Design and Development of Single Point Incremental Sheet Forming Machine

*Yogesh Kumar¹, Santosh Kumar²

¹²Mechanical Engineering Department, Indian Institute of Technology (BHU), Varanasi (UP), India, 221005
E--Mail: ¹yogeshiitbhu@gmail.com, ²santoshkr.mec@gmail.com

Abstract

Single Point Incremental Sheet Forming (ISF) is one of the most advanced techniques in the domain of flexible sheet forming process to produce complex products, which do not require any expensive and dedicated forming tools (punch & die). The Laboratory setup of Incremental Forming Machine has been developed. A Motion card has been used to control the 3 servo motors giving capability of individual 3 Axis controlling. The forming trials are carried out based on simulation study of incremental forming process. The strain distribution over the length of deformation has been computed.

Keywords: Incremental Sheet forming, Dieless forming, Modeling, Simulation etc.

1 Introduction & Literature Review

Incremental sheet forming is a new technique for deforming sheet metals by the application of step by step incremental feed to the deforming tool. For the production of parts by conventional sheet forming techniques dedicated tools are required. The dedicated tools are complex in design and thus are expensive. The design of tooling (die and punch) for complicated shapes is difficult and expensive. In Incremental forming technique, only a deforming tool is required for deforming the sheet metals. There are four major elements of incremental sheet forming as shown in Fig. 1: (i) a sheet metal blank, (ii) a blank holder, (iii) a single point forming tool or deforming tool, (iv) CNC Machine.

![Figure 1: Basic Elements of Incremental Dieless Sheet Forming [Y. Kumar et. al., 2013].](image1)

Before going to actual deformation of the sheet metal for ensuring the proper deformation of sheet.

In Incremental Sheet Forming (ISF) specific terminologies are used as seen in Fig. 2, with definitions below:

![Figure 2: SPIF Terminology in ISF [Ham et. al. 2007].](image2)

\[ t_i = \text{Initial sheet thickness.} \]
\[ t_f = \text{Final sheet thickness.} \]
\[ \Delta z = \text{Incremental step -- down size.} \]
\[ \phi = \text{draw angle or forming angle.} \]

The incremental step-down size (step size, \( \Delta z \)) is the amount of material deformed for each revolution of the forming tool (similar to depth of cut in machining). The step size affects the machine time and the surface quality. The step size parameter is set in CAM software. Feedrate is the speed of forming tool moves around the mill bed (similar to cut rate in machining). The federate had a direct impact on the machine time for forming. It is measured in mm/minute. The federate parameter is set in CAM software and is then varied on the mill. The spindle
rotation speed is the speed at which the tool rotates. The spindle rotation speed varies the heat generated at the contact point between the material and the forming tool. The spindle rotation speed is also set at the mill. The angle between the horizontal, undeformed sheet metal and the deformed sheet metal is defined as the draw angle or forming angle $\phi$ as shown in Fig. 2. The forming angle can be used as a measure of material formability. The maximum angle ($\phi_{\text{max}}$) is the greatest angle formed in a shape without any failures. The forming angle is set within CAD software [Ham et. al. 2007]. A summary of recent literature done by Y. Kumar and S. Kumar has been represented in Table 1.

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<thead>
<tr>
<th>S.N.</th>
<th>Issue</th>
<th>Research Highlights</th>
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<tbody>
<tr>
<td>1</td>
<td>Classification</td>
<td>Single Point Incremental Forming SPIF&lt;br&gt;Two Point Incremental Forming, TPIF&lt;br&gt;Two Point Incremental Forming with Partial Die&lt;br&gt;Two Point Incremental Forming with Full Die</td>
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<td>2</td>
<td>Formability</td>
<td>The formability of sheet metal appears better than conventional forming.&lt;br&gt;Double-forming technique improves formability.&lt;br&gt;The deformation occurs due to plane-strain and bi-axial stretching.&lt;br&gt;The forming limit curve is expressed as a straight line with a negative slope.&lt;br&gt;Depth and diameter have no effect.</td>
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<td>3</td>
<td>Surface Quality and Geometric Accuracy</td>
<td>In hot incremental forming the quality of bottom surface is better as compared to the one in contact with the punch.&lt;br&gt;Some errors along the oblique walls&lt;br&gt;Elastic spring back causes geometric inaccuracy.&lt;br&gt;The results of process model and experimental results are approximately same.</td>
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<td>4</td>
<td>Deforming Force and Sheet Thinning</td>
<td>The forming forces depend on tool path.&lt;br&gt;The forming force is slightly lower than the experimental values.&lt;br&gt;Sheet thinning depends on the wall angle $\alpha$.&lt;br&gt;Sheet thinning is given by the sign law $t_1 = t_0 \sin (90^\circ - \alpha)$&lt;br&gt;Thickness measurements with the process model and experimental results obtained are approximately same.</td>
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2 DEVELEOPMENT OF MACHINE SETUP

The major elements of incremental sheet forming are identified as: (i) a sheet metal blank, (ii) a blank holder, (iii) a single point forming tool or deforming tool, (iv) CNC Machine. The path of the deforming tool is responsible for the shape, size and accuracy of the final product. Thus the quality of the product depends on the proper tool path planning. The development of different parts of incremental forming Machine has been discussed as below:

2.1 Sheet Metal Blank

The Incremental forming Machine is basically used for deforming product from metals sheets. The current research is mainly focused on the development of incremental sheet forming process for light alloy. The Material for metals sheet can be Aluminium alloys, Brass, Titanium alloys etc. For testing the Machine Developed at IIT (BHU,) a brass sheet of blank size 100mm*100mm*0.5mm has been used for current experimental study. The sheet has been deformed using incremental forming machine and a finished product as shown in Fig. 5 was obtained.

The shape, size and accuracy of the finished product are compared with the simulation model. The shape and size of the processed model as compared to the simulation model has been found approximately same.

2.2 Blank Holder or Blank Holding Arrangement

Blank holder is the most important element of the incremental forming machine. The proper blank holding arrangement is necessary for properly holding the blank sheet. A CAD model of the blank holding arrangement as shown in Fig. 3 was developed for simulation study. Also based on the simulation study a modified blank holding arrangement and a single point Incremental Forming Machine has been developed as shown in Fig. 4. The metals as well as alloys can be deformed easily by incremental sheet forming process. For the current investigations the initial blank of brass is selected for finding the capabilities of incremental sheet forming process.
because brass is having good formability at room temperature.

![Figure 3: CAD Model of Blank and Blank holding Arrangement.](image)

In order to adopt a suitable forming methodology, a recent survey by Y. Kumar and S. Kumar (2013) in the area of Incremental forming has been kept into consideration as shown in Table 1.

![Figure 5: Defect free product (Brass).](image)

For the successful implementation of ISF, a proper forming methodology has to be followed as shown in Fig. 6. The first step in ISF is to identify need for the components. As soon as the need analysis is done the geometrical dimensions of the product to be manufactured, are decided. Based on geometrical dimensions a 3D CAD model of the product is developed using CAD/CAM package. Moving forward with the help of CAD/CAM package, the tool path suitable for movement of the tool is generated. In the next step the workpiece is held in the proper blank holding, and test pieces are produced using the generated tool path. The accuracy of test pieces is tested against the desired profile.

![Figure 6: Forming methodology in ISF.](image)

### 2.3 Single Point Forming Tool or Deforming Tool

The single point forming tool also known as Deforming Tool is another major element of most important element of the Incremental forming machine. The Deforming tool may be spherical or elliptical or conical in shape. For the current research a conical tool, having hemispherical shape at tip has been used as shown in Fig. 4.

![Figure 4: Single Point Incremental Forming Machine.](image)

### 2.4 CNC Machine

The CNC Machine is needed in order to control the tool path. A Motion card having capability of controlling 8 independent axis has been used. A 3 Axis in house CNC machine has been developed for controlling the tool path.

### 3 RESULT AND DISCUSSION

The Single point incremental forming is capable in producing 3D complex components. The success of this process depends on mainly on Tool path.

In deforming sheets by Incremental forming, Methodology of deformation plays an important role.

![Diagram](image)
mm in length. The cone (Top circle radius $R = 20$ mm, Bottom circle radius = 5 mm).

**Figure 7:** Grid pattern on the Bottom surface.

For the analysis of strain distribution in the sheet deformed by incremental forming process the following 5 regions were identified on the deformed sheet:

- **Region A:** Starting from centre point (Point 1) of bottom circle next 5 grids (Point 2) were identified as the region A.
- **Region B:** Starting from Point 2 of next 5 grids i.e. upto Point 3 were identified as the region B.
- **Region C:** Starting from Point 3 of next 5 grids i.e. upto Point 4 were identified as the region C.
- **Region D:** Starting from Point 4 of next 5 grids i.e. upto Point 5 were identified as the region D.
- **Region E:** The portion beyond Point 5 was identified as the region E.

The Strain was found to be distributed normally over the length of deformation as shown in fig. 8.

**Figure 8:** Normal plot

**4 CONCLUSION**

The incremental forming process is a flexible forming process and it can be easily used for producing 3D complex shapes. The process can be used for larger forming angles with proper forming methodology. The Laboratory setup of Single Point Incremental Sheet Forming Machine has been developed using Motion card to control the 3 servo motors giving capability of individual 3-Axis controlling. The defect free product of brass has been produced using the ISF. The strain distribution over the length of deformation has been computed. The strain distribution in ISF has been found to be distributed over the length of the deformation. Thus, this process has a larger scope for producing complex shapes. A proper attention is to be paid on forming methodology and tool path.

**References**