



PROGRAMMING A FANUC INDUSTRIAL ROBOT FOR INCREMENTAL SHEET FORMING

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ABSTRACT

Robotic Incremental Sheet forming (ISF) is an ideal method for prototyping parts in various applications such as aerospace, automotive, and medical. While the process needs strong and rigid industrial robots, some industrial robot manufacturers haven't developed any add-on designed explicitly for ISF in their software. Thus the programming of the robots for ISF can be challenging and needs innovative design and programming methods when done in the robot's original software. Although third-party software designed explicitly for ISF is available in the market, it is not entirely compatible with some robots.

In this research, a robust industrial robot, FANUC R-2000ic 165F, was programmed and used by two mechanical engineering undergraduate students under the supervision of a faculty to perform incremental sheet forming on the AL3003 sheet. The innovative design and programming strategies used for robot programming are presented in this research.

Keywords: incremental sheet forming, ISF, Robotic ISF, Fanuc Robot programming, offline programming

1. INTRODUCTION

Incremental Sheet forming (ISF) is an ideal method for prototyping parts in various applications such as aerospace, automotive, and medical [1]. ISF was initially developed using CNC milling machines, but robotization in ISF has been growing due to the more degrees of freedom available by using multiaxis robots [2]. While the process needs strong and rigid industrial robots [3], some industrial robot manufacturers haven't developed any add-on designed explicitly for ISF in their software. Thus the programming of the robots for ISF can be challenging and needs innovative design and programming methods when done in the robot's original software. Although third-party software designed explicitly for ISF is available in the market, it is not entirely compatible with some robots.

In this research, a robust industrial robot, FANUC R-2000ic 165F, was programmed and used by two mechanical engineering undergraduate students under the supervision of a faculty to perform incremental sheet forming on the AL3003 sheet. The design and programming strategies used for robot programming are presented in this research.

2. AN INTRODUCTION TO FANUC PROGRAMMING

Roboguide is the Fanuc proprietary software. Within Roboguide, different setup options can change or define how the robots can be operated. Three programmable movements are Joint, Linear, and Circular. The Joint movement (J) allows the robot's joints to move simultaneously to get to each point. This type of movement is not as predictable as the other two movements as the entire robot moves with no set determined style (linear or curvature path). The next type of movement is defined as linear movement (L). This movement moves the tool

from point to point in a straight line. Circular movement (C) defines the tool's circular arc motion by three points: a starting point, an ending point, and an intermediate point in between.

Along with motion types, different position types can be programmed within Roboguide. The first position type is called position (P). This type of position will describe a position in the cartesian coordinate system recorded by jogging the robot to a set point and recording it. The next type of position is called position register (PR). This position will be created by a predefined location where a position can be found. Position location is defined by $P[N] = (x, y, z, w, p, r, \text{config})$. The x, y, and z are typical cartesian coordinates that show location in 3D space. The coordinates of w, p, and r define jog, pitch, and roll. These coordinates can be described as the orientation components of the robot. The "config" part of the position location describes the axis condition at the desired location. It defines how the robot will move to the desired point whether the wrists are flipped, elbows go up or down, or the robot can be front or back.

Lastly, there are parts of the code that describe termination types. There are two main termination types. The first is the FINE termination type. This means that the robot will physically stop its path at each point it reaches. The other termination type is CNT or continuous. This will cause the robot to decelerate as it approaches the point and thus essentially rounding off the corner of the path to keep the continuous movement. For example, a CNT0 will be very similar to the FINE movement because there is 0 continuous movement. However, a CNT100 will show a very rounded curvature movement between points.

An example one line code can be seen below to give a better understanding of how to read the code in Roboguide, as:

```
J P [1] 100% FINE ACC100
```

To begin, the J defines the different types of motion. For example, the robot could move in joint (J), linear (L), or circular (C) styles. The following letter, P, defines the position type that the robot is reading. Next to it is the position number. The 100% is the movement speed. This example would be 100% movement speed of the maximum default robot speed. FINE describes the termination type. Lastly, ACC100 describes the different motion options that are allowed.

3. FANUC OFFLINE PROGRAMMING

In offline programming, robot code is generated in simulation software (Roboguide for Fanuc) and transferred to the robot controller afterward. A work cell should be created in the robot simulation software, and a User Frame and a User Tool should be defined [4].

3.1 Work Cell Setup

The first step to set up the Fanuc Roboguide work cell is to press "New Cell" from the opening menu. Next, Roboguide will give 9 steps to complete the work cell setup. The first step is to choose the correct process. The ISF process is not defined in Roboguide. The defined processes are "HandlingPRO", "Paintpro", "PalletPRO and PalletTool" and "WeldPRO". Some other robot manufacturers, such as ABB, have a machining add-on which is a better process for doing ISF, but the option is not available for Fanuc standard Roboguide. "HandlingPRO" process, which is the basic material handling, was selected for this research.

After selecting the process, Robuide will ask for a name for the work cell and the method to create a robot. Choose “create a new robot with the default HandlingPro config. Next, it will ask for the Robot application/tool chosen from either the CAD Library or the Default Tools that come with Roboguide. Step 6 is the most critical step when creating a new work cell inside Roboguide; it is important to ensure that the correct robot is chosen. The last two steps overview the work cell contents and provide additional software options. If the controller asks for a specific flange type during the initial startup, the issue can be resolved by entering “1”.

3.2 User Frame Setup

A User Frame setup allows the robot operator to define a new coordinate system, including the origin location and the three axes’ directions [4]. The new origin location can be measured directly from the robot base or automatically calculated inside the work cell.

If a User Frame is already created, the restored User Frame data can be retrieved on the Teach Pendant by following the below path on the Teach Pendant:

Menu>Setup>Setup2>Frames>F3>ToolFrame/User RTCP.

The data includes the correct User Frame number and the correct 6 axis coordinate system values. Following the below path on Roboguide, the coordinate values can be implemented in the work cell.

UFRAME# properties>“EDIT UFRAME”

3.3 User Tool Setup

A User tool setup allows the robot operator to define a new tool and modify the new tool’s tip location [4]. The new location can be measured directly from the tool or automatically calculated inside the work cell. The data can be retrieved from the Teach Pendant in the same fashion as described for User Frame data If User Tool data is already created in the robot. Following the below path on Roboguide, the new values can be implemented in the work cell.

pointer properties> UTOOL> Edit UTOOL

Since our ISF tool is symmetric, all the coordinate values were zero except for the “Z” coordinate, identifying the tool length.

3.4 Importing the ISF workpiece CAD model to the cell

After implementing the correct User Frame and User Tool, the next step in the work cell setup is to add CAD models of the real-world ISF workpiece (sheet metal) and workpiece holder frame. Before a CAD model can be implemented into Roboguide, the file must be saved as an “IGES” file. Inside Roboguide, click the “Cell” tab at the top left of the screen and select “add fixture”. In the next menu that opens, click” Single CAD file” and scale the part as “1”. Roboguide will then ask for the location of the workpiece holder frame to the robot. It should be noted that it is crucial to accurately measure the frame’s dimensions to the robot to prevent any

collisions. Adding the workpiece (sheet metal) to the Roboguide work cell is relatively the same as adding a frame. The “add part” option should be selected instead of the “add fixture” option in this case.



FIGURE 1: COMPLETED ROBOGUIDE WORK CELL

Figure 1 showcases a completed work cell within Roboguide and the selected program to be operated with. The work cell shows the FANUC robot inside the work cell with two workpiece holder frames. User Frame and User Tool are set up using the left-hand side menu. The coordinate system is shown by the red triad on the top left corner of the frame. Without this coordinate system, the robot in real life would not know where the frame is, thus possibly causing collisions. The created program using the CAD-To-path process can be seen visually with the multi-colored pathlines near the center of the frame. Lastly, the created program has been selected and can be seen on the virtual teach pendant with the user frame and tool defined in the program.

4. DESIGN PROCESS IN CAD

From the literature review, many researchers use simple cone shapes [5] to study the design limitations such as maximum wall angles, maximum depth, spring-back effect, pillow effect [6, 7], and the orange peel effect [8]. In the following research, the design process began with a simple conical frustum shape with a constant wall angle of 45 degrees and a constant step size of 1mm. There are some limitations with using the CAD model in Roboguide for ISF. The first limitation is that the tool path should be created in CAD, not in Roboguide. That means any ISF surfaces should be turned in edge lines in CAD since we are using the “HandlingPRO” process in Roboguide, which only traces lines. For example, in designing the cone, a CAD model was created that had the profile of a triangle extruded into a conical frustum. This was done because a continuous edge line can be found across the entire part with the triangle profile. Figure 2 shows the CAD model of the conical frustum shape developed using Solidworks.



FIGURE 2: CAD-MODEL OF CONICAL FRUSTUM SHAPE

After the conical frustum shape is created, there are different techniques to change the wall angle and step size. The helical spiral can be edited, and the start angle and the pitch can be altered to change the wall angle and step size.

5. CAD TO PATH PROCESS

Before Roboguide can be used for ISF forming, the Roboguide work cell must be set up correctly as explained in Section 3. When creating a work cell, three parameters need to be inputted by the user. Selection of the correct robot (FANUC R-2000ic 165F in our research), inputting the correct user frame and user tool gathered from the real-life cell, and importing the workpiece and workpiece holder frame as (IGES) files with correct coordinate values measured in the real-life work cell. Without this data set up correctly, a program will not be executed as expected. The robot will perform actions set up differently because of the different data values assigned for the user frame and tool.

As discussed earlier, Roboguide is not designed for ISF forming and has some obstacles that need to be avoided to use it for ISF. When using the “draw features on parts” feature of Roboguide, there are limitations to what someone can trace on the part, such as surface edges. All the ISF surfaces should be turned into edge path lines. In CAD, we draw the model with helical edge profiles as the robot tool path, then in Roboguide, we generated the code by clicking on the starting point, a middle point, and the ending point to select the path. It could take several attempts to get the desired result. The result should look similar to Fig. 3 shown below of the generated tool path.

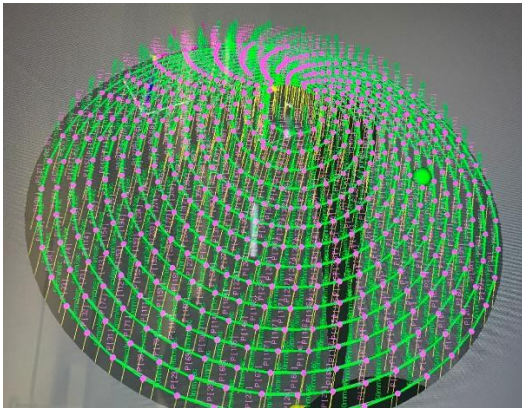


FIGURE 3: TOOL PATH GENERATED ON ROBOGUIDE

Once the user defines the edge process through Roboguide and has a similar setup to Fig. 3, the program is almost set to be transferred. The last step before transferring the code is to make sure any retreat or attract points are set up, and movement speeds, user frame, and tool data are defined. Once these parameters are set, within the “draw features on parts” popup, there is a button to generate the program to the teach pendant. This will transfer the data hit points that have just been created and send the program to the virtual teach pendant. The user can hit the “select” button on the virtual teach pendant within Roboguide and start the program simulation in an attempt to see if it works as desired.

6. RUNNING THE PROGRAM ON THE ROBOT

Once the program is created in Roboguide, it can be transferred to the robot controller (teach pendant) and be run in the real-life work cell. The program can be transferred through the internet or using a USB drive. It should be noted that a “TP” file (Teach Pendant file) is the only file format that Fanuc robots will accept, so the option of “save program as TP file” should be selected. After the file is saved onto a USB drive, the next step is to plug the USB into the Robot Teach Pendant and follow the below path:

Menu>File>F5(Utilities)>SetDevice>USB on TP.

Next:

Select Prev>TP(all TP programs)>F3(Load)>F4(Yes)

These steps will transfer the program onto the robot. To run the program, select FCTN>Abort(ALL), press Select>, and choose the desired program. While holding the deadman switch & Shift: press reset (to clear faults) and press FWD to run the program. It is recommended to run the program in teach mode and at reduced speed during the first cycle to prevent any damage to the robot in the case of a collision.

7. FORMING PROCESS

The generated program for the cone was run on the robot to deform 36”x36”x 0.019” aluminum 3003 flat sheets. The two forming parameter sets, as listed in Table 1, were used.

TESTING PARAMETERS							
SET #	WALL ANGLE (DEG)	STEP SIZE (MM)	TOOL DIAMETER (MM)	TOOL ROTATION	SPEED (MM/S)	LUBRICANT	MAXIMUM DEPTH (MM)
1	45	2	6	FIXED	125	LITHIUM GREASE	51
2	45	2	20	FIXED	125	LITHIUM GREASE	51

Table1: Forming parameters for two forming processes

The experimental setup, including the robot and the sheet holder frame, is shown in Fig.4. The forming area is covered by white lithium grease.

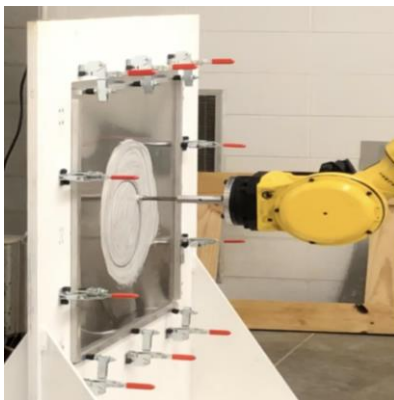


Figure 4: Experimental setup showing the Fanuc robot and the sheet holder frame.

With the set #1 parameters, The forming process was smooth until the forming forces increased enough to punch a hole in the aluminum sheet metal. It happened at the very final step of the program. Fig. 5 shows the formed cone.

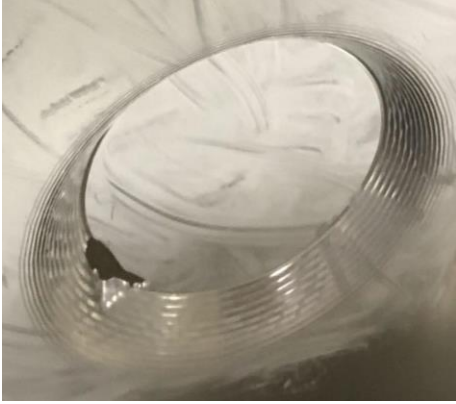


Figure 5: Conical shape produced using parameter set#1.

Using the set#2 parameters, a bigger tool, as listed on the second row of Table1, was used to decrease the localized forming forces on the aluminum sheet. Parameter set# 2 uses a tool diameter of 20 mm. Both tools are shown in Figure 6.



Figure 6: Side by side comparison of bigger tool (left) used in set #2 parameters versus smaller tool (right) used in set#1 parameters.

With the new tool, the code was run completely without any puncture in the sheet metal. Fig. 7 shows the formed cones using set#2 parameters.



Figure 7: Conical shape produced using parameter set#2.

8. SURFACE FINISH COMPARISON

A Mitutoyo Surftest SV-3000S4 surface tester was used to measure and compare the surface parameters of deformed sheets. Fig. 8 shows the surface profiles for both cones. Using the bigger tool improved the average surface roughness from 12.7 microns (for set#1 parameters) to 4.5 microns (for set#2 parameters).

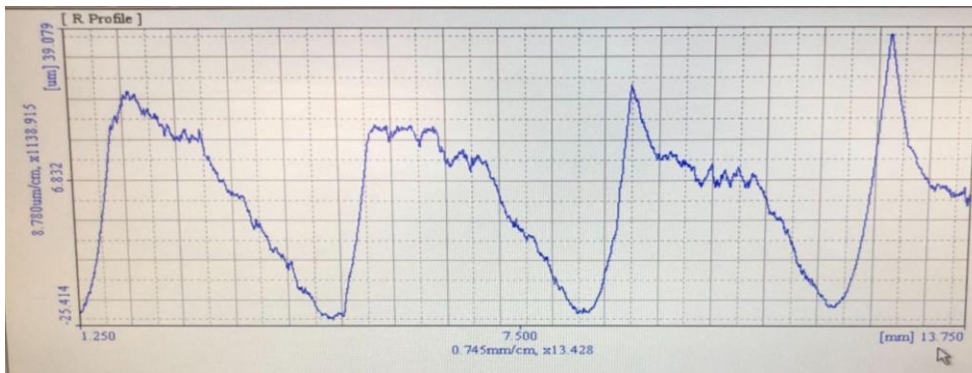


Figure 8. a : Surface roughness testing results for set #1 parameters.

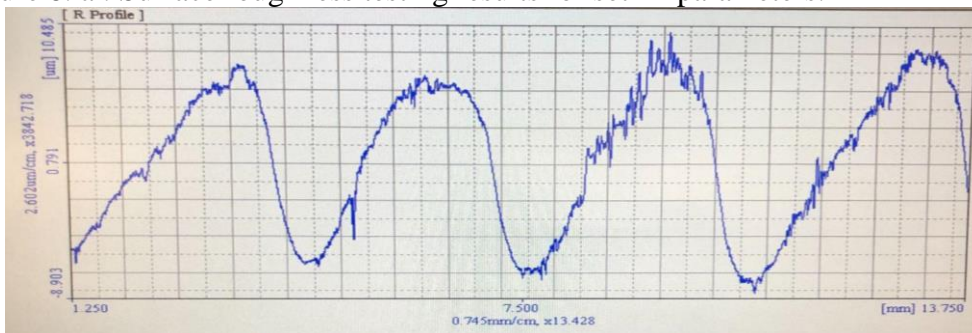


Figure 8. b: Surface roughness testing results for set #2 parameters.

9. GEOMETRICAL COMPARISON BY 3D SCANNING

To compare our formed model to our analytical model, a 3D scan was completed of each parameter set part and compared to the Solidworks model. The scans are shown in Fig. 9. Both scans showed an approximate depth of

23 mm. Due to the large size of the sheet holder frame, there were a large amount of springbacks on the flat part of the sheets. The springback can be compensated in the program or can be minimized by using a smaller frame size or supporting the back of the sheet metal by partial molds or another robot.

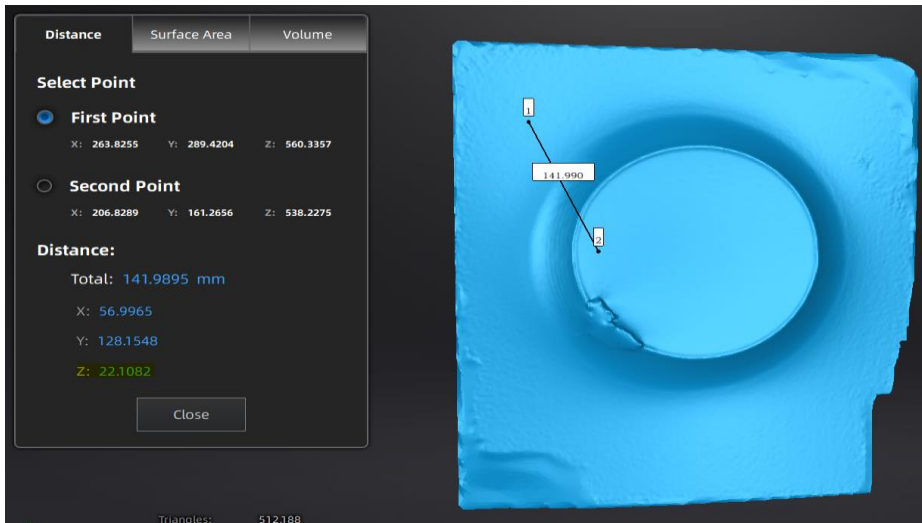


Figure 9.a : Depth value (Z) achieved (in mm) using set#1 parameters

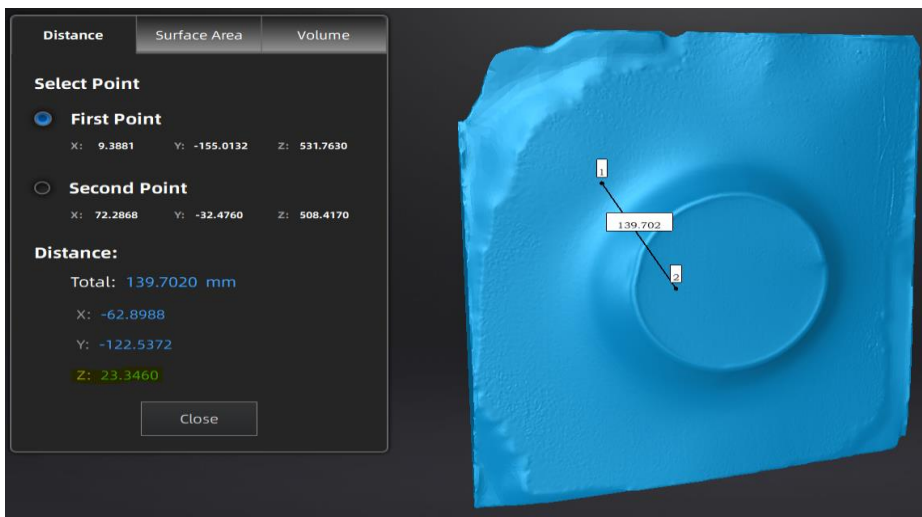


Figure 9.b: Depth value (Z) achieved (in mm) using set#2 parameters

10. FUTURE WORKS

Future projects will include altering more parameters and comparing the data to the literature. This will include altering the wall angle, step size, speed, and lubricant to achieve a better part and surface finish. Furthermore, the maximum depth will be altered to establish a forming limit on the Fanuc Robot and aluminum sheet.

11. CONCLUSION

This paper explains the offline programming of a Fanuc industrial robot for incremental sheet forming. The Fanuc proprietary software, Roboguide, doesn't include any specific module or add-on for ISF. According to our review, useful resources are lacking on this matter. The process explained in this research will serve as a

unique and valuable resource for future readers to program and use their Fanuc robots for ISF process. The generated program was run to form cone shapes on 3003 aluminum sheets. Two different tool diameters of 6 mm and 20 mm were used, and the formed cones were briefly compared using a surface tester and a 3D scanner.

REFERENCES

1. Kumar, A., et al., *Forming force in incremental sheet forming: a comparative analysis of the state of the art*. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2019. **41**(6): p. 1-45.
2. Trzepieciński, T., et al., *Emerging trends in single point incremental sheet forming of lightweight metals*. Metals, 2021. **11**(8): p. 1188.
3. Belchior, J., et al., *Offline compensation of the tool path deviations on robotic machining: Application to incremental sheet forming*. Robotics and Computer-Integrated Manufacturing, 2013. **29**(4): p. 58-69.
4. *FANUC Robotics SYSTEM R-30iA and R-30iB Controller KAREL Reference Manual*. Vol. MARRC75KR07091E Rev D. 2012: FANUC Robotics America Corporation.
5. Kumar, G. and K. Maji, *Investigations into Enhanced Formability of AA5083 Aluminum Alloy Sheet in Single-Point Incremental Forming*. Journal of Materials Engineering and Performance, 2021. **30**(2): p. 1289-1305.
6. Feng, J.-W., L.-H. Zhan, and Y.-G. Yang, *The establishment of surface roughness as failure criterion of Al-Li Alloy stretch-forming process*. Metals, 2016. **6**(1): p. 13.
7. Maqbool, F., *Targeted generation and suppression of the deformation mechanism and residual stresses in incremental sheet forming to improve the geometric accuracy*. 2021, BTU Cottbus-Senftenberg.
8. Hamilton, K. and J. Jeswiet, *Visual categorization and quantification of the orange peel effect in single point incremental forming at high forming speeds*. Proceedings of the Transactions of the North American Manufacturing Research Institution of SME, Kingston, ON, Canada, 2010: p. 26-28.