Robotic Polishing of Streamline Co-Extrusion Die: A Case Study

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Abstract

This paper presents a case study on the use robotic polishing used to polish co-extrusion dies using an active force control sensor. A system to test samples was setup using an ABB IRB 140 robot and an active force torque controller. A series of test samples was tested by the system using different force loads of 30N, 40N and 50N to determine the optimal force load required for the polishing process. Once the optimal force level and tool parameters were determined the polishing was carried out on the co-extrusion die. The results of the experimentation process are presented.

Keywords
Robotic Polishing, Force Torque Sensor, Co Extrusion Die

1. Introduction

Polishing is a material removal process normally carried out as the last step in the manufacturing process of a component. The process requires the use of an abrasive material which is rubbed against the surface to remove material and produce the required surface finish. Different size abrasive materials are used, normally starting with coarser material and finishing off with less coarse abrasive material. Assessing the quality of the finished surface can be accomplished using a surface analyzer. Traditional the polishing process is carried out by experienced operators relying on their experience. Obtaining the required surface finish is achieved by varying the amount of physical force applied during the process, using different tools and abrasive materials. The process is not only time consuming but physically demanding. This project was carried out as a feasibility study on behalf of Brampton Engineering, Ontario, Canada, to study the possibility of automating the polishing process of the extrusion die molds. The existing manual polishing process typically takes around 12 to 24 hours depending on the extrusion die mold complexity. To automate the polishing process using a robotic manipulator, will require controlling the contact force, the feed rate, the speed, programming the polishing tool path, and the polishing wheel speed. The paper presents the requirements for the robot hardware, robotic path planning techniques, the experimentation process and the results obtained for optimal extrusion die mold polishing.

2. Robot Polishing System

2.1 System Setup and Requirements

A key parameter in quality of final product and the performance of blown film multi-layer dies is the surface finish of the injection path. Accuracy and uniformity of the injection path surface finish plays an important role in film thickness, film flatness, molten resin resistance, prevention of premature degradation of thermally sensitive materials, and avoiding carbon build up.

Currently, due to complexity of injection path geometry which has a spiral form that has a sharp undercut and section profile, dies are manually polished at Brampton Engineering to ensure that the sharp undercuts are maintained, with an average process time of 12-24 hours per die. Polishing of dies is a labor intensive and inefficient process requiring many labor hours to get the desired surface finish results. Due to limitation of manual process, several tools are used by the operators to get the desired results including pneumatic power tools, buffing wheels and buffing compounds. The work environment in which the polishing process is carried out is hostile with noise and metal particle pollution, making it uncomfortable and stressful for the workers carrying out the polishing process. In order to make the process more efficient, Brampton engineering partnered with Sheridan College to investigate the feasibility of automating the polishing process.

The proposed project aims to enable Brampton Engineering to develop a new robotic cell to carry out the die polishing process to increase the efficiency of polishing process as well as to improve the product quality, and at the same time reduce the lead time for product delivery to customers.

2.2 The Robot Hardware

For this project a 6 axis ABB IRB140 robot is used. The robot has a payload capacity of 6kg. The end of arm tooling mount had to be custom designed and fabricated to hold the pneumatic polishing tool. The overall weight of the force torque sensor and tooling was under 3kg. The Fig.1, below shows the experimental setup.

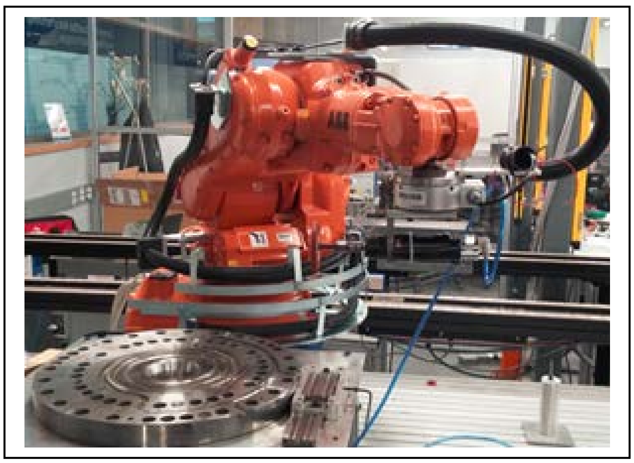


Figure 1. The robotic setup with force torque control

2.3 Force Torque Sensor

There are several force torque sensor systems available on the market. For this project the ABB Sensor 165 was used. The sensor 165 has a 165N force measuring capacity in axis X and Y, and 495N in axis z. The moment force capacity of 15Nm in axis X, Y and Z. The sensor 165 has features that make it ideal for robotic grinding, polishing, deburring, and also assembly tasks that require torque measurements such as piston and clutch assembly [1]. The force sensor also has the capability to determine the amount of tool wear and compensate for it within a given constraint. Limitations in the axial movement can also be specified which ensures that the robot does not compensate in the wrong direction. Integrating the force torque sensor to the robot manipulator controller allows the end effector to adapt its path, speed and also control the contact force between the tool and part surface. This ensures that the tool and part are not damaged and also ensuring a longer tool life.

2.4 Force Control

Most robotic applications do not require compliant devices when performing their operations. On the other hand, operations such as assembly and machining processes, require compliant devices to ensure accuracy of the process. Compliant devices can be either passive or active. Passive systems are usually open loop systems which do not provide any feedback to the system to make necessary adjustments to the process parameters. Simple passive systems are designed using pneumatic actuating devices, elastic elements such as springs or simple mass counter weights [2]. In a spring controlled system, the amount of contact force (F) is proportional to the spring constant (K) multiplied the deflection ($X-X_0$).

$$F = k.(X-X_0) \qquad (1)$$

In passive pneumatic actuating devices, the force (F) is proportional to the pressure (P) inside the cylinder multiplied by the piston area (A) [2].

$$F = P.\ A \qquad (2)$$

Simple mass counter weights systems rely on the weight and gravity to oppose the cutting forces [2]. On the other hand, active compliance devices provide the system with feedback that allows the system to adjust the output. The active force control systems can be controlled with either constant speed with controlled force which causes the robot path trajectory to be adapted according to the curvature of the surface. If the system is set to have variable speed with constant force, the trajectory path remains constant. Fig.2, shows the two possible scenarios possible with active force torque sensors.

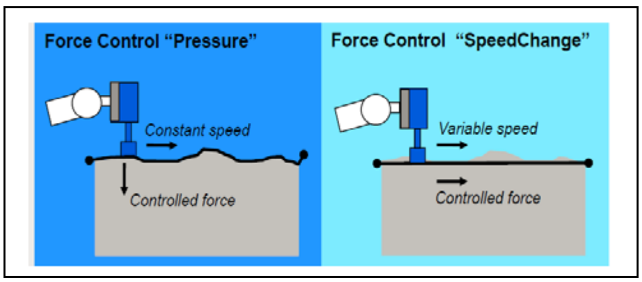


Figure 2. Active Force Control. [1]

2.5 Robotic Path Planning

The robotic path planning for the project could be accomplished by either on-line programming or off-line programming. ABB has developed a simplified HMI for the on-line programming when using the FT sensor. In the first method, the desired target points along the desired path are taught by using the teach pendent to jog the tool to the required targets or by simply moving the tool by hand along the desired trajectory which is also called the lead through programming. The Fig.3, shows the ABB HMI for the force control.

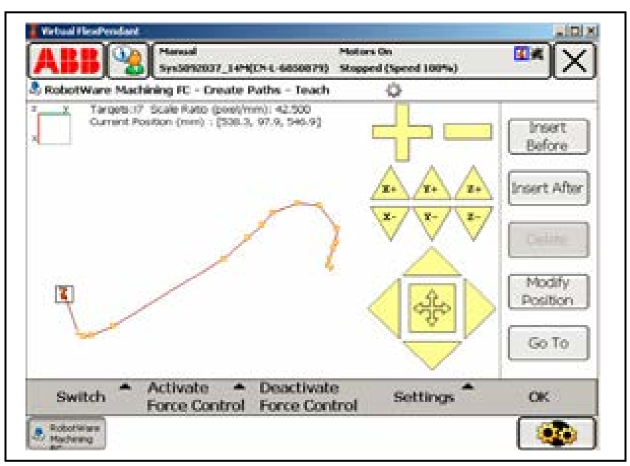


Figure 3. HMI for Online Programming [1].

Once the target points have been taught, the required force and speed that needs to be applied can be specified. In the offline programming method, offline simulation tools such as RobotMaster [3], Octopuz [4] or ABB Machining Pack [5] can be used. All three software packages work on a similar concept. In the first step the 3D CAD model of the component is designed. A CNC software package is then used to generate the G-codes along the required trajectory. The G-code is then entered into either of the above three software package. A post processor built into the software packages converts the G-code into the appropriate robot trajectory commands. The programmer can choose the appropriate robot model from a list of different robot manufacturers.

2.6 Sample Program

A sample of the Rapid program written for the ABB robot is shown below.

```
! Calibrate the force sensor
FCCalib t3_LD;
! Approach surface and start move to P20 at specified force
FCPress1LStart P20, v20, \Fx:= n1ForceX \Fy:= n1ForceY \Fz:= n1ForceZ, 10, z20, t3;
! Move Radially from P40 to P50 while maintaining force
FCPressC p40, p50, v20,20, z20, t3;
! Leave surface and move to P60, Force control
! is disabled after this instruction
FCPressEnd P60, v100,t3;
```

2.7 Polishing Tools and Compounds

In order to achieve the required polishing surface finish, the polishing wheels and polishing compounds as used in the manual polishing process were used. Different size polishing wheels made out of felt were used according to the path profile of the die mold. The polishing process is done using a twostep process. In the first run, felt wheels dressed using an adhesive material on to which abrasive grit material is dressed onto are used as shown in Fig.4, below. In our experimentation process a 240 grit abrasive was used similar to the specifications as used in the manual process. In the finishing step, a felt wheel coated with green bar polishing compound is used to complete the polishing buffing process

Figure 4. Undressed and Dressed Felt Wheels.

The Fig.5, chart below shows examples of buffing compounds used on different materials types. The green compound is used exclusively for polishing stainless steel materials as is the case of our co-extrusion die mold. The A in the chart refers to rough cut to remove scratches, the B refers to final cut and initial finish, while the C refers to the final finish.

	Plastics			Silver, gold & thin plates			Nickel and Chrome Plate			Copper, Brass, Aluminum, Pot Metal & Other Soft Metals			Steel and Iron			Stainless Steel		
Buff Type	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Sisal										X			X			X		
Spiral Sewn								X			X			X			X	
Loose												X			X			X
Canton Flannel						X			X									
String	X	X	X															
Compound	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Black										X			X			X		
Brown											X							
White								X				X		X				
Blue	X	X	X			X			X						X			
Green																	X	X
Red						X			X						X			

Figure 5. Chart of Materials and Buffing compounds [6].

2.8 Sample Test Pieces

As discussed earlier the manual polishing process requires the expertise of the polisher who constantly varies the pressure, examine the surface purely by sight and makes decisions as to whether more polishing is required or not while using different polishing grit paper and compound. Replicating the process done by the operator is difficult with a robotic system. In order to achieve the required surface roughness finish, a series of trial and error experiments had to be conducted on sample test pieces that had similar groove profiles as the actual die mold and also made of the same material. Each test sample material allowed 6 areas to be tested (4 channels and 2 flat areas) on. The dimensions of the test sample where 4” long by 2” wide and 0.5” thick. The test sample piece is shown below in Fig.6, below.

Figure 6. Sample Test Piece.

2.9 Pneumatic Polishing Tool

To carry out the polishing process an Atlas Copco G2440 low speed grinding pneumatic tool was used for the experiment as shown in Fig.8. The Atlas Copco G2440 tool is designed for polishing and grinding operations with a built in gear reduction mechanism and speed governor to help maintain the optimal power and grinding speed. The maximum speed rating of the tool is 4300 rpm. For our experiment purposes, the tool was set to a speed of 2990 rpm. The speed was measured using a digital laser tachometer. A special mount was fabricated to attach the pneumatic tool to the force torque sensor which is mounted on the ABB robot.

Figure 8. The Atlas Copco Pneumatic Polishing Tool.

3. Experimental Results

In order to determine the optimal force level that will be required for the polishing tool, three different force levels were tested on sample test pieces as described earlier. The force levels were set at 30N, 40N and 50N. The table and the graphs below show the results of the surface roughness obtained at the different force levels and the number of passes required to obtain the surface roughness. A total of three trials per force level were conducted. The surface roughness obtained in the manual polishing process was Ra 8 (µin) which was the bench mark used in this experiment. Any value less than Ra 8 (µin) would be more optimal for the plastic extrusion process. From the experimentation process, at 30N of force, Ra values of around 1.5 were obtained after about 8 passes during the polishing pass. At 40N, Ra values of less than 3 were obtained after only 3 passes, and at 50N, Ra values of 1.4 were obtained after 3 passes. Based on the experimental results, the total time to polish the die mold was determined. The total surface area that needs to be covered was $0.17m^2$. The surface area covered by the robot based on the set speed in 1second was $0.00064516m^2$. The time taken to cover one pass for the full surface was 263.50 seconds. Time taken to cover 20 passes which was determined to be the optimal number required to achieve the desired surface finish would be 5270.01 seconds or 87.83 minutes. The desired results required 20 rough passes and 20 finish passes, so the total time would be 175.66 minutes or 2.93 hours.

Table 1. 30N Force Setting with 240 Grit Polishing Material and Resulting Surface Roughness

DATA POINT A	FORCE CONTROL 30N	ACCESSORY TOOL- FELT WHEEL
EXPECTED RA 8 (µIN) OR LOWER	TIME TAKEN PER PASS – 3 SECONDS	METHOD – ROUGH POLISHING
SURFACE METERS COVERED PER PASS	TOOL SPEED – 2990 RPM	ABRASIVE MATERIAL – 240GRIT

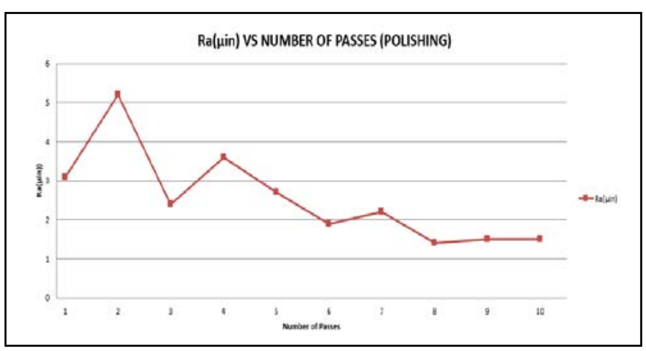


Table 2. 30N Force Setting with Green Bar Abrasive Polishing Material and Resulting Surface Roughness

DATA POINT A	FORCE CONTROL 30N	ACCESSORY TOOL- FELT WHEEL
EXPECTED RA 8 (µIN) OR LOWER	TIME TAKEN PER PASS – 3 SECONDS	METHOD – POLISHING
SURFACE METERS COVERED PER PASS	TOOL SPEED – 2990 RPM	ABRASIVE MATERIAL – GREEN BAR

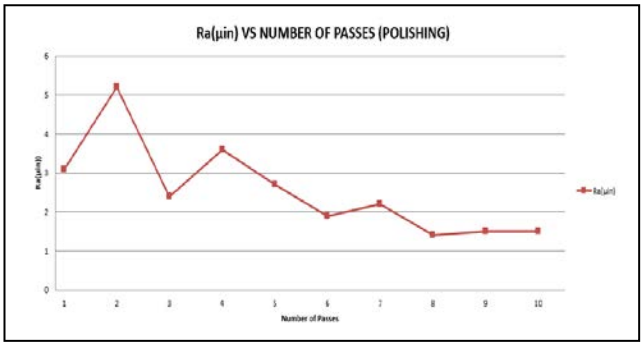


Table 3. 40N Force Setting with 240 Grit Polishing Material and Resulting Surface Roughness

DATA POINT A	FORCE CONTROL 40N	ACCESSORY TOOL- FELT WHEEL
EXPECTED RA 8 (µIN) OR LOWER	TIME TAKEN PER PASS – 3 SECONDS	METHOD – ROUGH POLISHING
SURFACE METERS COVERED PER PASS	TOOL SPEED – 2990 RPM	ABRASIVE MATERIAL – 240GRIT

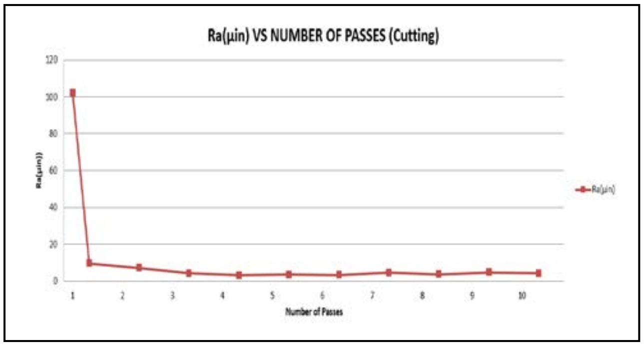


Table 4. 40N Force Setting with Green Bar Abrasive Polishing Material and Resulting Surface Roughness

DATA POINT A	FORCE CONTROL 40N	ACCESSORY TOOL- FELT WHEEL
EXPECTED RA 8 (μIN) OR LOWER	TIME TAKEN PER PASS – 3 SECONDS	METHOD – ROUGH POLISHING
SURFACE METERS COVERED PER PASS	TOOL SPEED – 2990 RPM	ABRASIVE MATERIAL – GREEN BAR

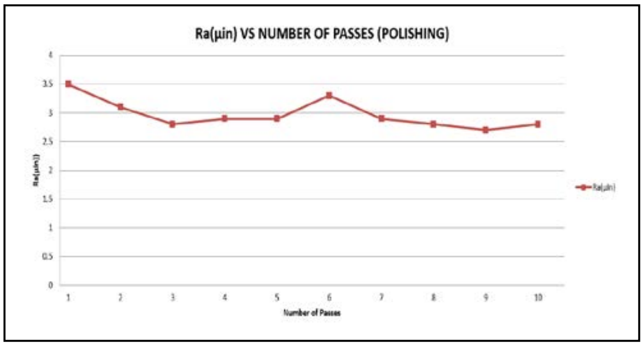


Table 5. 50N Force Setting with 240 Grit Polishing Material and Resulting Surface Roughness

DATA POINT A	FORCE CONTROL 50N	ACCESSORY TOOL- FELT WHEEL
EXPECTED RA 8 (μIN) OR LOWER	TIME TAKEN PER PASS – 3 SECONDS	METHOD – ROUGH POLISHING
SURFACE METERS COVERED PER PASS	TOOL SPEED – 2990 RPM	ABRASIVE MATERIAL – 240GRIT

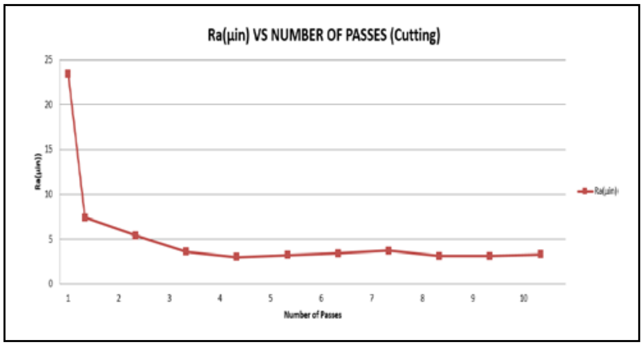
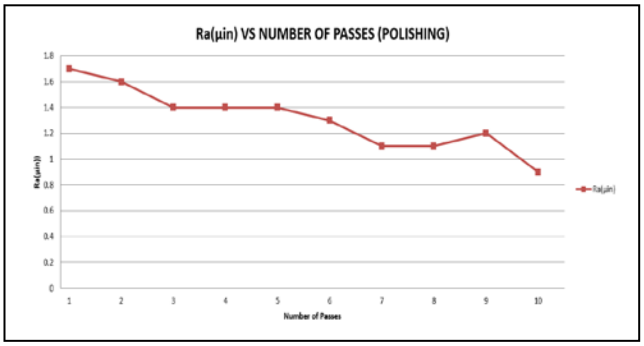


Table 6. 50N Force Setting with Green Bar Abrasive Polishing Material and Resulting Surface Roughness

DATA POINT A	FORCE CONTROL 50N	ACCESSORY TOOL- FELT WHEEL
EXPECTED RA 8 (μIN) OR LOWER	TIME TAKEN PER PASS – 3 SECONDS	METHOD – ROUGH POLISHING
SURFACE METERS COVERED PER PASS	TOOL SPEED – 2990 RPM	ABRASIVE MATERIAL – GREEN BAR



4. Conclusion

The use of industrial robots in the automated polishing process has been limited mainly due to the requirements of the surface finish and also the complexity of the surface being polished. With advances in force torque sensor technology and also programming techniques it is now possible to achieve improved performance results for the polishing process at the same time reducing the lead times. In this paper a six axis robotic system with a force torque sensor for high precision extrusion die molds has been shown to producing results better than the bench mark requirements as well as reducing the lead time considerably. However the research has shown that the polishing process of the co extrusion die could not be polished a 100%. Final finishing will still need to be completed by manual process.

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Biography

Dr.Srinivas Ganapathyraju is a Professor and program coordinator for the Electromechanical Engineering program at Sheridan Institute of Technology in Ontario, Canada. He has over 15 years of experience in industry and academia. He has worked as an automation design engineer in Singapore, designing pick and place manipulators used in integrated microchip testing and assembly. As an engineering intern at Jaguar Cars in Birmingham, England, he worked on an artificial neural network system to test for spot weld quality, which was part of his master's project work. He was also an industrial engineering intern at Helwig Carbon Products in Milwaukee, Wisconsin, USA. He was a teaching assistant at the University of Wisconsin – Milwaukee, prior to joining Sheridan

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