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Automated Finishing of Aluminum Castings: Approach for Reducing Programming and Setup Time

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ABSTRACT

With sufficient setup for integrating the robotic cell, casting cleaning can be performed with relatively simple tools in a timely fashion. Programming times see drastic decreases as familiarity and confidence in the cell layout are established. Further, commercially available tools can be integrated to help compensate for part and defect variation, speeding up machining time over simpler fixed path robot programs, requiring less time in troubleshooting.

Keywords: robotic cell, casting finishing, aluminum

INTRODUCTION

Finishing is a necessary step in producing any cast part. Material must be removed to extract the desired part geometry from the rigging (gates, risers, and other features) that is used to facilitate pouring when producing a quality casting. However, this task can be a particularly dirty, loud, and repetitive process making it one that is hard to recruit and retain workers. As a consequence, there is naturally a desire to automate some of the casting cleaning process to simultaneously deal with the shortage of workers willing to perform this task and provide a better environment for those already cleaning castings.

However, automation of the cleaning process presents its own set of challenges. Methods like traditional teach pendant robotic programming present a satisfactory method for programing a finishing operation; however, the teaching process can take a large amount of time particularly for complex part geometries. This time can be justified in the case of large part runs where programming costs can be recovered over the life of the casting run. However, with higher mix lower volume runs other methods are needed to reduce the programming and setup time to continue to justify robot use. This can be a particularly demanding challenge with castings where incoming part variation and quality can be irregular. Approaches using tools including offline programing with CAD models, and programming driven from sensor data have shown the potential to reduce programming time and improve robot accuracy. In particular, the increased use of sensors has great potential to reduce programming time as part complexity and variation increase.[1,2,3]

The University of Northern Iowa Metal Casting Center and Foundry 4.0 Center conducted experimental setups to demonstrate robotic casting cleaning operations that could be performed with simplified robotic setups. A set of three aluminum sample castings were selected to evaluate setup and programming methods and demonstrate the potential for flexible robot casting finishing.

Programming, setup and machining time would be key metrics to demonstrate if robotic finishing could be viable for more low-volume casting finishing applications.

EXPERIMENTAL METHODOLOGY

CELL PLANNING/SETUP

The physical cell was constructed around a former sand milling cell. The new casting finishing cell, utilized the existing robot mounted machining spindle with an associated tool rack and turntable. The Human Machine Interface (HMI) and robot were then upgraded by a local integrator to give more options in programming and part variety with the addition of a machine vision system. This cell then added a robot equipped with a pneumatic gripper for material handling. A force compliant dual head grinding wheel and abrasive grinding belt, and a legacy 15hp abrasive cut-off saw were placed in the operating range of the material handling robot for use on parts held by the robot. This system setup is shown in Fig. 1.

Figure 1. The casting finishing cell with material handling robot and related tools.

Parts were fitted onto the fixture plates to secure and repeatably locate castings for finishing. The fixturing setup, shown in Fig. 2, used fixturing rails to provide low profile and simple fixturing setups to ease programming and maximize robot access to the parts. The fixturing was located to allow access for the robot spindle while still allowing the part to be picked from at least one side.

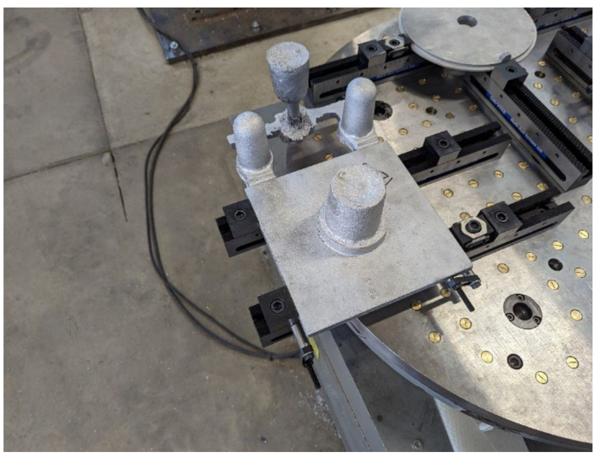

Figure 2. The modular fixturing setup.

The physical components of cell were then modeled in a 3D CAD environment. This model(Fig. 3) was used to facilitate robot programming with a separate offline programing software. Individual cell components were then located in the model by verifying locations with their associated robots. These machine locations were then further refined with operating points on the individual components, i.e. the edge of the cutting wheel or face of the belt, to provide accurate reference frames for programming.

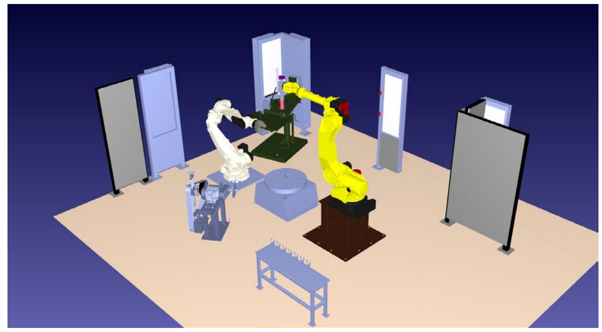

Figure 3. The digital cell model.

FINISHING PROCESS SELECTION & PARAMETERS

The general process for planning part operations was as follows. If the part was less than 10 kgs the part was processed using the material handling robot and associated cut-off and combo wheel machines. For parts capable of being processed by the material handling robot, operations were planned in the following order. First, an operation removed gates and risers with a cut-off wheel. Then an operation to grind down the gate remains used the grinding belt. For the compliant grinding process, a speed of 1150 rpm was used for an 80-grit belt on a 12” wheel to give a sufficiently smooth surface finish while maintaining a high material removal rate. This process continued with a step to grind the outside edge of the part using the grinding belt to remove remaining parting line edges. A regrip step was included to process the edge of the part first covered by the robot gripper during the initial grinding operations.

Material handling operations were then followed by final finishing operations using the robotic spindle while the part was secured in a fixture. This operation was used to clean internal features and finish the surfaces close to the final part geometry. For robotic spindle cutting, the feed rates had to be reduced from standard milling values. This was due to the lack of rigidity in the robotic spindle system relative to traditional CNC milling systems. To reduce the occurrence of chatter, poor cut surface quality and potential tool breakage, cutting rates were reduced. For the cast aluminum parts, the spindle speed for a 1 in. 4 flute end mill was selected at 2700 RPM with 10mm/s feed rate. Depth of cut was limited to 1mm per pass. This set of speeds was determined by experimentation to deliver an acceptable surface finish within the motor power capacity of the robot mounted spindle and avoid chatter.

An end mill was selected for this operation to simplify the robot programming process. As opposed to other methods like abrasives, if the spindle speed and feed rates were kept within a known working range, the final position of the cut surface could be known from tool geometry and robot position. This allowed for a number of passes to be easily calculated for any given new part with a range of potential part tolerances.

PROGRAMMING

The provided 3D CAD models of the three castings were brought in to the modeled 3D CAD cell. Additional versions of each part were then created to visualize rigging geometry present in the unfinished parts shown in Fig. 4. A key to quick locating in the cell was to strategically locate the part origin in the 3D CAD model. Origins were located on easy to orient locations on each part. These included circle centers or 90° corners which were easy to find with a vision camera or by manual teaching.

Figure 4. The three test castings.

Parts located in the cell were then targeted for picking with the material handling robot. The activation of robot tools such as grippers and machines were programmed in the offline programming software as digital inputs on the robot controllers. Each input was kept simple to avoid complicated chains of commands, and to make programming non-robot motion actions a single line of instruction.

Gate and riser removal were planned using the in-cell abrasive cut-off saw. The saw was fitted with an abrasive blade designed specifically for aluminum to avoid potential failures during the cutting process. The virtual model was then used to create cutting targets on the part gates. As can be seen in Fig. 5, a tolerance from the part surface was used to account for variable parting line width. The changing parting line can shift the part location in locating fixture. For riser removal, extra restrictions to cutting wheel access left the riser target at .75 in. from the part surface.

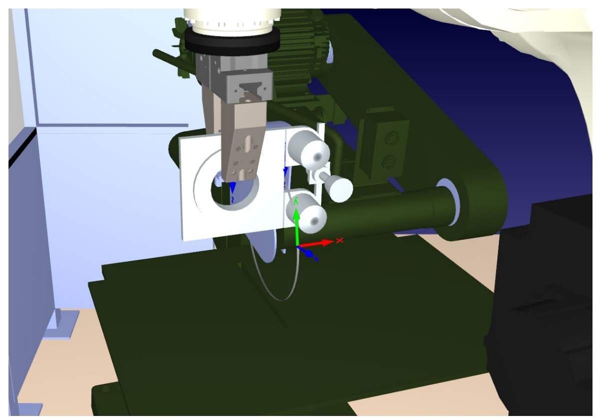

Figure 5. Offline programming of gate cutting.

For parting line and gate remains removal, the grinding belt was used with programming in a remote tool configuration. When programming for the grinding process a target against the wheel surface was used to avoid excessive grinding. The part was then run against the belt at an angle to avoid tearing the belt with any excess material on the parting line. This is shown in Fig. 6, and was done to allow the gripper to hold the part without slipping and angle the part against the wheel to allow grinding parallel to the part surface. Paths were then programmed using the curve follow tool in the offline programing software. This allowed for easy programming for grinding against the part edge at a steady feed rate without excessive force on the part or gripper. An added benefit was the ease of programming a consistent approach that avoided excessive grinding when starting each pass, regardless of edge geometry.

Figure 6. Parting line grinding is shown.

For the machining spindle robot programming, all machining actions were planned for 1mm (~.04in) passes at the 10mm/s travel speed as noted in the process selection section. Initial passes were programmed against the part with sequential passes being created by offsets 1mm away from the part surface moving in as part geometry demands. Part locations relative to the robot were obtained via taught part frame using an identifying feature on each casting.

For the three castings, the following operations were planned based on part geometry:

<u>Top Riser Casting</u>
Rough cut of gates and risers using abrasive wheel. Edge grind with abrasive belt to remove parting line and clean gate remains (including regrip to reach all edges). Machining of riser down to top boss surface. Machining of gate remains to part surface.

<u>Center Ring Casting</u>
Rough cut of gates using abrasive wheel. Edge grind with abrasive belt to remove parting line and clean gate remains (including regrip to reach all edges). Machining of gate remains to part surface. Machining of inner ring to remove parting line and edge flash.

<u>Slip Ring Casting</u>
Machining of inner ring to remove parting line and edge flash. Machining of outer ring edge parting line and gate remains.

RESULTS AND DISCUSSION

Following the robotic finishing of the three castings to an acceptable finish. A tally was made of the times taken for each phase of the robotic finishing and programming. They can be seen along with the final state of each casing in Fig. 7.

PROGRAMMING, TESTING, AND MACHINING TIMES

<u>Top Riser Casting</u>
Programming time: 6.5 hr.
Setup time: 0.85 hr.
Machining Time: 55 min.
Troubleshooting Time: 12 hrs.

<u>Center Ring Casting</u>
Programming time: 5.5 hr.
Setup time: 0.75 hr.
Machining Time: 11 min.
Troubleshooting Time: 4 hr.

<u>Slip Ring Casting:</u>
Programming time: 2.3 hr.
Setup time: 0.85 hrs.
Machining Time: 9 min.
Troubleshooting Time: 1 hr.

In this set of times, setup and programming time may be seen as the main targets. Machining time may be seen as an approximation of the amount of finishing work required for each casting. Some setup time is required regardless of how complex a finishing operation is required, but gains may still be noted in each casting.

It was notable in the first casting that machining time was significantly longer than the other two castings. This can mainly be attributed to riser removal and the limited cut clearance of the abrasive cut off wheel. This left a large amount of remaining material that had to be handled by the machining spindle. With its high accuracy, but slow material removal rate, the riser removal took a significant part of the total machining time. The limited material removal capacity of the machine tool, limited to 1mm per pass, also led to increased machining time when used for flash or gate remains. Due to variation in the parting line width on individual castings, gates were cut with a potential ¼" of remaining contact. The machining paths had to start out far from the part and were slowly moved closer to avoid excessive chatter and tool damage due to extreme depth of cut in the case of maximum material remaining on gate contacts. With this range of material, it can take as many as 7 passes before any material was removed.

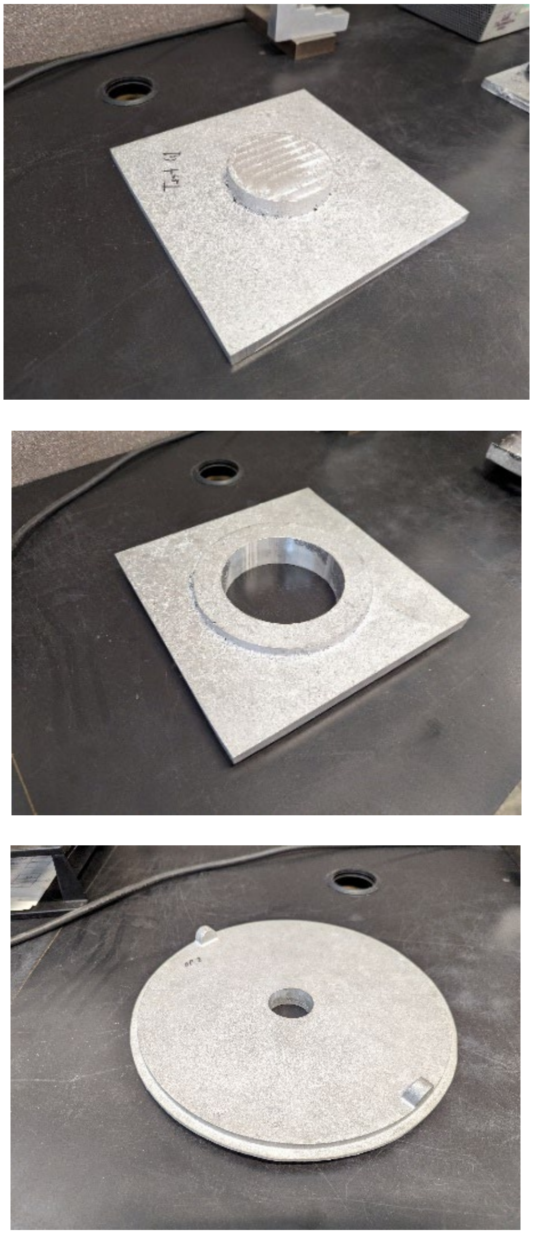

Figure 7. The three finished castings.

The other notable change was the reduction in programming and troubleshooting time as the planning and programming process became more familiar. Time savings came from increased material removal process knowledge as well as refinement of robot locations. This was further aided by increased programmer familiarity with the offline programming software as well as robot specific features being integrated into the offline programs.

CONCLUSIONS

The cell setup and programming methods used were effective at reducing programming and setup times as familiarity improved. However, there is still some room for improvement in the finishing tools utilized in this paper. Offline programing tools were helpful in dealing with a variety of castings and allowed for rapid program creation. However, to be efficient at quickly programming new parts for a robotic process, different approaches need to be taken for material removal over some that were selected for this work.

Offline programming software proved to be a useful tool in reducing setup and programming time with a variety of castings. Utilizing already existing 3D CAD models and offline programming software program were significantly easier to create over manually driving the robot to each work location. Of particular note is the use of remote tools and generating contour following programs such as the grinding operation on parting lines. The speed of programming and accuracy of these operations were greatly improved by offline programming.

Options exist to further reduce machining and programming time. With the significant machining time needed for extra material removal, a better rough cutting option will be necessary. This issue was also compounded by using an abrasive cutting wheel. The abrasive wheel made specifically for aluminum had a high rate of breakdown for each cut. This led to rapidly shrinking the cutting area and frequent blade changes in the cell. These issues made it a poor fit for an automated cell as the cutting motion targets needed to be frequently updated and the robot stopped often to replace blades. An alternative cutting method is advised and, in the future, the testing cell will utilize a band saw for these rough cuts.

There is also great potential to reduce programming and machining time by switching to abrasives for material removal over machine tools. In this case, the lack of rigidity in the robot arm led to significant tool chatter on cuts that were at any notable depth. With the 1” end mill, cuts had to be limited to 1 mm/ pass at 10 mm/s travel speed, which is drastically lower than what can be achieved with a traditional mill even at conservative cutting speeds. Robot-mounted abrasive pads or belts present the option for material removal with less concern for arm rigidity and chatter. Several commercially available options already exist for this process in robotic applications and could easily be applied to a high mix finishing cell. As long as dimensional accuracy can be maintained while removing significant amounts of material.

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REFERENCES

1. V. Villani, F. Pini, F. Leali, and C. Secchi, “Survey on human-robot collaboration in industrial settings: Safety, intuitive interfaces and applications,” *Mechatronics*, Article in Press (2018).
2. F. Pini and F. Leali, “Reconfigurable Robotic Solution for Effective Finishing of Complex Surfaces,” *AFS Transactions,* American Foundry Society (2022).
3. Pan, Zengxi; Polden, Joseph; Larkin, Nathan; van Duin, Stephen; and Norrish, John, "Recent progress on programming methods for industrial robots," *Faculty of Engineering and Information Sciences-Papers: Part A.* 29 (2012).