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Making Prototypes

Many people in the field of engineering are required to create prototypes every day. These prototypes are a crucial portion of any production company, and are an important step in beginning the production process. In the following process, the basics of creating a prototype will be illustrated through the creation of an aluminum metal die. This process is useful for machinists in the field of engineering who commonly use their skills of machining to create prototypes

Step 1 - Understanding Key Terms

It is important to understand the materials and tools involved in the process of machining before beginning. In order to prevent confusion and injury, one must properly learn all about the equipment involved in the process of machining. The first important tool that will be used in the following steps is a horizontal bandsaw. As it may sound, this machine clamps onto the workpiece and cuts it perpendicular to the surface it is lying on. Another key tool involved in the process is a knee-milling machine, which is a very complicated machine used for shaping the prospect piece of metal into the final product. A mill spins a bit, a tool used for drilling or boring, in order to shave away at the

metal, requiring many passes on the mill. Lastly, keep in mind that a “die” is the singular of dice.

Step 2 - Gathering Materials

In order to effectively machine a piece of metal into a final prototype, one must be properly supplied with the needed materials. These materials include an aluminum metal bar, many milling bits for shaping the metal, and the needed heavy machinery for machining. The aluminum metal is called “multipurpose 6061 rectangular aluminum bar” and is sold by McMaster-Carr for \$4.71 for 1 foot of a 3/4 inch square bar (“Multipurpose”). This bar of metal will be perfect for creating the perspective dice, because this metal is very workable and light. Additionally, it already has the wanted height and width dimensions, only requiring it to be cut to length. The next object required in this process is a horizontal bandsaw. This will be used to cut the previously mentioned piece of aluminum bar to the desired length. A Vectrax horizontal bandsaw can be purchased from MSC Direct for \$1,599 (“Vectrax”). The only other piece of machinery required in this process is a knee-milling machine, used for carving the metal workpiece into the final product. Picture a mill as a humongous drill that is fixated above the workpiece for extremely precise cutting and crafting of metal. A Bridgeport knee-milling machine can be purchased from MSC Direct for \$16,499 (“Bridgeport”). Along with the mill, many smaller bits are needed to work with the mill and do the actual cutting of the metal. This process requires 3 different types of end mill bits, each serving a particular purpose in the process. A 7/8 inch square-edged end mill will be used for

cutting away at a flat surface of metal to shave it down to the desired size. This bit is called a “steel two-flute end mill” and will cost \$35.64 from McMaster-Carr (“TiN”). Additionally, a 1/8 inch ball-end mill, used for drilling rounded holes into a piece will be used for all of the holes in the die. This bit is called a “ball-end steel two-flute end mill” and will cost \$20.09 from McMaster-Carr (“Ball-end”). Finally, a 1/16 inch radius cutting end mill will be used for creating the rounded edges that will produce a smooth, refined-feeling product. This bit is called a “corner-rounding steel two-flute end mill” and will cost \$44.67 from McMaster-Carr (“Corner-rounding”). After acquiring all of the aforementioned materials and equipment, the process can now be carried out.

Step 3 - Cutting the Bar

The first step in the process of fabricating a die involves using a horizontal end mill to cut the aluminum bar of metal into a workpiece just a little bigger than the final product will be. The purpose of this is so that we can use the mill to take off a few layers of metal before we get our desired dimensions, allowing for a smooth finish. We cannot cut the piece perfectly using the horizontal bandsaw (Appendix 2) because it does not make the fine, even cuts needed for creating a nice, smooth final product, and therefore resulting in the need for the mill (Appendix 1). To begin, mark off a spot on the bar that is 7/8 inches away from the end. Then, place the metal bar in the vice of the bandsaw, looking down at the blade and lining it up with the line marked. Tighten the bar in this position, making sure that it is flat on the bottom of the vice. Before starting the bandsaw, it is recommended to squirt a line of oil on the marked line, where the

bandsaw will be cutting (“Horizontal”). Turn the bandsaw on and allow it to begin descending to the piece. Using a pair of heavy gloves, preferably heat resistant, hold onto the piece that is being cut off in order to prevent it from falling on the floor when it is cut off. This will prevent the piece from any unnecessary dents or dings, that could reduce the quality of the final product. The piece is now ready to be milled.

Step 4 - Milling Down to Size

Next, the mill will be used to refine the edge that has just been coarsely cut by the bandsaw. Place the workpiece flat in the vice (Appendix 3) of the milling machine, with the recently cut side facing up. Using a wrench, loosen the mill with a 3/4 inch wrench and slide a steel end mill bit (Appendix 3) into the collet, the piece that holds the bits in the mill. While sliding the end mill into the collet, tighten the mill until the bit is secure and has no free play. Center the bit above the piece using best judgement, then lower the end mill to the top of the workpiece and rest it on top. Using the digital readout on the z-axis, which is perpendicular to x and y axes of the mill (Appendix 1), set the readout equal to zero where it is. Move the bit to the side of the workpiece, assuring that it seems to be centered and will touch the entire side facing up if it were slid on top of it. Then, using the vertical digital readout on the mill, lower the end mill 1/16 of an inch. Turn the mill on, and slowly slide the mill across the top of the workpiece. This will shave a layer of metal off of the top. Be sure to use oil on the surface that is being milled, it is recommended (“Using”). After making one pass on the mill, repeat the process of shaving off another 1/16 inch of metal, but this time from the other side.

These two passes of the mill have reduced the workpiece down to a 3/4 inch cube that is now the proper size for creating the die made in the process. Now, the die is ready for the holes that make it into a die.

Step 5 - Measuring Holes

Now that the workpiece is the appropriate size for a die, it needs the holes that give a die its purpose. Before we can drill the holes, analyze an existing plastic die, and take note of the positions of the holes (Appendix 4). Then, calculate the distances at which the holes will be located on the workpiece. The location of the holes on the die is as follows: the “1” numbered side will have a hole located exactly at the center of the die, the “2” numbered side will have holes located at opposite corners, the “3” numbered side will have a hole located at the center with two holes at opposite corners, the “4” numbered side will have holes located at all four corners, the “5” numbered side will have holes located at all four corners and a hole in the center, and the “6” numbered side will have holes located at all four corners and holes between them on opposing sides (Appendix 4). Center holes will be 3/8 inches away from all sides. Outer corner holes will be drilled an 1/8 inch in from both sides closest to them. Outer side holes will be drilled 3/8 inches from one side and an 1/8 inch away from their respective sides. Knowing that the outside is 3/8 inches away from the center, we can subtract 1/8 inch, the distance from the outside to the center of the outer holes, to get 1/4 inch. This is the distance of all outer holes from the center in the x-axis and/or y-axis directions. Holes will be located at coordinates with the center of the die acting as the origin. Hole

coordinates are as following: the center hole will be located at (0,0); the outer corner holes will be located at (0.25,0.25), (0.25,-0.25), (-0.25,-0.25),and (-0.25,0.25); and the outer side holes will be located at (0.25,0) and (-0.25,0). This can be confusing to understand in sentences; see the provided pictures (Appendix 4) to clarify the location of the die's holes. The holes are now properly measured and can be cut into the die.

Step 6 - Centering the Mill

Before the holes can be drilled into each side, the mill needs to be “centered” over the piece each time, to ensure that the measurements that have been acquired can be properly applied to the workpiece. The “center” refers to the exact middle of the piece, which will be shown as the coordinates (0,0) after “centering” the mill. In order to “center” the mill, first the ball end mill that will be used to drill out the holes must be tightened into the mill. Using a wrench, loosen the mill with a 3/4 inch wrench and slide a steel ball end mill bit into the collet. While sliding the end mill into the collet, tighten the mill until the bit is secure and has no free play. Then, place the workpiece flat into the vice with any side facing up. Move the ball end mill (Appendix 3) to the right of the piece and lower the bit so that it is below the level of the workpiece. Turn the mill on, and slowly approach the piece, until a faint whirring can be heard. This faint whirring is the bit barely touching the workpiece. Then, keeping the mill where it is, press the button the digital readout to enter a measurement into the x-axis readout (Appendix 1). Enter 0.4375, the decimal form of 7/16 inches. This length is the distance from the the center of the workpiece to the center of the ball end mill. The ball end mill has a radius of 1/16

inches and the workpiece has a length of $\frac{3}{4}$ inches, half of which is $\frac{3}{8}$ inches. Adding the two together gives a distance of $\frac{7}{16}$ inches. The mill has been properly centered in the x-axis dimension, and now must be centered in the y-axis dimension (Appendix 1).

To do this, repeat the same steps used for centering the bit above the x-axis, but instead, replace the right side with the top side of the die and the left side with the bottom side. After both sides have been centered, the mill is properly set up for the drilling of the holes. The entire process described in this step must be repeated each time a new side of the die is to be drilled, for a total of 6 times.

Step 7 - Drilling Holes

Now it is time to drill in the holes that have been measured in a previous step. First, begin with the side that will have only one hole. After, “centering” the mill, as directed in step 6, move the bit in the mill until the digital readout produces the coordinates (0,0). Then, tighten the levers on the mill that lock the x and y axes on the mill. This will prevent the bit from wandering during drilling. Finally, turn on the mill and begin lowering the drill bit to the workpiece. Right as the bit makes its first contact, zero the z-axis digital readout, and proceed to drill 0.025 inches into the workpiece. Use oil while drilling to prevent excessive heat, as well as produce a better cut. This process of moving the drill to the correct coordinates, locking the x and y axes, zeroing the z-axis, then drilling 0.025 inches down will be repeated 20 times, accounting for the rest of the holes in the die. Using the steps for “centering” the mill in step 6 and the coordinates mentioned in step 5, repeat this step to drill holes into the remaining sides.

Step 8 - Refining Corners

The final step in this process is to round-off the corners on the workpiece, in order to create a smooth, professional product. Using a wrench, loosen the mill with a 3/4 inch wrench and slide a 1/16 inch radius cutting end mill bit (Appendix 3) into the collet. While sliding the end mill into the collet, tighten the mill until the bit is secure and has no free play. Then, place the workpiece flat into the vice with any side facing up. Turn the mill on and approach the piece with the vertical part of the radius cutter until a faint whirring sound can be heard, and zero the x-axis digital readout (Appendix 1). Then repeat this by approaching the piece with the horizontal part of the radius cutter until, again, a faint whirring can be heard, this time zeroing the z-axis on the digital readout. Now, move the radius cutter to the zeroed position anywhere along the edge ("Tips"). Move the radius cutter 0.003 inches into the piece in both the x and z axes and then lock the x and z axes. Finally, make 2 to 3 passes of the radius cutter on the edge of the die, until the edge has a smooth, rounded edge. Repeat the beginning of this step for the remaining 13 sides, until the die is completely smooth, with no rough edges.

Following the steps of this process has produced a fully functioning die. This process illustrates the basics of designing and fabricating a prototype. Prototyping is an extremely important process in any manufacturing company, and is required before a company can begin mass producing a product. Without the process of prototyping, engineers could not transform their designs into reality.

Appendix A



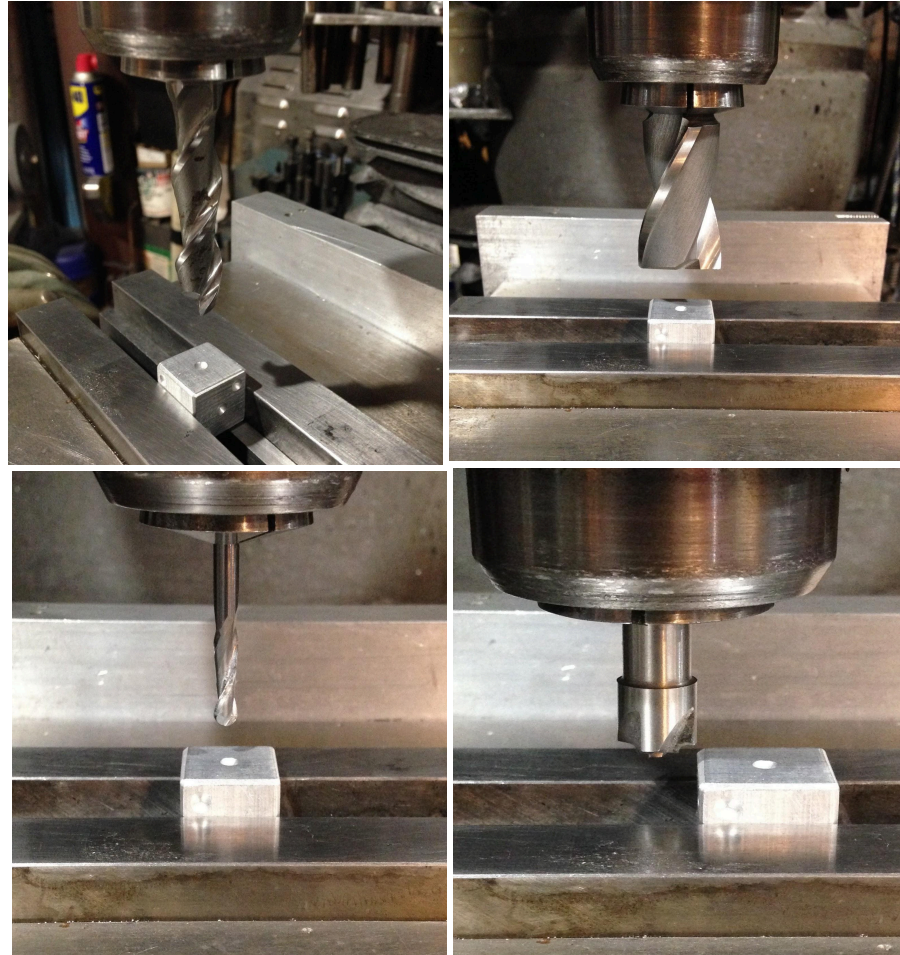
Shown to the left is a knee-milling machine, which is used during the majority of the prototyping process. The picture in the top right is the digital readout for the x and y axes. Lastly, the picture in the bottom right shows the digital readout for the z-axis of the mill. These digital readouts have buttons used to zero them located to the far left on the x and y axes readout, and on the bottom of the z-axis readout.

Appendix 2



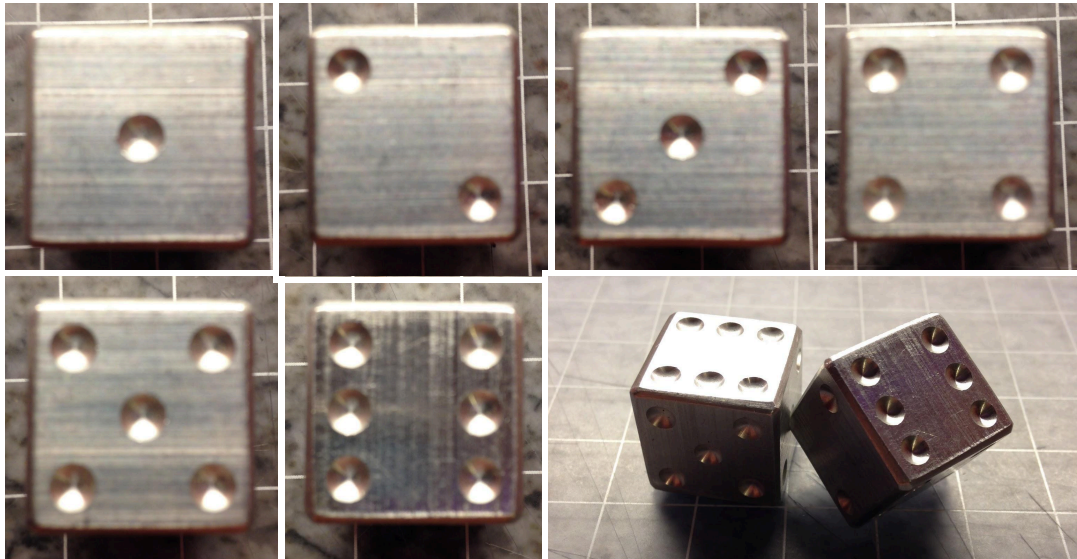
Shown above is a horizontal bandsaw, used in step 3 of the process. The saw is shown open, ready to be clamped and turned on.

Appendix 3



Shown above are the various end mill bits that are required throughout this process to be used with the mill. The top left picture shows a bigger look of the workspace, the vice holding the die, and the bottom of the collet holding an end mill. The top right picture shows a close-up of the end mill positioned above the workpiece. The bottom left picture shows a ball-end mill positioned over one of the die's holes. Lastly, the bottom right picture shows a corner-rounding end mill positioned near an edge of the die.

Appendix 4



Shown above are all of the faces of one die, along with a picture of dice that were created by following the aforementioned process. These faces show the layout of the holes to help clarify any uncertainties.

Works Cited

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