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Robotic Casting Finishing Cell with Thermal End Effector

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ABSTRACT

Torch cutting is a crucial process in the foundry industry that plays a vital role in shaping and preparing steel castings. Utilizing an oxy-fuel torch, this cutting method involves the controlled application of a high-temperature flame to oxidize and remove unwanted sections of metal from large castings. The process offers several advantages, such as its versatility in cutting various metal thicknesses, including thick sections, which makes it particularly well-suited for the foundry environment. However, the current method of torch cutting is a dangerous task. Currently, the operator takes an oxy-fuel torch, lights it manually with a flint striker and moves the torch by hand. This leaves the operator vulnerable to molten metal splashing, sparks and dealing with a flame that can exceed 3000C (5432F). Safety precautions are of paramount importance due to the intense heat involved, and proper training and protective gear are necessary to ensure the well-being of workers and the successful execution of torch cutting. The University of Northern Iowa (UNI) Foundry 4.0 Center has developed an automated process for torch cutting that can take these workers out of harm's way.

Keywords: torch cutting, automation, robotics, metal casting, thermal end effector

INTRODUCTION

There are several critical considerations when developing a cell for robotic torch cutting. First, the size of the castings to be used determines the size of the cell and the reach of the robot. The working portion of the UNI Foundry 4.0 Center's cell measures an area of roughly 11'5" x 17'4" (Fig. 1). Fuel and oxygen storage and safety considerations stretched out the footprint of the overall system as they required 20' of separation or a 2-hour fire wall between oxygen and fuel. The Kawasaki BX200L industrial robot in the cell has a reach of 8.52 feet. The base of the robot and the center of the table are 6' apart which leaves plenty of room for maneuvering the robot. This cell is developed for castings under 1000 pounds but can fit larger castings with the proper lifting equipment. For extra-large castings the table can be removed and the casting can be set directly in the sand pit. The robot is also fitted with a thermal suit to protect against splatter and residual heat in the cell during operation. The robot is fitted atop a cast pedestal for anchoring purposes as well as offering more flexibility for moving the robot.

Figure 1. Finished interior of the cell with all working equipment.

CELL CONSTRUCTION

The containment cell (Fig. 2) is designed around ease of construction and to provide a combination of safety and visibility.[1] Steel tubing with steel plates makes up the posts which are anchored into the concrete. Between each post is a 1/8" thick steel sheet that are 48" x 48" in size. Above that is a 72" x 48" piece of plexiglass. Plexiglass improved visibility into the cell and facilitated demonstration of the cell.

Two swing doors (Fig. 3) are attached on the front for loading and acting as the safety fence for the cell by being equipped with a sensor that closes off gases to the torch if they were to be opened during operation.


Figure 2. Construction of the cell walls and placement of the working pedestal.


Figure 3. Enclosure doors closed and safety triggers engaged.

The work table (Fig. 4) is designed to accommodate a large variety of castings, different rigging options and ease of repair. Slats allow splatter to fall into the sand pit below the table. If any of the slats are damaged during operation, they can be removed and replaced.


Figure 4. Slatted work table for casting placement.

Determining which fuel to use is another critical component of the set up. There are two main components to torch cutting, oxygen and fuel. Fuel is split into 2 categories, acetylene and other gases which include: propane, propylene, MAPP and natural gas.

Acetylene has several conditions that necessitate its own category. Fuel lines, piping, type of torch and type of torch nozzle are all chosen with special considerations in mind to deal with acetylene styled cutting. Acetylene tends to be much more expensive than other fuels and is also less stable. However, acetylenes' primary flame tends to be much hotter than the other fuels and the flame also requires less oxygen to maintain a cutting flame. With that being said, the propylene fueled torch has no issues cutting through steel castings. At the time of purchase, propylene was almost ten times less expensive than acetylene. However, safety concerns made the final decision when choosing gases. Acetylene can become explosive if the gas pressure exceeds 15 psi.

There is also a general rule regarding the flow rate of gas being used referred to as the 1/10th rule.[2] For example, when using a 75 cubic foot cylinder, one cannot use a nozzle that consumes more than 7.5 cubic feet of fuel per hour. Propylene does not have these safety concerns.

There is an assortment of torches that can be used to attach to the robot. Track torches are designed to be attached to a rail or track system which allows it to be easily rigged for attaching to a robot (Fig. 5). Determining nozzles type is also important as using an oversized nozzle for a small part will waste fuel. Nozzles used in this cell are currently 4," 8" and 18" maximum cutting depth (Fig. 6). Each nozzle has specific fuel settings required for use and must be calibrated and tested before use for proper cutting.

Figure 5. The machine cutting torch used for the cell.

Figure 6. A variety of cutting tips (4", 8", 18" respectively).

The manifold (Fig. 7) is the main controller of all fuels. There are two inlets in the manifold, one for oxygen (Fig. 7-A) and one for propylene (Fig. 7-B). The oxygen is supplied to the manifold via another manifold (Fig. 8). The oxygen manifold allows for multiple oxygen cylinders to be set up simultaneously.

The oxygen splits into 2 feed lines in the full manifold, one for preheating oxygen (Fig. 7-C) and one for cutting oxygen (Fig. 7-D). The outlets each have a solenoid (Fig. 7-C, D and E) that can be controlled by an electrical output by the robot controller to open and close.

These lines lead into the torch attached to the robot. All gas and oxygen valves stay open on the torch and only receive the gases when triggered by the robot controller by opening the solenoids. Figure 7-F shows the control box which acts as an intermediary between the solenoids, the alarm lights and the robot cabinet.

Figure 7. The oxygen and fuel manifold delivery system.

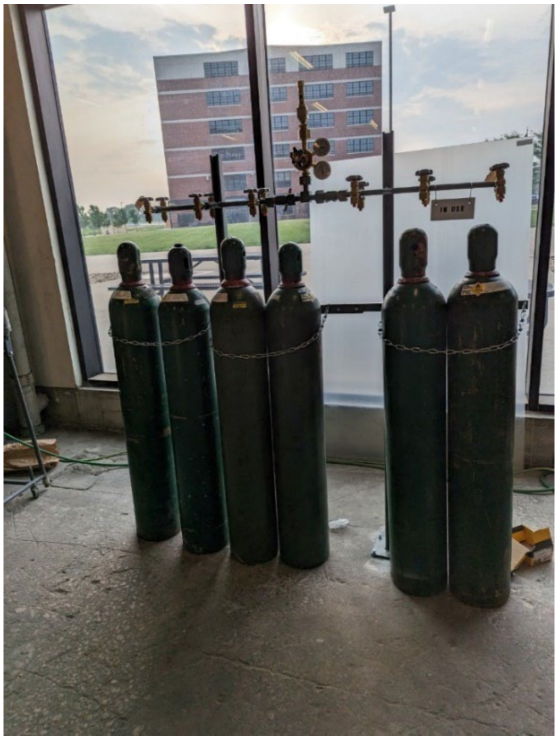

Figure 8. Oxygen delivery manifold leading into full gas manifold.

The last major component of the cell is the igniter station (Fig. 9). This igniter's design incorporates a switch that can be installed directly into the robot controller. A spark plug is triggered by the robot controller during a robot program which ignites the fuel.

The procedure for igniting is a consistent, repeated process (Fig. 10). The robot moves to the igniter station (Step 1) then moves close to the actual lighter. When it is close enough the robot program sends a signal controller to open the propylene solenoid on the manifold (Fig. 7-E). Almost immediately afterwards the program sends another signal to the controller to spark the igniter station which in turn lights the fuel (Step 2). At this point, the robot moves near the part and stalls for a few seconds (Step 3). During this time the preheat oxygen solenoid opens and the operator needs to introduce the oxygen up to operating pressure over a period of a few seconds. If the oxygen is at operating pressure when the solenoid is opened the flame is immediately extinguished.

Figure 9. Igniter station for torch lighting.

After reaching preheat oxygen pressure, the torch is moved towards the casting where is dwells a few seconds (Step 4). This time will vary dependent on the casting thickness and the tip currently attached to the torch. In this case, the torch needs to dwell for approximately 10 seconds at which point the cutting oxygen is turned on (Step 5). The robot continues to the move torch along the programmed path until finished. When it finishes its path, it will cut the oxygen and fuel to the torch and return to home position (Step 6). The casting shown in Fig. 10 took 1 minute and 19 seconds from start to finish for a single cut.

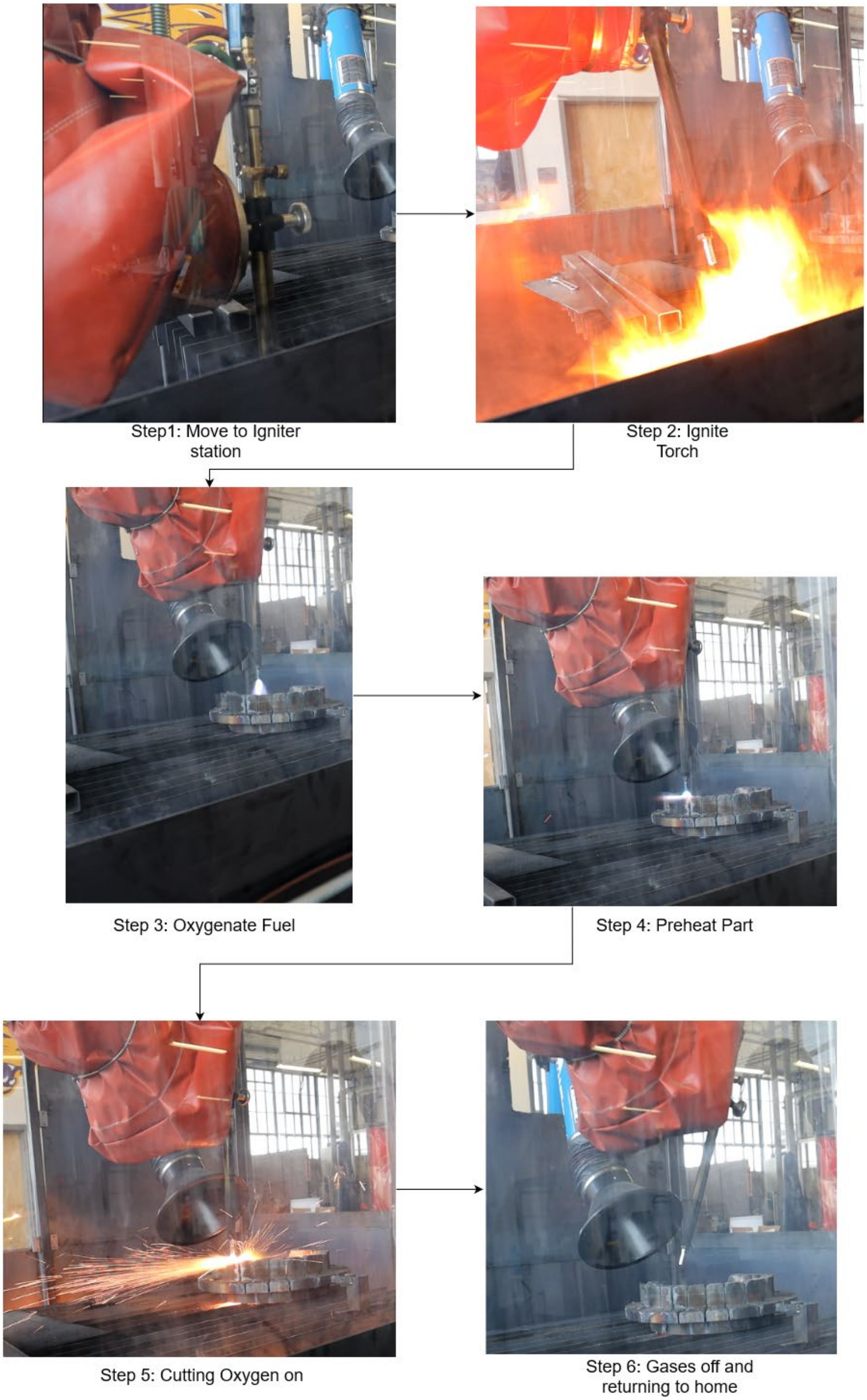

Figure 10. Six step robotic procedure for lighting and cutting.

OFFLINE PROGRAMMING

Currently, two different methods for programming are employed. Through teach pendant and offline programming via RoboDK. This software allows for the creation of a digital environment importing standard 3D models. With this digital environment a system of reference points and targets can be used to generate robot paths and commands without the use of a teach pendant. There are several programs on the controller that can be used as functions as well. A function is a program that is designed for executing multiple actions that several or all programs use. For example, the torch lighting procedure is a function that can be called in both teach pendant programming and offline programming and that section of any program will be identical. Another example is the closed solenoid function. This function is occasionally run after a cutting cycle to ensure all the gases to the torch have been fully shut off and the solenoids are closed. These functions can be made via teach pendant or offline programming. Figure 11 shows a setup for offline programming. Call ignition, shown in Fig. 11, is the function on the robot that runs a pre-determined set of moves and triggers that light the torch.

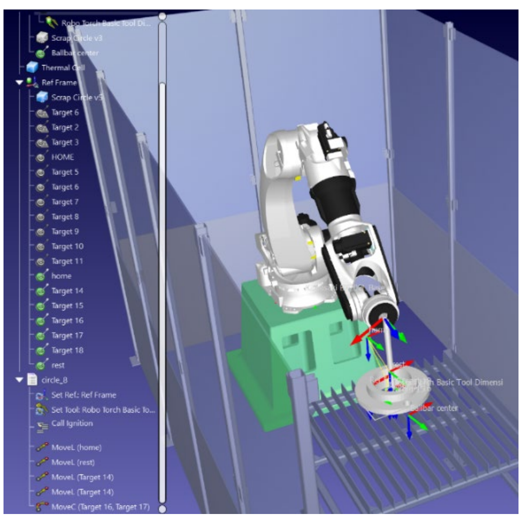

Figure 11. Virtual environment for thermal cell.

The next step for offline programming is too generate multiple models of the casting for use in the programming environment. For simpler castings, a fully rigged model and a fully finished model (Figs. 12 & 13) are all that is required. The fully cut and finished model helps with developing tool paths with some of the integrated tools of the software that for instance let you set up targets along the finished part lines. Meanwhile, the fully rigged models allow for the software and the user to detect collisions that may occur during robotic movement. For more complex geometries that may require many cutting paths and part orientations, it may be necessary to have several stages of the model at different orientations. If there is fixturing associated with the part it is also beneficial to model those fixtures for collision detection and for part locating.

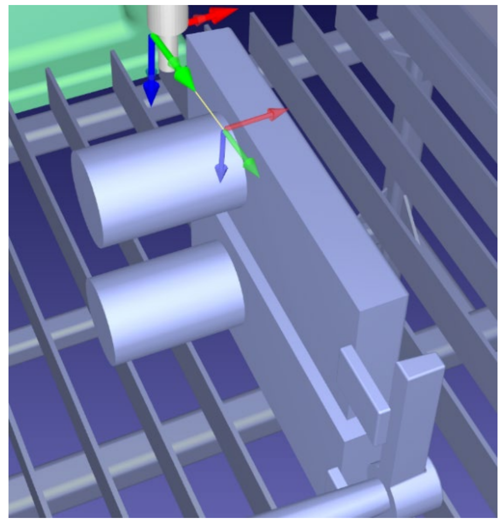

Figure 12. Fully rigged casting model for rigging removal.

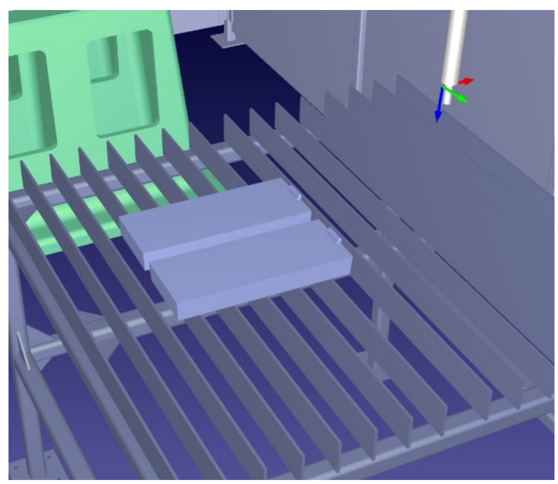

Figure 13. Finished model with rigging removed.

After all models are generated for the program they need to be located in both the digitized cell and in the physical cell. The digital parts alignment and location needs to be as close to the real world as possible. However, reference points can be located in an offline programming environment and later located by the operator via controller to align the digital cell to the real cell. Thus, eliminating the need for them to be perfectly aligned in both environments.

The torch lighting function mentioned earlier finishes in a start location on the edge of the table. This is generally where the fuel is oxygenated but it can be done near the casting as well. For large castings this location may need to be moved to avoid preheating the casting prematurely. After the fuel has been oxygenated the robot will move to the casting to be preheated. The amount of preheat time is going to vary on a variety of factors that including: thickness of the casting, torch tip used and fuel type. For the casting shown in Fig. 14, the first 4" riser to be cut is preheated for approximately 10 seconds in a semi-circular motion using an 8" maximum cutting depth torch tip. Afterwards, the program calls for the cutting oxygen to turn on and cut a straight line across the riser. For this size riser, roughly a 20 mm/s cutting speed is used but will vary depending on casting thickness.[3] Once the first riser is cut (Fig. 14), the cutting oxygen is turned off through the program then moves to the next riser where this process is repeated again.

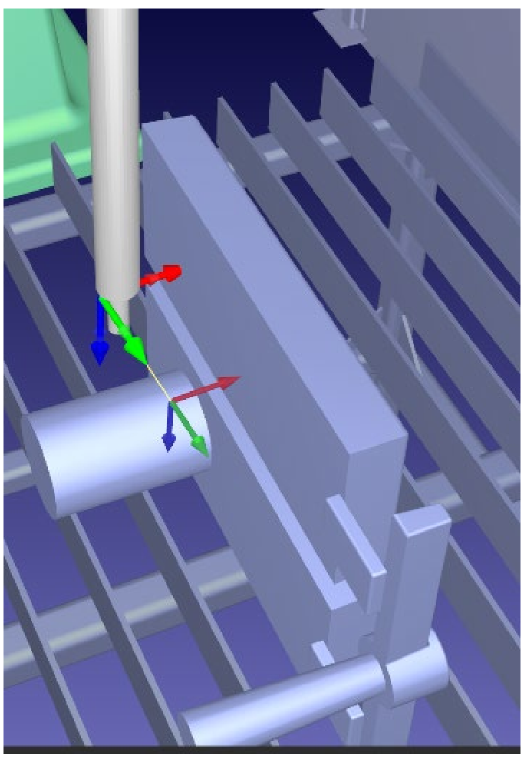

Figure 14. Casting with first riser removed for second cutting operation.

With both risers removed the fuel is turned off and the casting is reoriented (Fig. 15) so that when the first gate is removed the first plate does not drop to the floor. The same steps are repeated as before with just some slight changes to dwell times and cutting speeds as the thicknesses at these locations are significantly different. Preheating each gate for approximately 6 seconds with this tip size and a cutting speed of 25 mm/s is adequate.

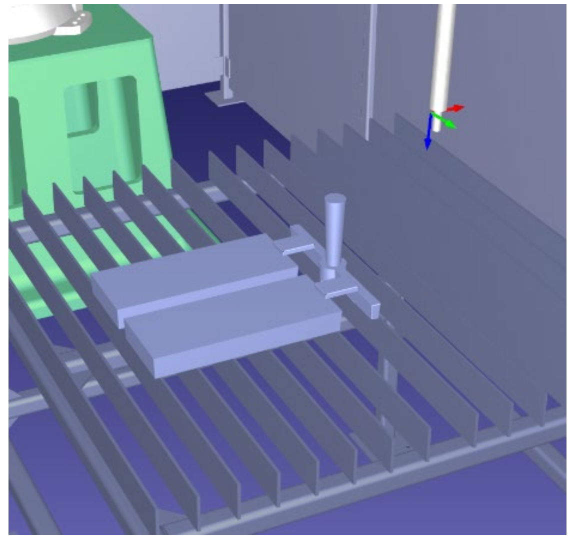

Figure 15. Risers removed and part reoriented for gating removal.

CONCLUSIONS

Torch cutting stands as a critical process within the foundry industry, offering invaluable contributions to the shaping and preparation of steel castings. Through the controlled application of a high-temperature oxy-fuel flame, it efficiently removes unwanted sections of metal, demonstrating its versatility across various metal thicknesses, including thicker sections. Nevertheless, the current method of torch cutting carries inherent dangers. By use of robotics and automation the risks involved with torch cutting can be greatly reduced. Also, repeatability and speed to efficiency can be increased across casting.

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