/N ratio was used for surface roughness because lower surface roughness ids desirable i. e. higher surface finish. Quality characteristic of the smaller is better is calculated in the following equation.

$$Z = -10 \log \left(\frac{\Sigma^{n}_{i=1} y^2_i}{n} \right)$$

Table 4 – Values of S/N ratio for Surface roughness (Ra)

	Factor				Response	
Exp . no	Wall Angle	Step Depth	Feed Rate	Spindle Speed	**Ra**	**S/N Ratio**
1	55	0.2	500	600	3.07	-9.791
2	55	0.5	800	800	3.28	-10.371
3	55	1	1200	1000	4.63	-13.326
4	65	0.2	800	1000	3.20	-10.128
5	65	0.5	1200	600	3.87	-11.828
6	65	1	500	800	4.13	-12.353
7	45	0.2	1200	800	3.99	-12.028
8	45	0.5	500	1000	3.45	-10.765
9	45	1	800	600	5.78	-15.318

Target is best S/N ratio used for wall thickness because level can be adjusted to change average output characteristic by using following equation.

$$Z = 10 \log \left(\frac{\bar{y}^2}{S^2} \right)$$

Where s^2 is sample variance.

Table 5 – Values of S/N ratio for wall Thickness

	Factor				Response	
Ex. no	Wall angle	Step Depth	Feed Rate	Spindle Speed	**Wall Thick - Ness**	**S/N Ratio**
1	55	0.2	500	600	0.98	26.0232
2	55	0.5	800	800	0.97	26.7728
3	55	1	1200	1000	0.99	24.4918
4	65	0.2	800	1000	0.73	29.6796
5	65	0.5	1200	600	0.77	26.9658
6	65	1	500	800	0.75	24.5992
7	45	0.2	1200	800	1.25	41.1325
8	45	0.5	500	1000	1.25	44.9485
9	45	1	800	600	1.26	42.0074

3.2 Analysis of Variance (ANOVA)

ANOVA was used to determine the significant parameters influencing surface finish and wall thickness in the forming of AA1100. Table 4.3 shows summery of ANOVA results for surface roughness and wall angle. In this study, analysis was a level of significance as 5% and level of confidence as 95%.

Table 6 – ANOVA Results for Surface roughness

Factor	DOF	Sum of Square	Mean Square	Contribution %
Wall Angle	2	1.0114	0.5057	17.23
Step Depth	2	3.7685	1.8843	64.19
Feed Rate	2	0.6664	0.3332	11.35
Spindle Speed	2	0.4244	0.2122	7.23
Error	0	0		
Total	8	5.8707		100

Table 7 – ANOVA Results for Wall thickness

Factor	DOF	Sum of Square	Mean Square	Contribution %
Wall Angle	2	0.38315	0.19158	99.79
Step Depth	2	0.0002	0.0001	0.05
Feed Rate	2	0.0003	0.0002	0.08
Spindle Speed	2	0.0003	0.000	0.07
Error	0	0	0	
Total	8	0.38398		100

From the above ANOVA results it is clear that surface roughness is depends on step increment (Depth) by 64.19 % and wall angle by 17.23 %. For thickness reduction only wall angle (99.79 %) is responsible. For achieving better surface finish we need to control three parameters but for thickness reduction we have to control only one parameter i.e. wall angle.

Design of experiments by using Taguchi Method gives the two responses, surface finish and wall thickness. S/N ration gives optimal combination and ANOVA gives most influencing parameter on the response. The results of the S/N ratio shows optimal conditions wall angle, step increment, feed rate and spindle speed are important for better Surface finish but for sheet thickness reduction only optimal wall angle must be set, because there is no large deviation in S/N ratios due to Step increment, Feed rate and
Spindle speed from mean value for thickness reduction.
ANOVA results shows step increment is important parameter for surface finish as its effect on surface roughness is 64.19 % and wall angle is most influencing parameter for wall thickness distribution as its effect on it is 99.79 %. For obtaining better surface finish we need to adjust two parameters, step increment and feed rate. Parameter which defines the contact between sheet and tool are important for surface finish, means surface finish is depends on contact area and contact time between tool and sheet. More thickness reduction can be achieved for greater wall angle, this is only due to the less sheet material is available for deformation at large wall angle.

4 Conclusions

1. More thickness reduction can be achieved for greater wall angle
2. From the S/N ratio and ANOVA results it is Concluded that
   a) Surface roughness is depends on step increment (Depth) by 64.19 % and wall angle by 17.23 %.
   b) Thickness reduction is depends on only wall angle,
   its dependency is 99.79 %
   c) Feed rate and spindle speed does not have Significant effect on surface finish and thickness reduction

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