



## Experimental Investigation of Dimensional Accuracy in Non-traditional Sheet Metal Spinning Process for Producing Rectangular Spun Part

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### HIGHLIGHTS

- The non-conventional spinning process for producing polygons cross-section.
- Dimensional accuracy to check methodology of producing rectangular cross-section.
- The measure opposite took place by offsetting the design points along normal vector.
- The NC milling machine was used to obtain the Data (x, y, and z coordinate).
- Forming ball diameter mainly increases the dimensional accuracy average error.

### ARTICLE INFO

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### ABSTRACT

The non-conventional spinning process was adopted for producing polygons, but one of the process limitations is the error between design and the final product especially with no-mandrel. Dimensional accuracy was adopted for this purpose which gives an indicator of the ability of the formed part to matches the design and checking validated of the adopted methodology for producing rectangular cross-section spun parts, by comparing the coordinating points of real part with the points of the design model. The point of a real part was measured by using a sphere probe fixed on the three-axis milling machine and capturing the data of machine axis movements for the center location of the probe, also, the measurements oppositely took place, by offsetting the points of design along the normal vector for comparison with the real part points. Three parameters were invested for study the effects on the dimensional accuracy, these parameters are spindle speed (48, 68, and 135 RPM), feed ratio (0.16, 0.22, and 0.32 mm/rev), and the ball diameter of the forming tool (16, 22 and 25 mm). The results show that tool ball diameter mainly affecting dimensional accuracy with a higher value of average error reach (6.47mm) when 16mm diameter of tool ball was used, on the other hand, the minimum average error was 1.705mm at low spindle speed.

### 1. Introduction

Generally spinning of sheet metal is known as a process that transforms circular flat metal blank sheet into an axisymmetric, hollow shapes part by using a forming tool that forces a blank onto a mandrel. On the other hand, the traditional spinning process limited to produces axisymmetric components [1]. But in the last 3 Decades, researchers were attempted to overcome this limitation by producing more complex parts such as the researcher, Zhen Jia et al (2014) [2], presented an Investigation of the spinning process to expose the mandrel-less spinning technique to produce the square section spun part. Furthermore, exposed development of modulation of finite elements accompanied by the formation of a roller path as a boundary condition and verified the accuracy of this modulation through several experiments [1]. Also, Yoshihiko Sugitaa et al (2014) [3], presented an experiment to form non-conventional forms by using a circular cone and transformed it to rectangular polygon. Where the cone was created by synchronous multi-pass spinning accompanied by rotational pass sets. In the cone forming the wrinkling occurred when the angle increases largely. On the other hand, the rectangular polygon was formed using rotational pass sets, folds appeared identical to the folds in conical types [2], furthermore Jacopo M. Russo et al (2020) [4], presented an investigation for manufacturing a non-conventional spun part using an adaptive new conceptual design machine, were attempted to produce a square and the form of a bean cross-section cup. Where In the beginning, a suitable design of blanks was achieved for such geometry, and showed that possible to eliminate the mandrel, and thus decreases costs, lead times, and materials substantially. Also, showed the methodology description for blanks development and tool paths, furthermore exhibits the results of the physical experimental for that adoptive machine [3], also, Zhen Jia et al (2020) [5],

presented an investigation of the roller path in mandrel-less spinning forming technique to fulfill a circular square section spun parts by using a 5-axis CNC machine of the spinning process, where a roller path was designed, and adjusted to calculate the degree of the square section edge parts. The methodology used to make this square section required the roller to move in the radial direction forward and backward linked with a rotation of the blank and progressing in the x-axis directions simultaneously, finally M. Razumov et al (2016) [6], presented a mathematical relationship proposal to calculate the shape of errors that happen through turning the polygons with an odd number of faces. The calculations were found that the real polygon profile differs from the real profile due to machining errors during the production of polygons with an odd number of faces. .

Finally, this study aims to check the validity of the non-conventional spinning of sheet metal process that adopted for producing the square section spun parts.

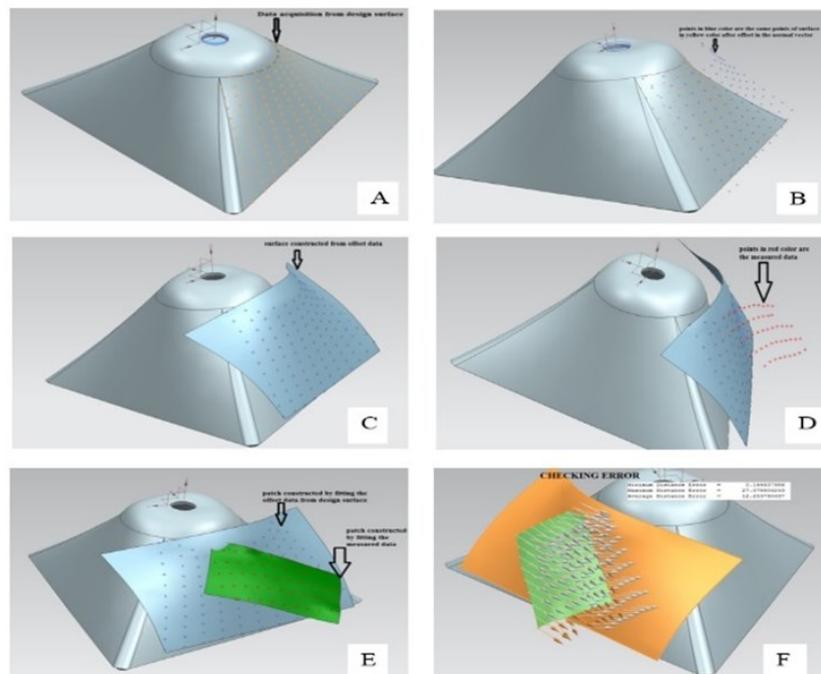
## 2. Theoretical considerations

The dimensional accuracy error can be well-defined as the distance error between the theoretical and experimental points on the surface in the spun part, where there is a distance error between the new geometry of the spun part and the design shape of the spun part assigned to the nature of the process [7].

The methodology was applied by calculating the contact location points of the designed surface by using Siemens NX software version 10, then transform these data to center location points by exporting that's data to Matlab Software version 2015 then calculate the normal vectors and then offset the data points along that's normal [8], finally import data by NX 10 Software from Matlab Software and change these points to surface by fitting operation which considers the reference surface for all measurement for the specific spun part [9], and comparing the measured surface were constructed by fitting the measured points by using NX10 Software also, on the other hands this methodology considers the opposite way for measuring error where the measure data don't transition along normal vector to become contact points because these data already have an error, also, consider the best way for accurate measuring especially when absence of the CMM machine. Figure (1) shows the steps that is used to measure the error between the design part and the manufactured part for rectangular shape.

## 3. Experimental setup

The geometrical errors that occur in the formed part are indicated of dimensional accuracy of the parts made by that forming process. The NC milling machine positioned in the University of Technology/Production and Metallurgy Engineering Dept./ metal cutting laboratory was used to obtain the experimental Data (x, y and z coordinate), by using a probe with a spherical head (diameter 10.3mm) and multimeter on buzzer position (when probe contact surface of the spun part give indicator light with sound), then register the displayed x, y, and z coordinate that's appeared on the NC machine screen, the data obtained by this method represent the center location of the probe. Figure (2) shows the measurement method by using the NC machine, probe, and multimeter.



**Figure 1:** The steps that used to measure the error between design part and manufactured part for rectangular shape as example, where : (A) data acquisition, (B) data offset along normal, (C) surface by fitting data, (D) measured data points, (E) surface fit from measured data, (F) illustration the measured error.

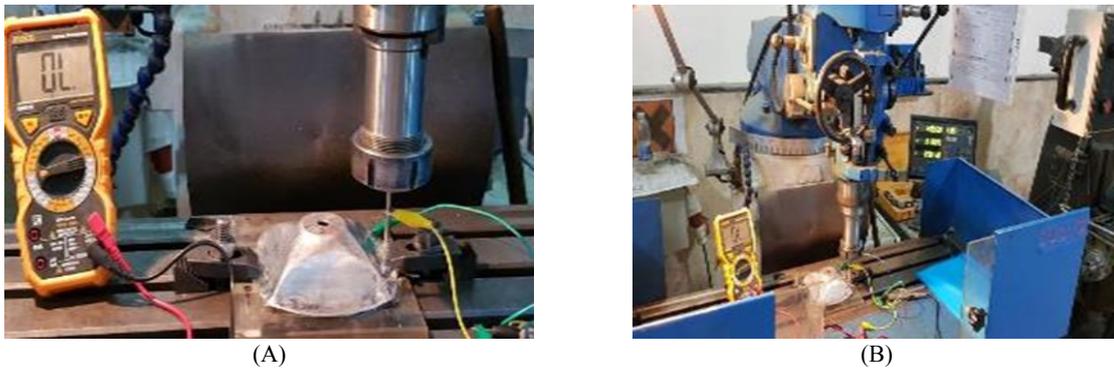


Figure 2: The measurement method, where: (A) focus on the probe, part and multimeter, while (B) displays the whole NC machine.

#### 4. Dimensional accuracy error comparison analysis for rectangular spun parts

The comparison has been done between the two patches by using Siemens NX 10 software, also, the analysis data from the comparison where the number of the points checked was 104 points depends on the 12 points in both U and V patch direction and the distance with angular tolerance were chosen to be 5 mm for all the checked parts depends on the nature of spinning process especially when the absence of the supports or mandrel part. Figure (3) shows the comparisons for all parts.

#### 5. Results and discussion

The results were illustrated in Tables from Table I to the Table IX for sample 1 to sample 9.

- From Table X it is clear that the tool ball diameter mainly effecting on dimensional accuracy with a higher value of average error in dimensional accuracy reached (6.47) in sample 8 where the error analysis for sample 8 was shown in the Table VIII. This way give better indicator than result depending on shape error as mentioned by M. Razumov et al (2016) [6].
- Table VIII elucidated that the number of points lie outside tolerance was 87 point from 101 point which consider a high error value or part was fail when 16 mm diameter of tool ball was used, as shown in figure (3) for the same sample 8.
- The minimum error in average dimension was 1.705 as shown in Table II for sample 2 which formed under spindle speed 48 RPM, feed ratio 0.22 mm/rev, and tool ball diameter 22 mm, due to the low spindle speed, which coincide with the result by Jacopo M. Russo et al (2020) [4].

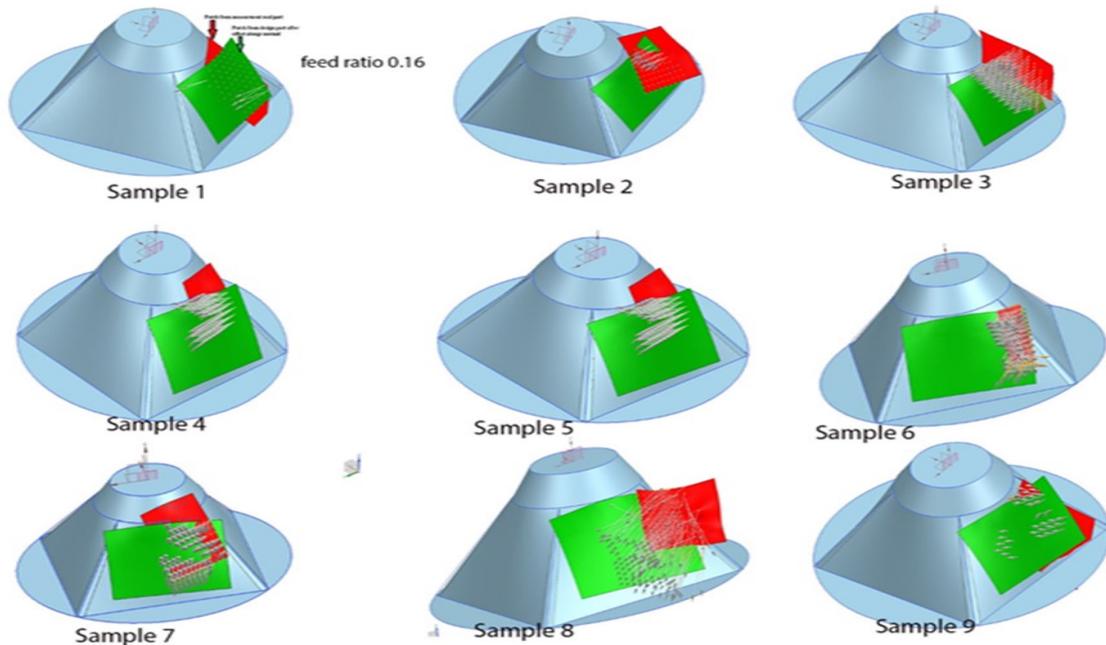


Figure 3: The design of rectangular parts with two patches, the red one represents the fitting measurement data from real rectangular part, and the red patch represents the data points acquisition from design part where offsets along normal vector, finally arrows represent the points at out of tolerance.

**Table 1:** The dimensional accuracy error analysis for rectangular spun parts (Sample 1) by Ss 48RPM, feed ratio 0.16mm/rev,

<b>SAMPLE 1</b>	<b>Distance Error</b>
<i>Number of Points Checked</i>	104
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	0
<i>Minimum Error</i>	1.637 mm
<i>Maximum Error</i>	4.145 mm
<i>Average Error</i>	2.79 mm

and tool ball diameter 16 mm.

**Table 2:** The dimensional accuracy error analysis for rectangular spun parts (Sample 2) by Ss 48 RPM, feed ratio 0.22 mm/rev, and tool ball diameter 22 mm.

<b>SAMPLE 2</b>	<b>Distance Error</b>
<i>Number of Points Checked</i>	75
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	0
<i>Minimum Error</i>	0.007 mm
<i>Maximum Error</i>	4.113 mm
<i>Average Error</i>	1.705 mm

**Table 3:** The dimensional accuracy error analysis for rectangular spun parts (Sample 3) Ss 48 RPM, feed ratio 0.32 mm/rev, and tool ball diameter 25 mm.

<b>SAMPLE 3</b>	<b>Distance Error</b>
<i>Number of Points Checked</i>	79
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	49
<i>Minimum Error</i>	0.37444 mm
<i>Maximum Error</i>	11.6947 mm
<i>Average Error</i>	5.84717 mm

**Table 4:** The dimensional accuracy error analysis for rectangular spun parts (Sample 4) Ss 68 RPM, feed ratio 0.16 mm/rev, and tool ball diameter 22 mm.

<b>SAMPLE 4</b>	<b>Distance Error</b>
<i>Number of Points Checked</i>	83
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	21
<i>Minimum Error</i>	0.7616 mm
<i>Maximum Error</i>	5.92 mm
<i>Average Error</i>	3.862 mm

**Table 5:** The dimensional accuracy error analysis for rectangular spun parts (Sample 5) Ss 68 RPM, feed ratio 0.22 mm/rev, and tool ball diameter 25 mm

SAMPLE 5	Distance Error
<i>Number of Points Checked</i>	114
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	2
<i>Minimum Error</i>	1.225 mm
<i>Maximum Error</i>	5.14 mm
<i>Average Error</i>	2.9 mm

**Table 6:** The dimensional accuracy error analysis for rectangular spun parts (Sample 6) Ss 68 RPM, feed ratio 0.22 mm/rev, and tool ball diameter 16 mm.

SAMPLE 6	Distance Error
<i>Number of Points Checked</i>	144
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	100
<i>Minimum Error</i>	3.082 mm
<i>Maximum Error</i>	9.0427 mm
<i>Average Error</i>	5.844 mm

**Table 7:** The dimensional accuracy error analysis for rectangular spun parts (Sample 7) Ss 135 RPM, feed ratio 0.16 mm/rev, and tool ball diameter 25 mm.

SAMPLE 7	Distance Error
<i>Number of Points Checked</i>	97
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	0
<i>Minimum Error</i>	0.0049 mm
<i>Maximum Error</i>	4.52 mm
<i>Average Error</i>	1.868 mm

**Table 8:** The dimensional accuracy error analysis for rectangular spun parts (Sample 8) by Ss 135 RPM, feed ratio 0.22 mm/rev, and tool ball diameter 16 mm.

SAMPLE 8	Distance Error
<i>Number of Points Checked</i>	101
<i>Tolerance</i>	5 mm
<i>Number Over desired Tolerance</i>	87
<i>Minimum Error</i>	3.932 mm
<i>Maximum Error</i>	11.109 mm
<i>Average Error</i>	6.470 mm

**Table 9:** The dimensional accuracy error analysis for rectangular spun parts (Sample 7) by Ss 135 RPM, feed ratio 0.32 mm/rev, and tool ball diameter 22 mm.

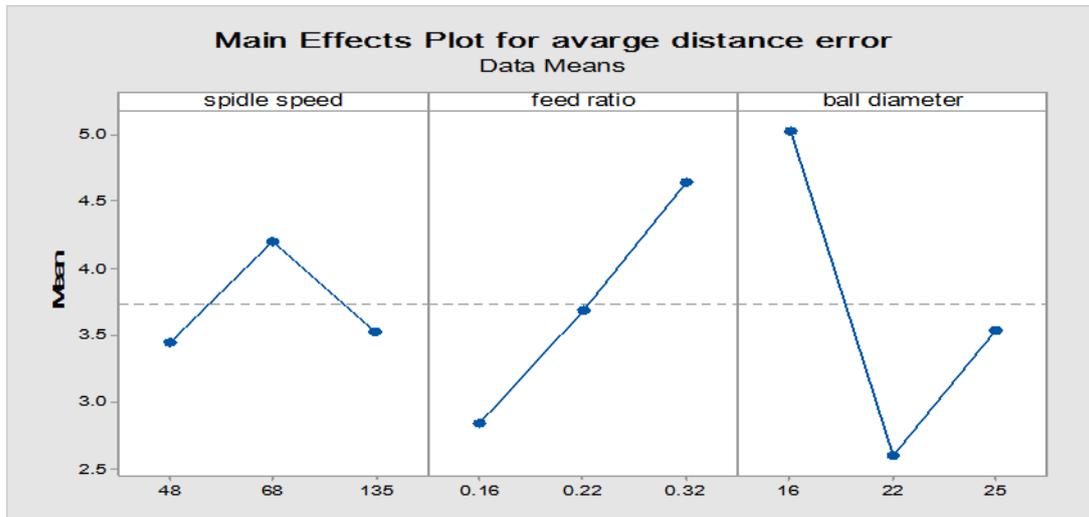
SAMPLE 9	DISTANCE ERROR
Number Of Points Checked	92
Tolerance	5 mm
Number Over Desired Tolerance	0
Minimum Error	0.007 mm
Maximum Error	4.745 mm
Average Error	2.244 mm

### 6. Analysis of Variance

Figure (4) shows the schematic illustration of the main effect of parameters on the average error. Also, Tables (X) shows the percentage effect of each parameter on the dimensional error, of the rectangular spun part

### 7. Conclusions

- 1) The results manifested that the maximum average of error in dimensional accuracy is 6.47 %, for rectangular spun parts, where were observed the big effect parameter was the diameter of the ball tool, where the effect percentage reach 32.43 %, for rectangular spun parts.
- 2) It was noticed that the minimum average error in dimensional accuracy is about 1.705 at spindle speed 48 RPM, feed ratio 0.22 mm/rev and ball diameter of forming tool was 22 mm.
- 3) Also , It was noticed that the feed ratio occupies the second order after tool ball diameter that effecting on the dimensional accuracy where the effect percentage reach 17.58 % where the error reaches 5.84717 mm in sample 2.
- 4) It was observed that the spindle speed has a very low effect on dimensional accuracy, where at 135 RPM the minimum error in dimensional accuracy reached to 1.868 mm and for 48 RPM the error reached to 1.705 mm.



**Figure 4:** Schematic shows the main effect of parameters on average error.

**Table 10:** The percentage effect of each parameter on the dimensional error of the triangular spun part.

PARAMETER	PERCENTAGE EFFECT	RANK
SPINDLE SPEED SS	3.71 %	3
FEED RATIO	17.58%	2
TOOL BALL DIAMETER	32.43 %	1

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### Author contribution

All authors contributed equally to this work.

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### Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

### Conflicts of interest

The authors declare that there is no conflict of interest.

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