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Manipulation and Automation of FBJ Short-Axis Fasteners

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FBJ Short-Axis Fasteners

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Master of Science

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ABSTRACT

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FBJ Short-Axis Fasteners

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Legislative and market pressures are pushing automakers to achieve new fuel economy requirements in the coming years. To help achieve these goals automakers are reducing the overall weight of the vehicle by increasing the use of high-strength aluminum and advanced high-strength steels, and with this increased use comes the desire to quickly, and securely, join these materials within the vehicle. Friction bit joining is a process that lends itself well to joining these materials. This process uses consumable fasteners that need to be used in an automated production line. The geometry of these fasteners causes two main problems: the bits have a short longitudinal axis, which makes them difficult to orient, and the welding platform may be used at different angles; requiring a robust reloading system that is indifferent to its orientation.

Our research explored ways that these short axis FBJ fasteners could be handled and transported using various automated methods. We tested the use of small mechanical carriages and magnetic tracks to test their viability for transporting FBJ fasteners. The two different types of fasteners that were used in the project are described. Blow feed tubes ended up being a reliable method of transportation given that the fastener has suitable geometry. The superior bit and feed system design were bench tested using a manually controlled feed system. The system was tested in various orientations to test the robustness of the system since the system was designed to be part of the end effector on a production line robot. The testing revealed that the feed tube is a reliable method of bit transportation and mechanical jaws are a suitable solution for FBJ fastener manipulation. These jaws have several key design features that dramatically increase their effectiveness. Suggestions for future work would be an optimized feed tube cross section, improved material properties in the bit jaw, and more air flow at a higher pressure through the feed tube.

Keywords: friction, bit, joining, automation, automated, stir, orientation, welding, aluminum, steel, high, strength, high-strength, ultra, DP, 7075, feed system, fasteners

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1 INTRODUCTION

1.1 Purpose of the Research

Revised vehicle standards and public opinion are encouraging higher levels of fuel efficiency in the transportation industry. With this new direction many companies are interested in joining aluminum to steel to increase weight savings and decrease fuel consumption. Friction bit joining is a joining method that is capable of joining high strength aluminum to advanced high strength steels. Friction bit joining technology utilizes a consumable fastener, the friction bit, which needs to be loaded onto the tip of a driver prior to welding. The process of loading friction bit joining fasteners onto a driver for high volume production needed to be better understood and further developed.

Current automated reloading technologies typically involve the use of long axis fasteners (fasteners with a length to diameter ratio greater than 1:1) such as self-piercing rivets and self-tapping screws. While this technology would have been easy to implement these processes are not able to effectively be used in advanced high-strength steels (Abe, 2009).

The purpose of this research is to explore different friction bit handling machinery to find a reliable feed system for the friction bit joining process. This includes the design and implementation of a system that is able to effectively manipulate and load a consumable weld bit onto a driver with an overall length to diameter ratio near 1:1 or less.

1.2 Research Hypothesis

In order to fulfill the objectives of the research the following hypotheses will be tested.

1. Mechanical conveyance will be the most dependable method of conveyance for the FBJ fastener.
2. A type of mechanical jaw will provide the most repeatable reloading performance.

Mechanical conveyance is an essential part of a reliable automated system. The conveyance types that were explored were primarily magnetism, air feed tubes, and mechanical tracks. Placing a bit accurately and reliably on the tip of the driver is also going to be a large component of this research. The two concepts for achieving this at the beginning of the research was to use a mechanical clamp that gripped the FBJ fastener in a set of mechanical jaws (Figure 1) and a lever type platform that held the bit from the bottom and loaded the bit onto the tip of the driver up from the bottom (Appendix A).

1.3 Objectives

The objectives of this research are to explore different methods of sorting and handling the friction bit fasteners as well as design and prototype a functional feed system. This feed system will be tested for reliability and suggestions will be given for future iterations of this system.

1.4 Delimitations and Assumptions

This research only investigates the exploration and creation of bit transport and driver loading. Further development would be needed to develop and implement electronic feedback controls within the feed system itself and within the vibratory feed bowl. It has been noted that these systems exist in a developed state and could be implemented fairly easily (Maul, 1994).

The cycle time of a reloading sequence was not recorded as the reloading sequences were done manually. Cycle times from manual trials would be inconsistent and not representative of the system as compared to the trials being completed by a computer controlled system since some of the movement on the machine can be done simultaneously, a feat not easily achieved by a single human operator manually operating the feed system.

1.5 Definition of Terms

Feed tray – the feed tray is responsible for transporting the bit from the feed tube to the tip of the driver.

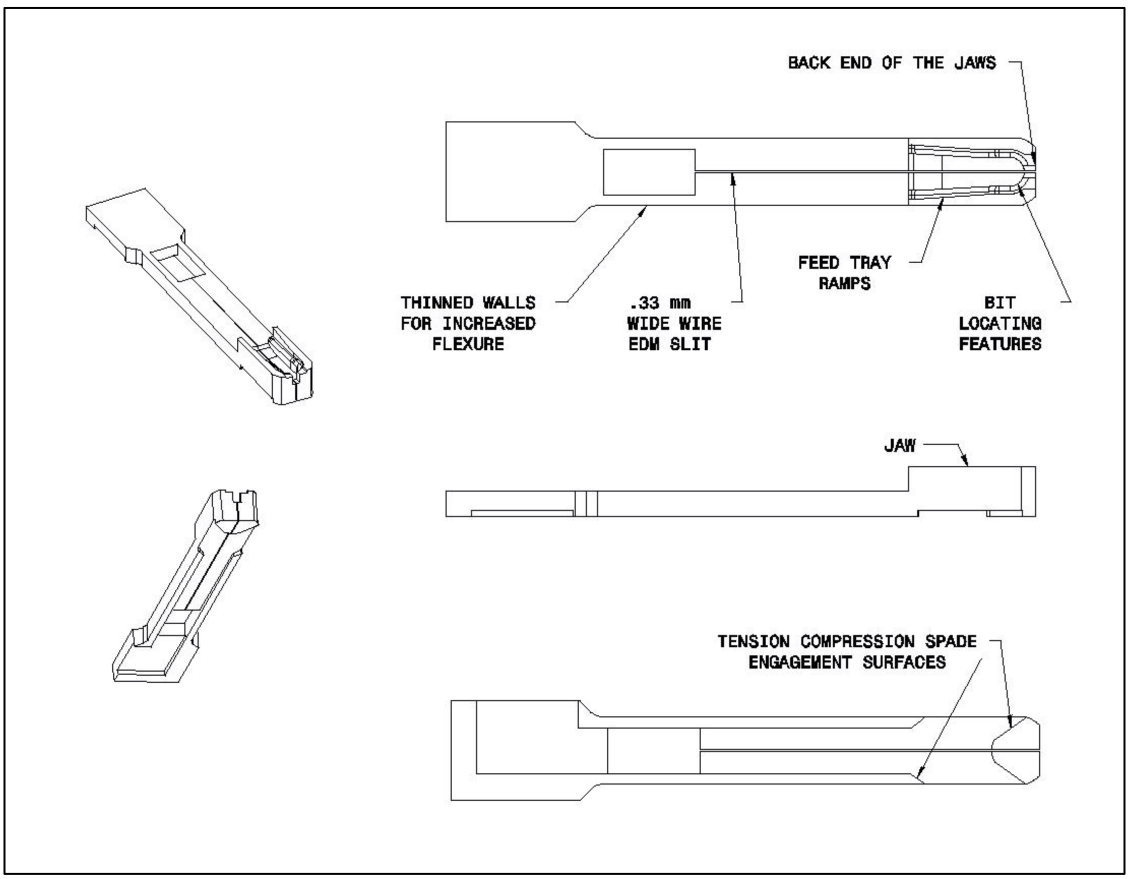

Figure 1 Basic Anatomy of the Feed Tray Component

FBJ – friction bit joining

SPR – self-piercing rivets

Bit – or FBJ bit, is a consumable fastener that is used in the FBJ process. During the course of the research there were two variants. Bit variant 1 and bit variant 2 (Figures 2 and 3).

Flash Cutter – a component that is responsible for removing the displaced material that issues from around the bit during welding (Figure 18).

Driver – a component that is responsible for transferring the downward and rotational force needed to complete a FBJ weld (Figure 19). This component has three small pegs that engaged in three similarly shaped cavities on the head of bit variant 2 (the bit variant used during the final testing).

Clocking – refers to the rotational alignment of the bit on the driver tip. The drive features need to be properly aligned rotationally so that the drive features of the driver and bit are properly engaged.

Clutching – refers to the continual, moving rotational misalignment that can occur during a bit locating sequence. During bit loading the driver comes down, rotating at a slow rpm (Figure 19). This allows the drive features of the driver and the drive features of the bit to engage. Clutching occurs when the drive features of the driver are not yet engaged into the bit but instead have enough friction with the top surface of the bit to cause the bit to rotate in the feed tray.

1.6 Bit Versions

During the course of the research there were two versions of the FBJ bit that were used. The older variant, bit variant 1, had a length to diameter ratio that was close to 6:8 (6.59mm to

9.8mm). This version was used for much of the early bit transportation and manipulation experiments.

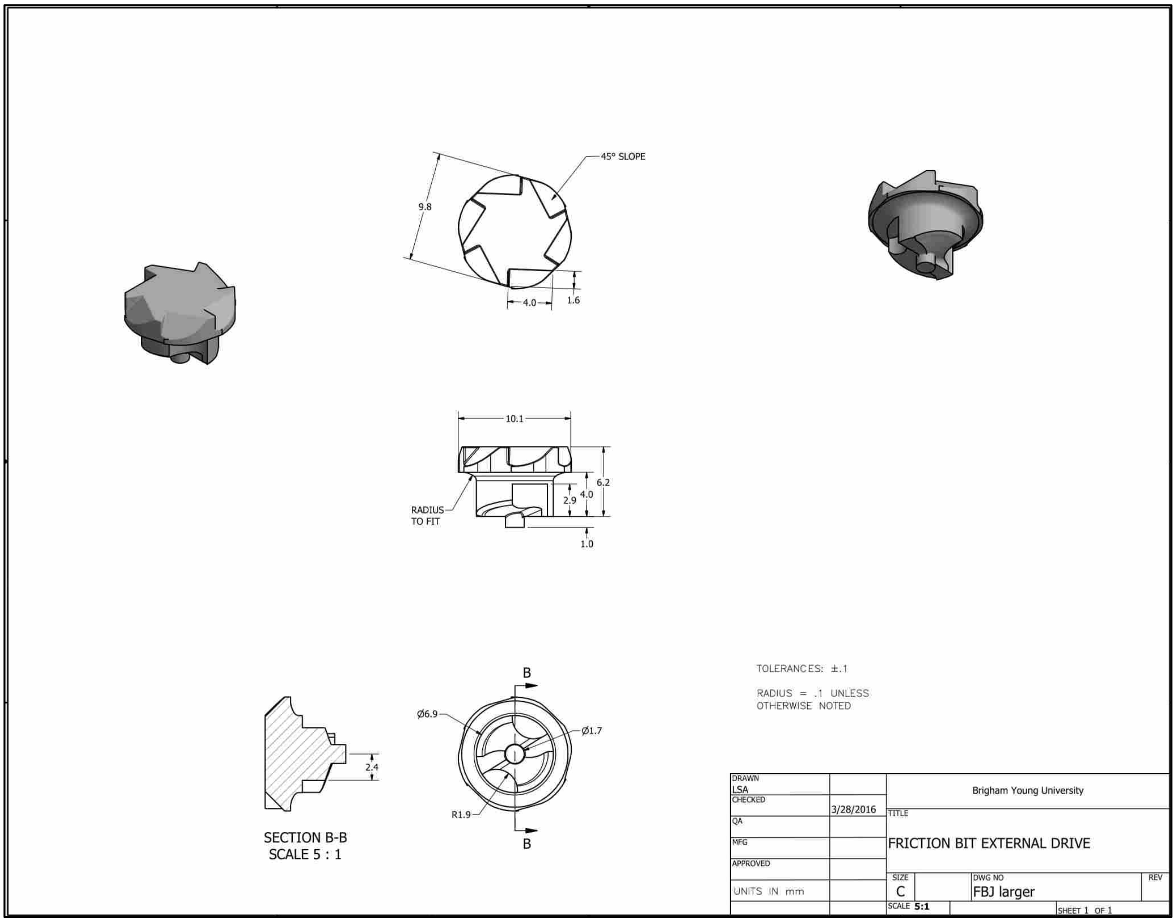

Figure 2 Bit Variant 1 Design

Bit variant 1 had the notable features of being externally driven and having a squarer aspect ratio than the variant 2 bit design. These characteristics made the bit variant 1 difficult to transfer through a blow feed tube due to its tendency to dig into the plastic of the feed tube with the drive features and the bit tip over time and bind. Binding was a particular problem due to the aspect ratio, the bit would rotate in feed tubes and wedge itself into the side walls (Figure 4). Later in the research project the design of the bits was changed (the bits and the automation systems being designed in parallel), this revised design is called bit variant 2. This fastener, shown in Figure 3, was the type used in the final testing and experimentation.

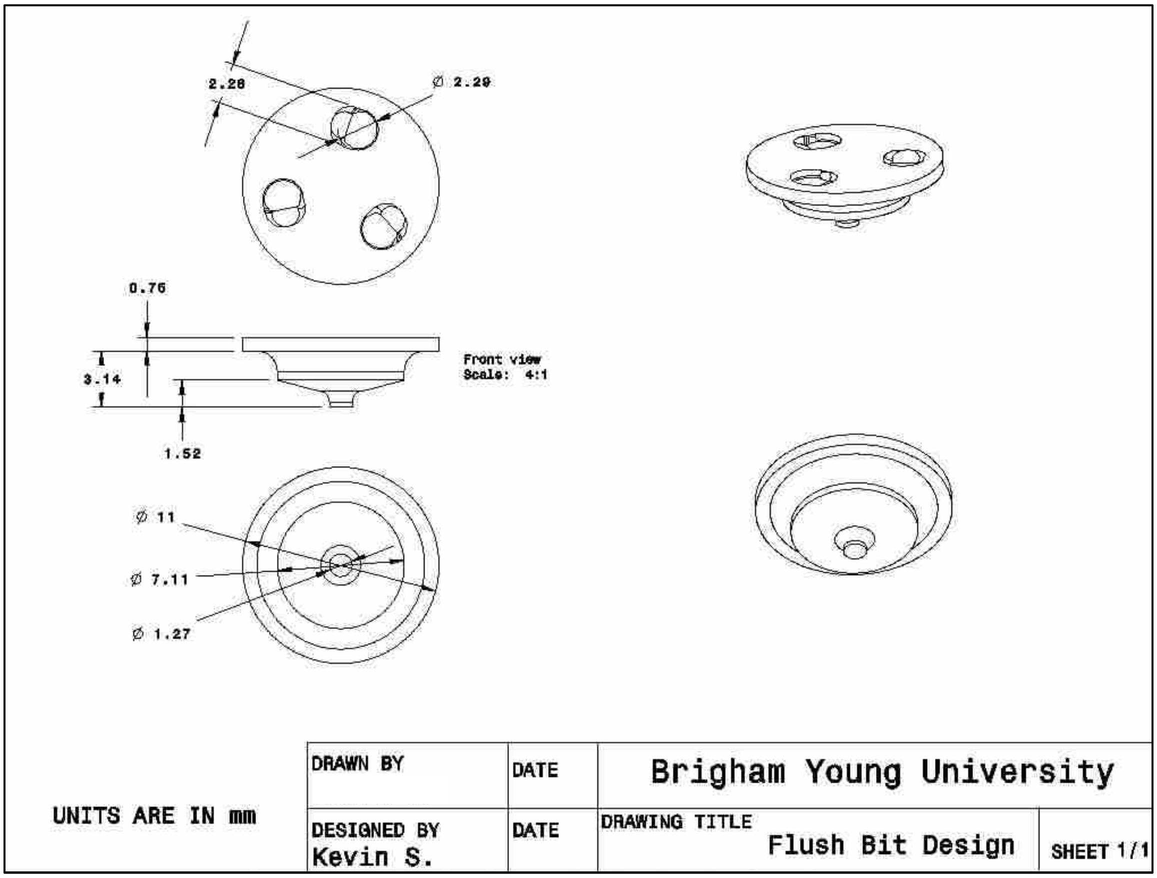

Figure 3 Bit Variant 2 Design

The variant 2 bit design has the advantages of a smooth outer perimeter around the head of the bit and a much lower head length to diameter aspect ratio, 3:8 (3.89mm to 11mm). These two characteristics made the variant 2 bit design a much better candidate for blow feed tube transportation over the variant 1 bit.

1.7 Bit Transportation

Transportation of the bit is essential to the automation of the FBJ welding process. Fasteners begin the process in a vibratory bowl and need to be transported to the welding head to be loaded onto the tip of the driver, for this to happen fasteners need reliable and accessible locating surfaces. In this regard both variant 1 and variant 2 bits are at a disadvantage due to the relatively small area under the head that can be accessed and gripped during transportation and loading (the head must remain uncovered during loading so the drive features of the driver and the bit can engage one another). The lack of available bit holding area on both bits posed a big problem for the majority of the project. The feed tray was partially chosen (among other advantages) because it could exert enough clamping force on the small area available to effectively hold the bit. Some of the efforts to solve this and other bit transportation problems can be seen in Appendix A.

Figure 4 Variant 1 Bits Jammed in a Feed Tube

1.7.1 Tri-Wire Transport

Tri-wire transport was an early idea used with bit variant 1 that tried to simplify the process of bit transport. This method involved two wires that supported the bit from the undercuts located beneath the head of the bit and a third wire located over the top of the bit to prevent the bit from escaping out the top of the two main wire guides. Two primary concerns that accompanied this design was that there was no convenient way to power the bits along the track, whatever momentum they came in with would have to carry them through the length of track or they would have to make use of gravity by traveling downhill. The other concern was that if the tri-wire track, being unpowered, moved into an uphill position with the welding robot changed position the bit would not reach its intended destination.

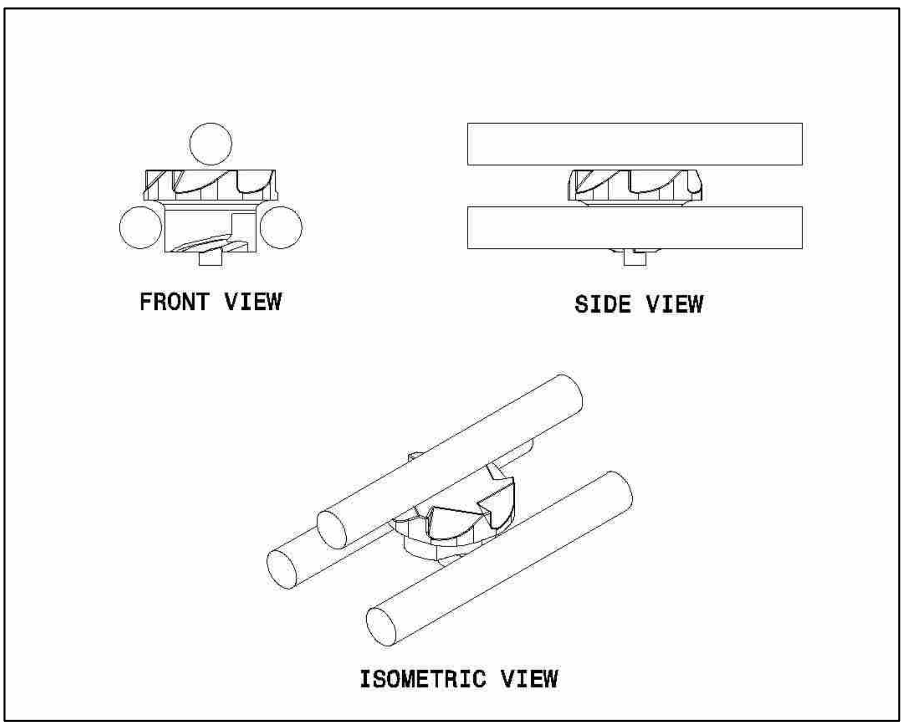

Figure 5 Diagram of Tri-wire Method of Conveying FBJ Fasteners

1.7.2 Pneumatic Feeder Tube

The pneumatic feeder tube is a common way of conveying small fasteners in a production environment. A concern that prevented us from using this technique with the bit variant 1 is that the sharp corners created by the drive and cutting features would eventually catch the plastic feed tube and cause the bit to jam (Figure 4). The fasteners, being much harder than the plastic tube, would cause wear and scarring in the plastic, particularly around corners. However, when bit variant 2 was selected the more rectangular aspect ratio and smoother edges made feed tube transport an attractive option, which we tested. The bit variant 2 fastener could be used with a well-designed feed tube, such as those depicted in Figure 6, that would prevent the bit from catching on the wall of the feed tube.

Figure 6 Profiled Feed Tubes from Weber USA

1.8 Bit Orientation

In the beginning of the project bit orientation was part of the scope of the project because we wanted to try a bit loading system with integrated orientation. As the project progressed bit variant 2 was adopted and the need for integrated orientation capabilities diminished with the ability to transport bits remotely though a feed tube. While the need to orient the bits had diminished the lessons learned from our orientation experiments still proved valuable in helping us understand bit behavior and characteristics. Some of the orientation methods were profile orientation (Figure 7), and plate orientation (Appendix A). These methods showed promise but with the adoption of bit variant 2 the responsibility of orientation was transferred to a vibratory bowl feeder.

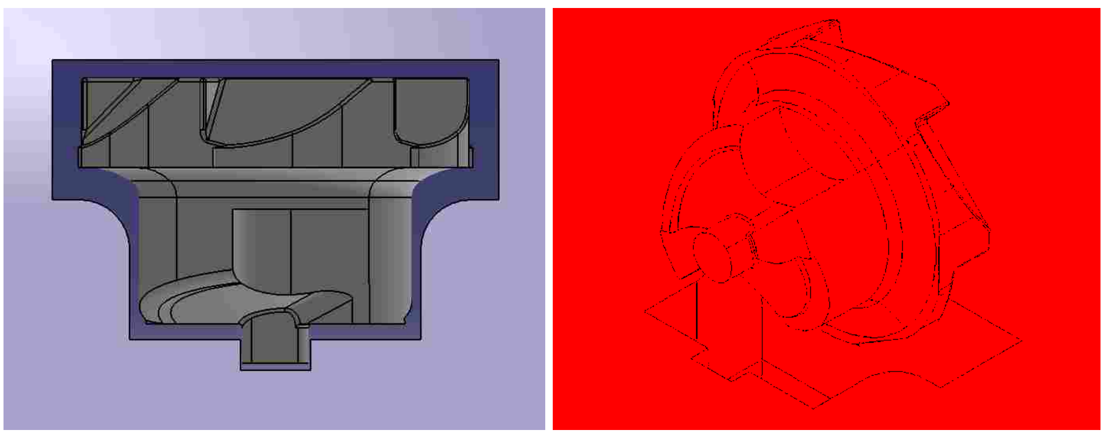

Figure 7 CAD Model of Profile Sorting System

1.9 Final Feed System

The final variant of the feed system uses three pneumatic actuators for movement and was designed to have a low, compact profile, a high level of stiffness, and permit the use of a vacuum system to clear away chips that are generated during welding.

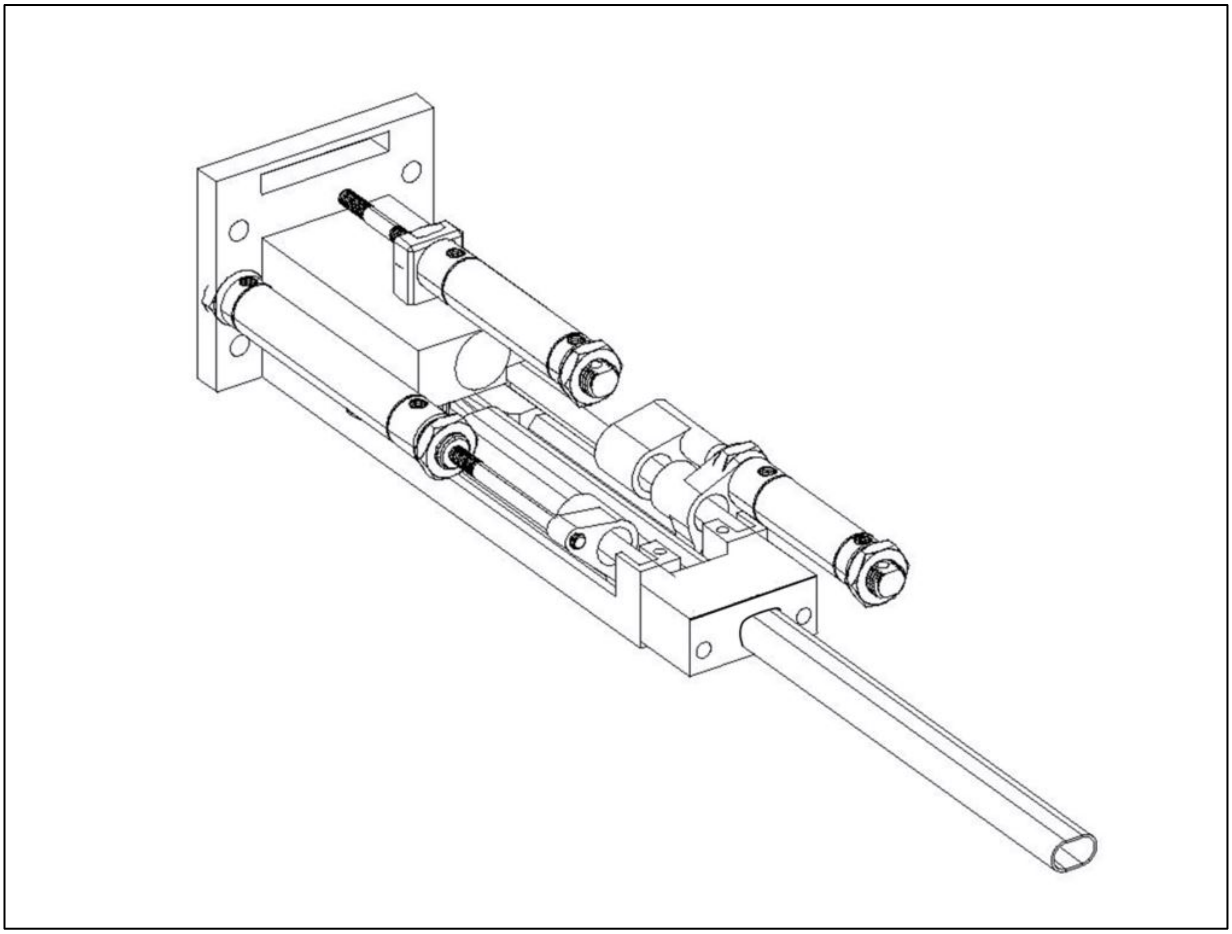

Figure 8 The Final System Fully Assembled

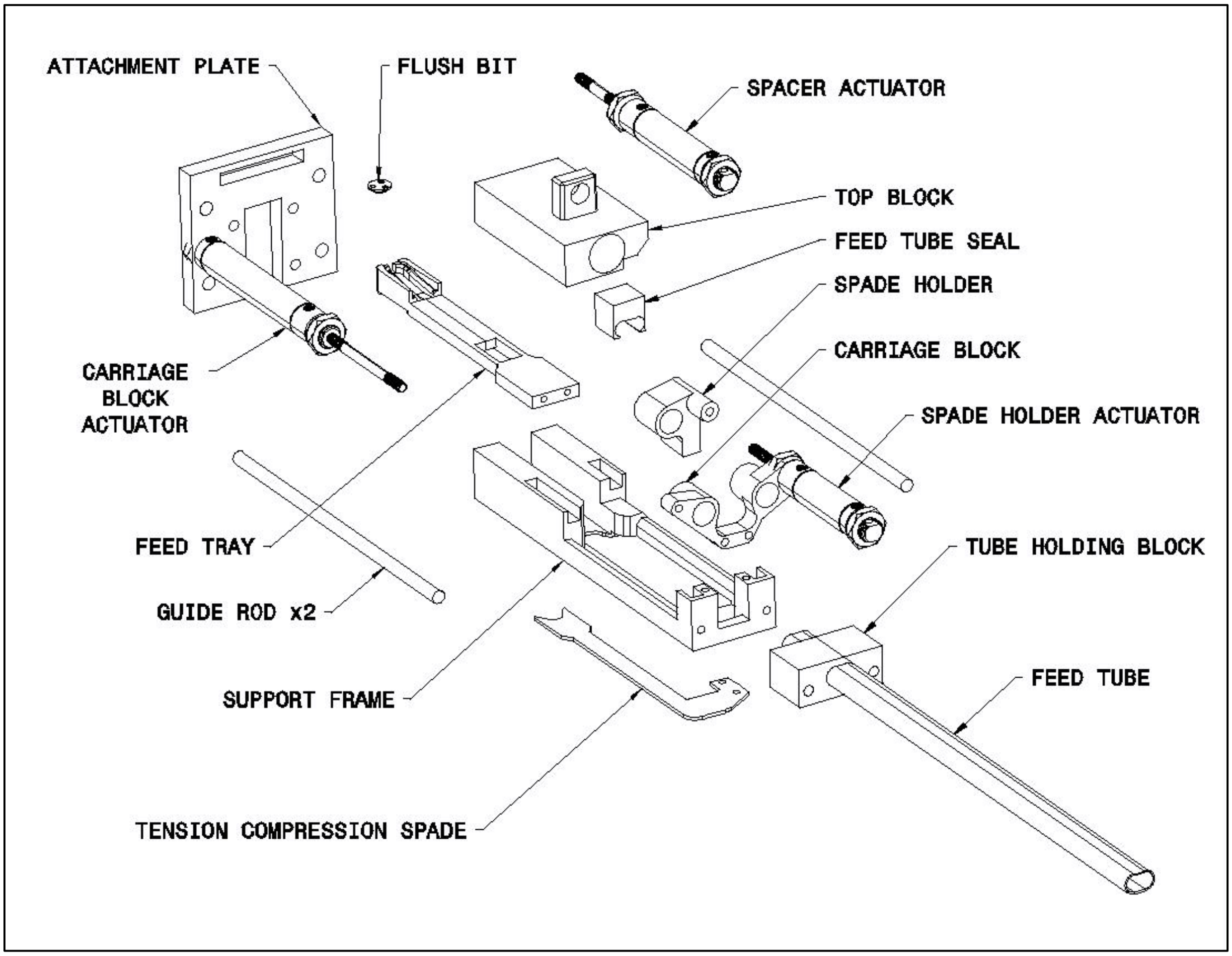

Figure 9 An Exploded View of the Final System

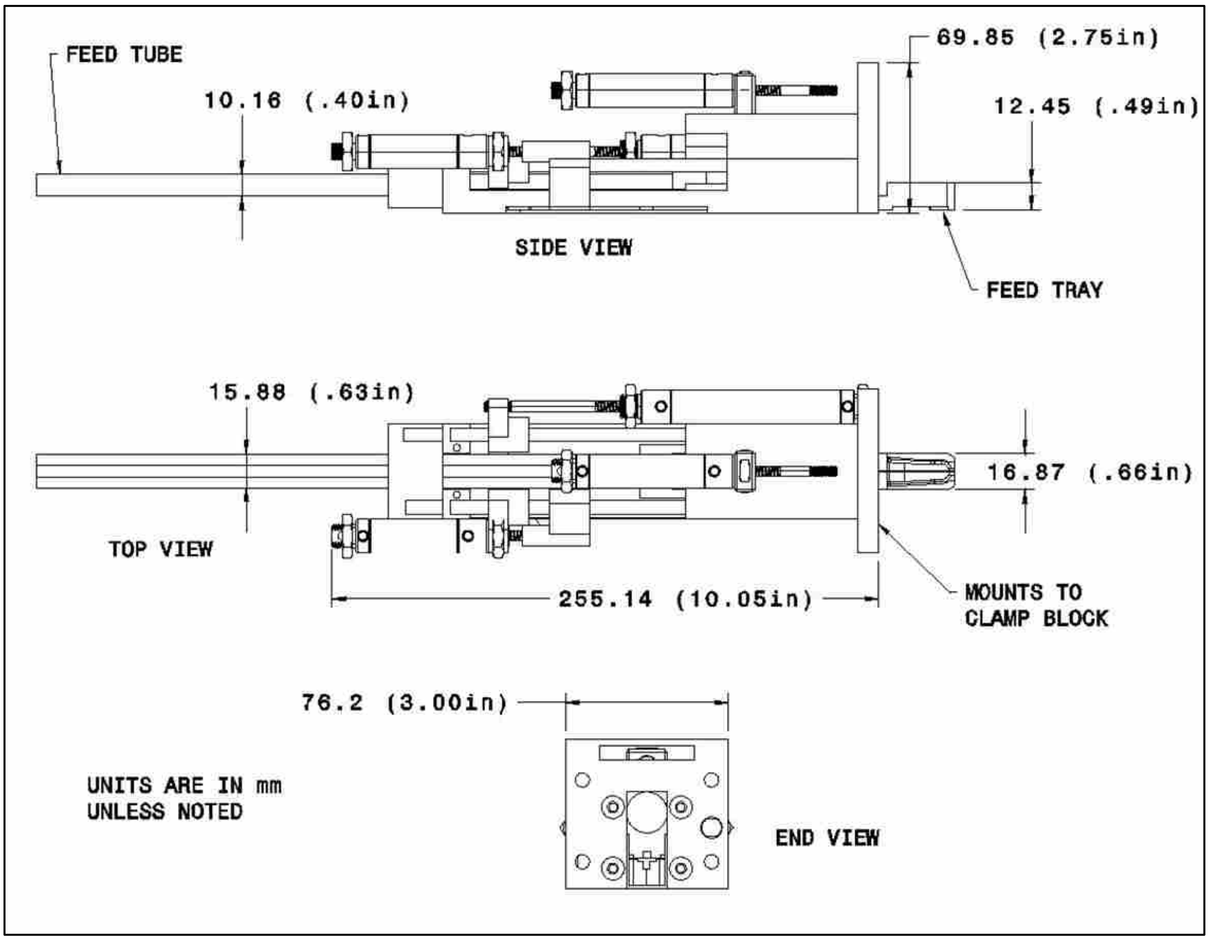

Figure 10 Basic Dimensions of the Final Feed System

2 LITERATURE REVIEW

2.1 Introduction

A reliable method is needed to load friction bit joining fasteners into the welder. There has been much interest over the use of automated fastener loaders, especially in the aerospace and automotive industries. These environments value low fastener installation cycle times and high machine reliability (Holden, 2007).

Articles in the literature review discuss current methods used to transport and automate fastener delivery and installation. The advantages and limitations of these methods are examined and how the current feed system design can fill in these deficiencies. These articles present solutions that involve a wide array of fasteners and applications.

2.2 Traditional Methods for Fastener Transportation

Many fastener feed systems use a pneumatic feed tube that the fasteners are blown through. Although blow tubes are capable of sending fasteners at speeds of 11-20 meters per second there is also the issue of slowing them down at the receiving end (Wallace, 2010). This can be done using physical stops or pressure differentials (Wallace, 2010). In the final feed system prototype slowing down the fastener was done by blowing the bit into closed jaws and the bit's kinetic energy was partially soaked up by spreading the jaws of the feed tray (Figure 27). From the literature it is apparent that transporting fasteners through blow feed tubes is a generally accepted practice. The initial concern about the bits was that they didn't have a great enough difference between length and width to be effectively transported through a tube. During early experiments it was observed that the variant 1 bits had a tendency to tip and jam in the feed tubes they were being blown through (Figure 4). The variant 2 bits, however, had a much greater diameter to length ratio and no external drive features and were able to be successfully blown through a feed tube.

2.3 Locating Fasteners to the Driver Tip

The methods for locating and loading a traditional long axis fastener are different than the method that was finally selected for testing with short axis FBJ fasteners. A solution in the literature with regards to fastener loading was to blow the fastener into a feed tube that was parallel to the axis of the driver and once the fastener was roughly side by side to the driver a rotating platter would rotate and the empty slot in front of the driver would rotate to align with a new slot that had a fresh fastener in it that moved into axial alignment of the driver (Guérin, 2004). This technique could work with the FBJ reloading process but the FBJ system has the variant 2 bit traveling sideways inside the feed tube, as opposed to the tip first orientation of most other systems. For this arrangement to work the variant 2 bit would be to be rotated 90 degrees once arriving at the end of the feed tube in order to properly engage the drive features of the driver. For this to work with our current welding machine the feed system would also have to located higher up on the machine as would be preferable because the current spindle arrangement has a lot of clearance built into because of its experimental nature. Clamping is also a concern because a rotating platter or a bit reloading-arm type mechanism, one similar in concept as those seen on a CNC milling machine for changing tools, would take up volume that would normally be used for strengthening the work holding clamp.

Another type of bit loading mechanism in the literature was a spring-loaded ring that firmly held the head of the bit during loading (LeCann, 2006). This reloading ring seemed like a promising solution and simple holding prototypes were made to see if a similar device might benefit our project. Unfortunately it became evident that the thickness of our head was too thin to effectively grip the ring and there was an added complexity of a solution to load the FBJ fastener into the spring loaded ring. Once it became apparent that two loaders, one for loading the FBJ fastener onto the ring and then one for loading the FBJ fastener onto the driver tip, needed to be constructed the idea was less attractive due to the added complexity and limited space in the FBJ welding machine.

The third mechanism that can be seen in the literature is a type of jaw system; wherein, for our application, the FBJ fasteners are held in a set of jaws or grippers that clamp down on the bit as it comes from the feed tube and release the bit once it is fully seated in the drive features of the driver (Felser, 2015). This system offered a high degree of control and could be adapted to the sideways oriented FBJ bit as it came out of the feed tube. This type of system was selected in the final design because it could be repackaged in a small form factor. This small sized allowed room for chip removal from the flash cutting process, minimal removed material from the welding clamp, and reducing the distance that the machine can be from a workpiece at any given time.

2.4 Summary

A variety of methods were tested to find adequate solutions for orienting and manipulating the FBJ fasteners. Prototype systems were built and the systems were put through testing and observations were made regarding their effectiveness. A far amount of iterative work was done as the friction bit design was also being developed in parallel with the feed system. This was problematic at times because changes in the bit design would drastically affect the design of the feed system. The major change occurred when we switched from bit variant 1 to bit variant 2. Although smaller, incremental changes were occurring in both variants frequently. A feed system design that ran off of compressed air as the prime motive force was selected and prototyped.

3 METHODOLOGY AND EXPERIMENTAL DESIGN

Testing of the feed system had two phases, first, optimizing the feed tray and bit handling designs and, second, running more extensive tests of the final feed tray and bit handling set up. During these tests a friction bit was placed into the feed system at the sending end of the feed system (Figure 11 and 12). At the sending end is a vibratory feed bowl with valve block that takes an individual bit and seals and isolates that bit in a feed tube. Once the bit is sealed in the bit valve block pressurized air then pushes the bit down the feed tube toward the receiving end of the feed system (Figure 14).

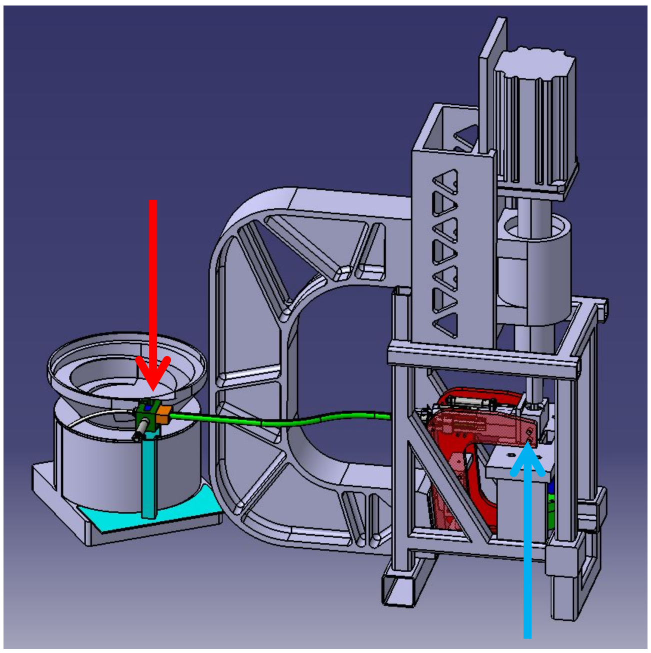

Figure 11 Overall View of the Welder, Bit Moves from the Red to the Blue Arrow

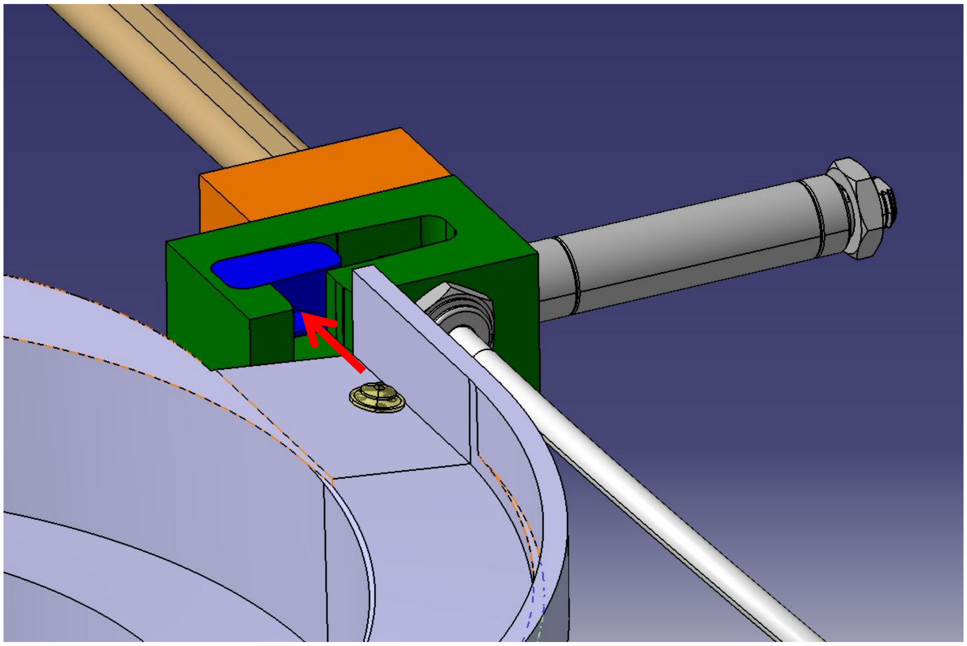

Figure 12 Bit (Yellow) Transfers from Vibratory Bowl to the Valve Block Carrier

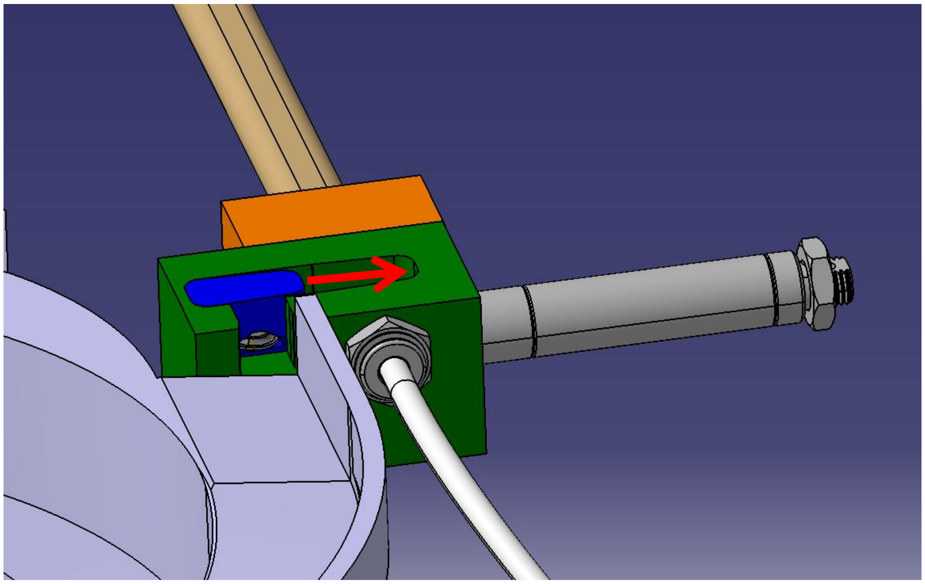

Figure 13 Valve Block Carrier Moves Into the Closed Position

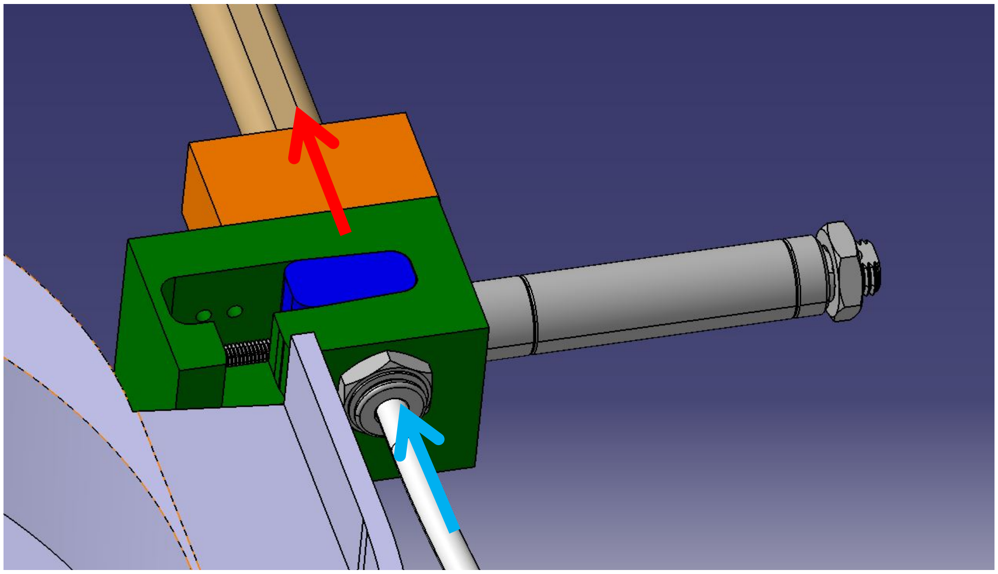

Figure 14 Pressurized Air (Blue Arrow) Blows Bit In the Feed Tube (Red Arrow)

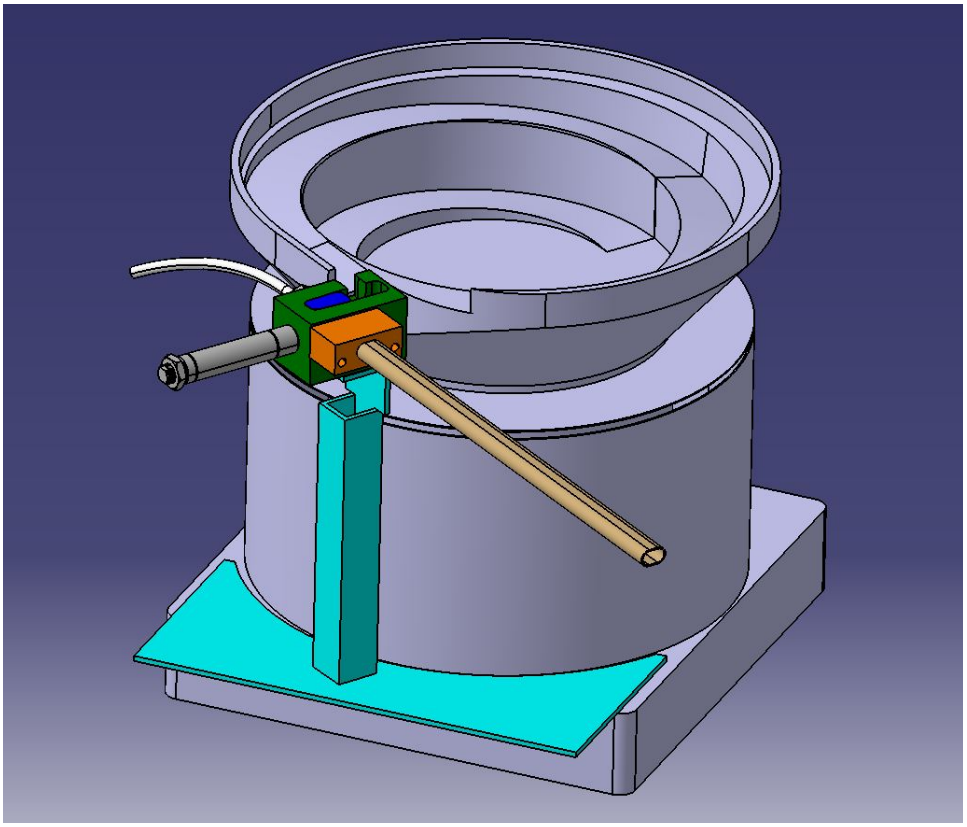

Figure 15 Overall View of the Feed Bowl

Once the bit reaches the end of the feed tube the bit is caught and slowed down by the tapered surfaces of the feed tray (Figure 16). The feed tray then transports the bit to the tip of the driver (Figures 17 and 19). After the FBJ bit is on the tip of the driver the machine is ready to start a weld (Figure 22). During the data collection of this work no welds were made. The bit was loaded onto the tip of the driver and that was considered a successful loading cycle.

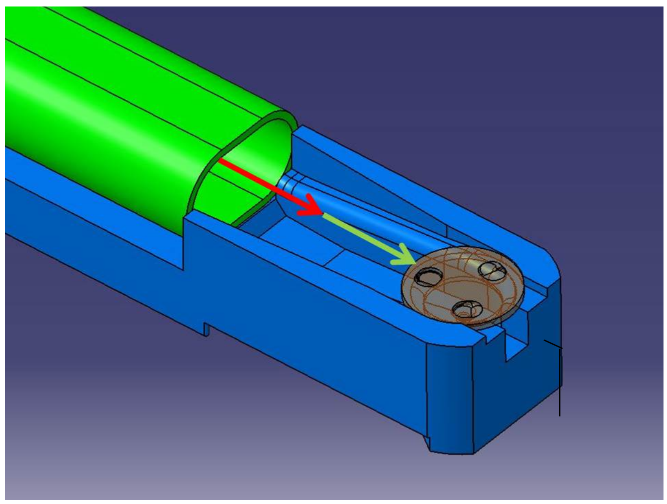

Figure 16 From Feed Tube (Green) the Bit (Brown) is Located in the Feed Tray (Blue)

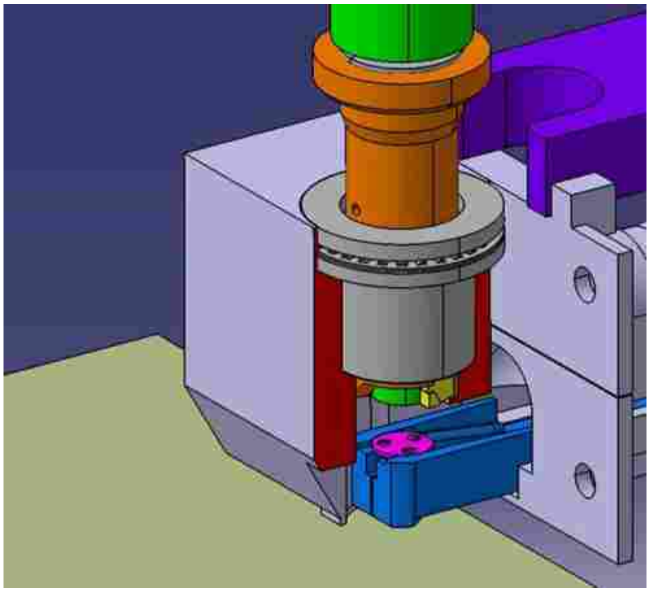

Figure 17 Bit (Pink) In the Feed Tray (Blue) Is Extended for Loading in this Cutaway

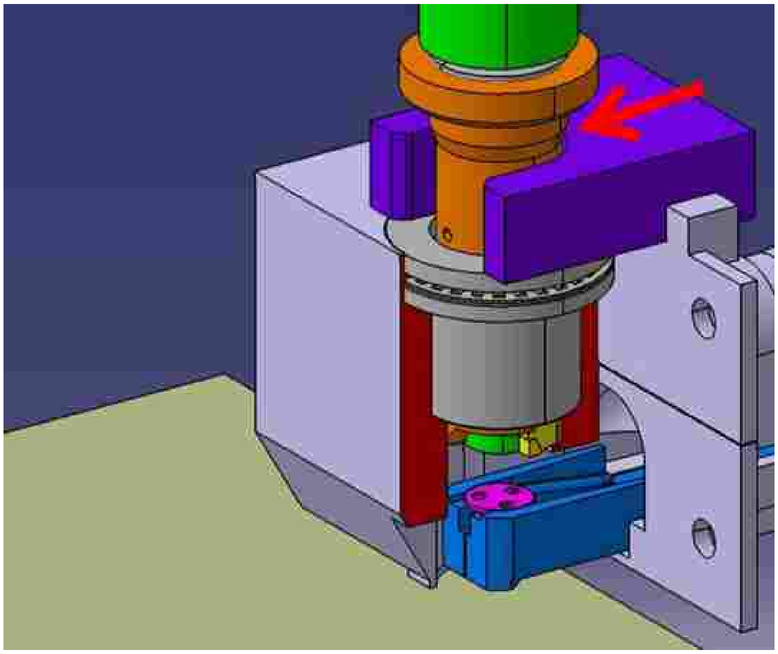

Figure 18 A Spacing Spade (Purple) Extends to Retract Flash Cutter (Orange)

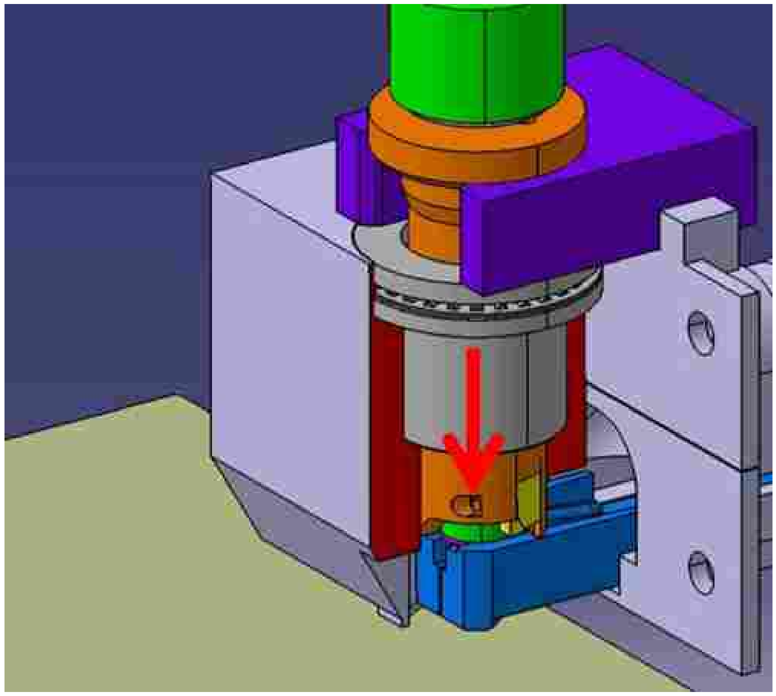

Figure 19 Driver (Green) and Flash Cutter Move Down, Bit is Loaded on Driver Tip

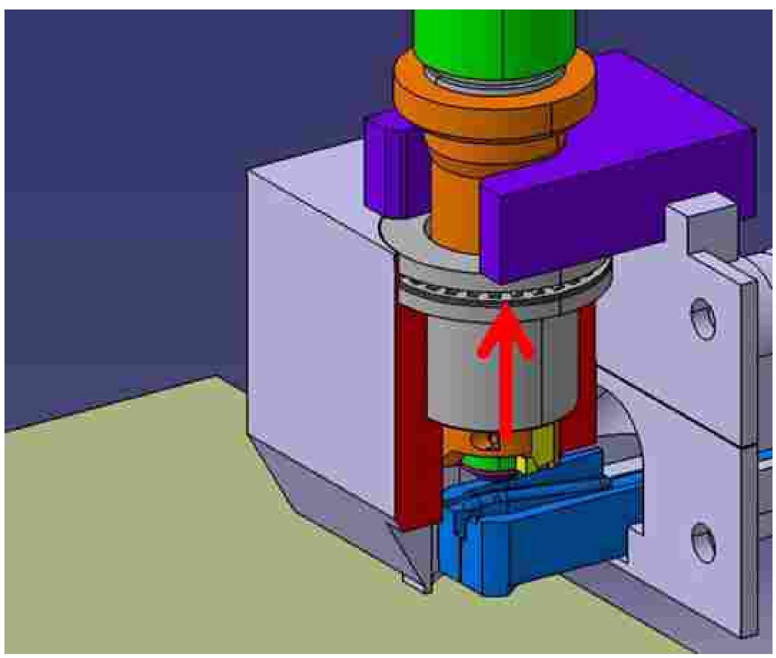

Figure 20 Driver and Flash Cutter Assembly Move up with Loaded Bit

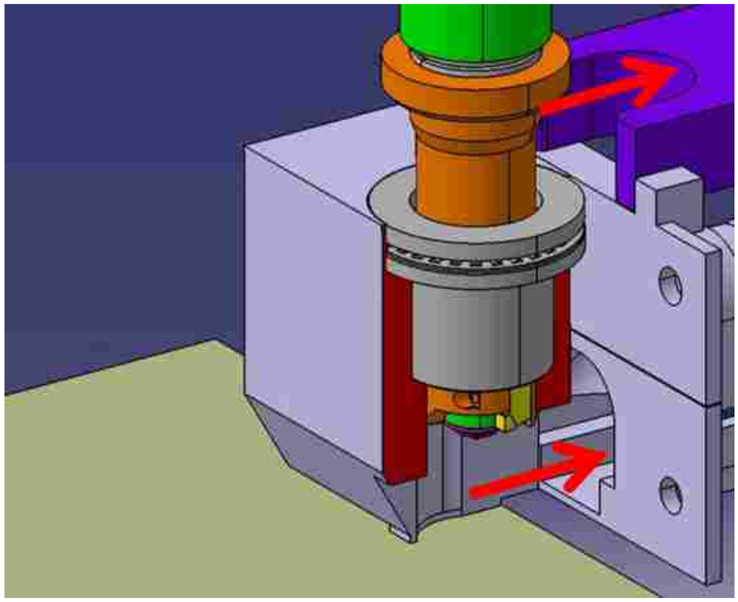

Figure 21 Spacer Spade and Feed Tray both Retract Out of the Way

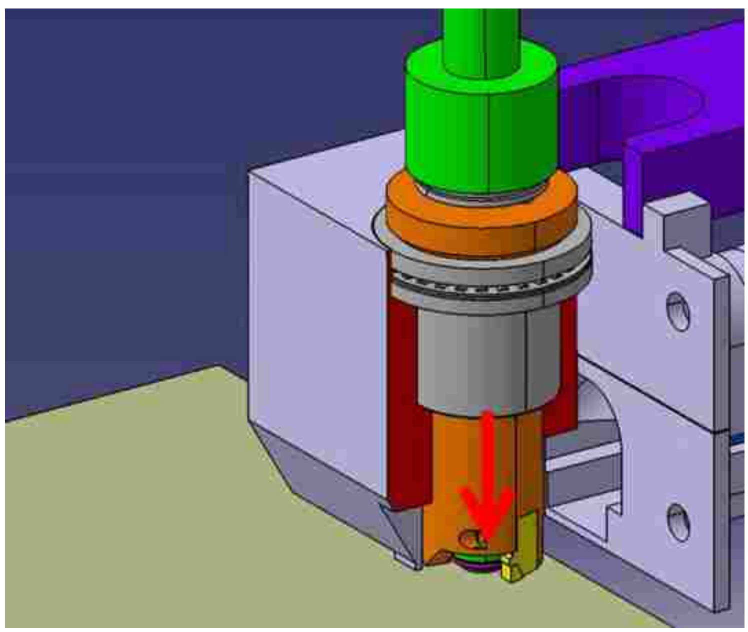

Figure 22 The Driver and Flash Cutter Assembly Move Down and Start the Weld

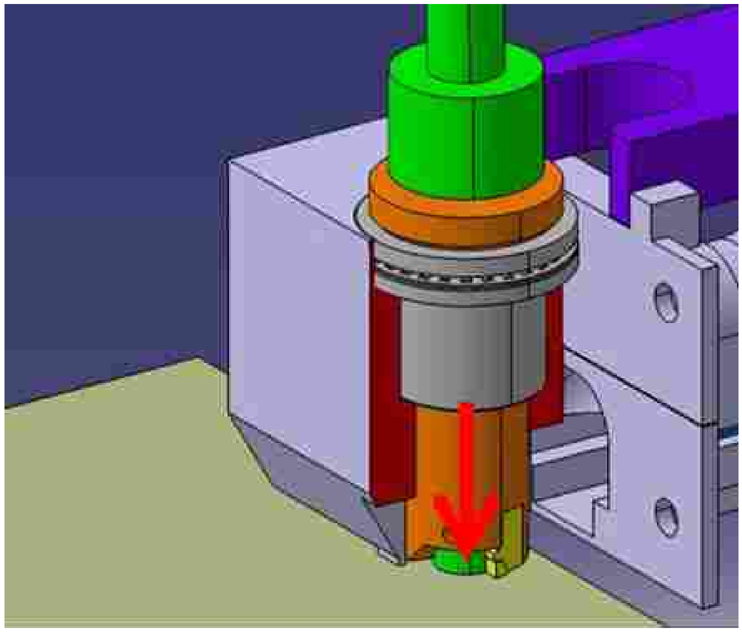

Figure 23 The Correct Depth is Reached and the Weld is Completed

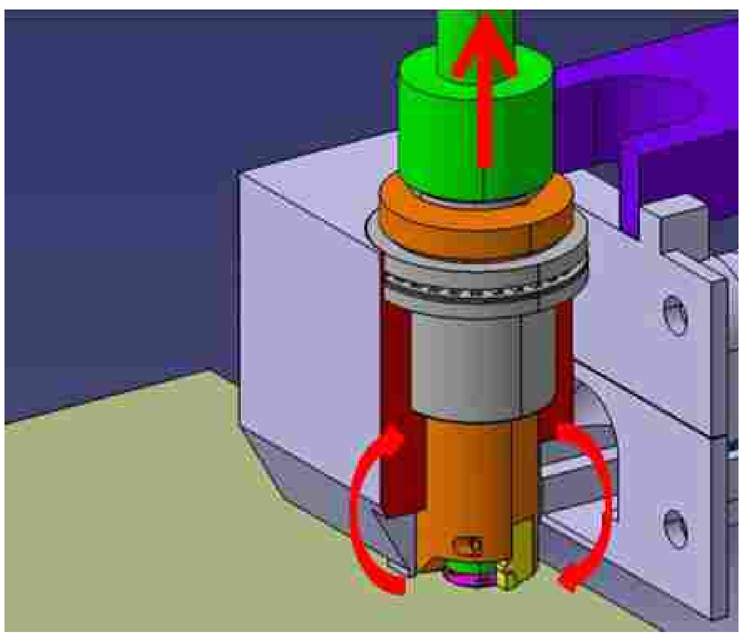

Figure 24 Driver Moves Up, Flash Cutter Stays Engaged with Surface and Cuts Flash

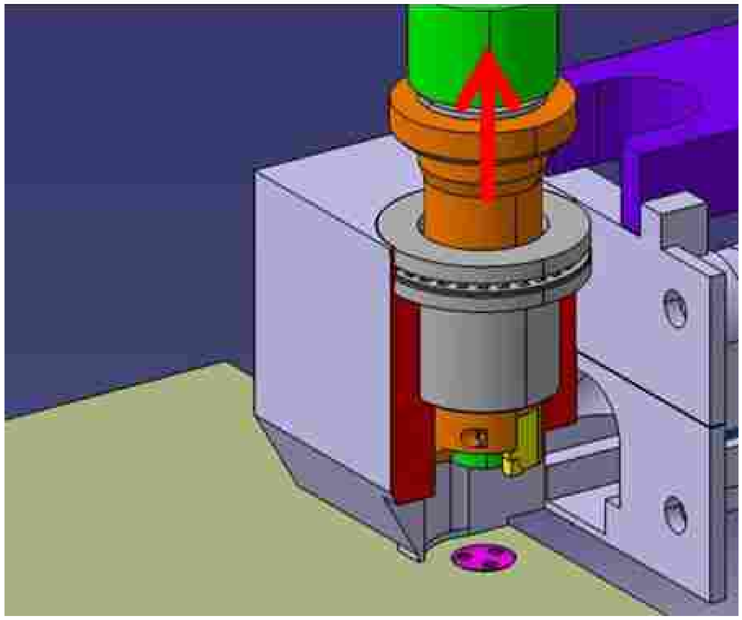

Figure 25 With Flash Removed Driver/Flash Cutter Assembly Move Up For Reload

4 RESULTS AND ANALYSIS

4.1 Trial Results

1,050 trials were run with the Gen 3 feed tray. Of these 12 failed to feed properly onto the tip of the driver.

Table 1 Results from Jan System Trials

	Horizontal, 0 degree	Horizontal, 90 degree	Horizontal, 180 degree	Vertical, Positive direction	Vertical, Negative direction
Number of trials	250	200	200	200	200
Successful trials	249	199	196	194	200
Success rate	99.6%	99.5%	98%	97%	100%

4.2 Test Failure Modes

During the trials two main failure types were identified. The first was that the bit was not clocked correctly on the end of the driver. This type of failure occurred 3 times throughout the testing. This happened because of clutching that would occur between the top of the bit and the drive features of the driver. This could be overcome in the future by having the reloading sequences be computer controlled. By having the sequence computer controlled the pressure exerted on the top of the bit would be more consistent and the parameters of the machine could be dialed in to mitigate this clutching effect. This could also be helped by increasing the air pressure to the spade holder actuator depicted in Figure 9. This would increase the gripping force on the bit preventing it from rotating.

The second failure mode that occurred was that bits were not fully seated into the locating features of the feed tray. This occurred 8 times throughout the testing. This was mainly attributable to indentions in the feed tray and skid plate caused the bit to lose too much momentum upon entering the area of the feed tray locating features. Blow-by and airflow restrictions in the feed tray area also contributed to inefficiencies in the airflow that prevented the airflow from being able to effectively move the bit into the locating features of the feed tray.

A third failure mode occurred that only happened once. During the first set of trials a bit misfed and upon inspection of the feed tray the bit was stuck to one of the side walls of the feed tray. The bit had hit the feed tray with enough force to create a weak mechanical bond with the feed tray wall. The bit was able to be picked out easily by hand but air flow alone could not dislodge the bit. After this the bit was coated in a thin film of grease and wiped off with a clean paper towel to get rid of the excess grease. This practice was repeated every 30-50 trials and this mechanical bonding didn’t happen again for the rest of the testing.

4.3 Key Design Elements of the Feed System

During our trials of the final feed system there were several design elements that greatly improved the performance of the feed system. These elements were: the use of the closed-open feed tray technique, new feed ramp features that capture the bit gradually, the design of the top skid plate, and increased air flow through the feed tube to help the bits locate.

4.3.1 Closed-Open Feed Tray Technique

During the first initial trials of the feed system the feed tray jaws were kept open so that the bit could move unhindered into the locating features. With this technique there would be periodic misfeeds, often the bit would be found oriented at an angle at the bottom of the feed tray (Figure 26). A clear, acrylic cover was placed over the feed tray and high-speed video was taken of bits as they entered the feed tray and interacted with the locating features. From the video it was observed that the bits hit the back of the feed tray jaws with considerable speed and bounced back toward the feed tube. This action was very quick and difficult to observe with the naked eye. The pressurized air from the feed tube would then quickly decelerate the bit as it bounced back and blow it into the locating features. In the instances of a misfeed the bit would usually hit the feed tube unevenly and cause it to rotate about an unfavorable axis, the pressured air would then push the bit in this unfavorable orientation and the bit would wedge itself into the ramps leading up to the locating features.

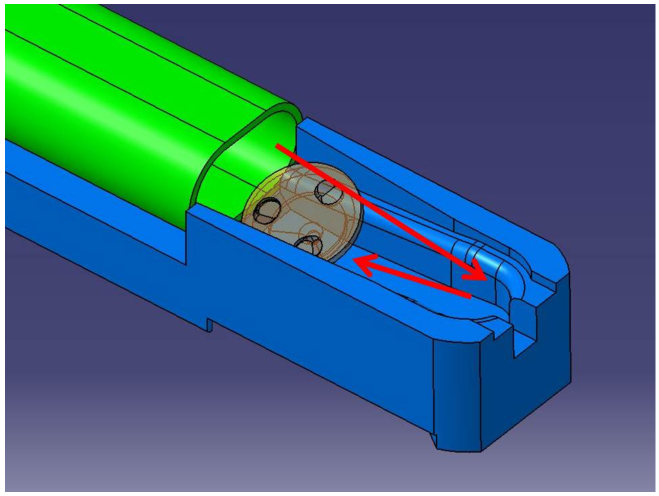

Figure 26 Open-Jaw Loading Technique, Bit Rebounds (Red)

To overcome this problem I started blowing the bit into the feed tray with the feed tray in a closed position. This acted much like a catcher's mitt and slowed the bit down gradually. With air still blowing through the feed tube the jaw was opened and the bit (now free to move) was pushed by the pressurized air into the locating features (Figure 27).

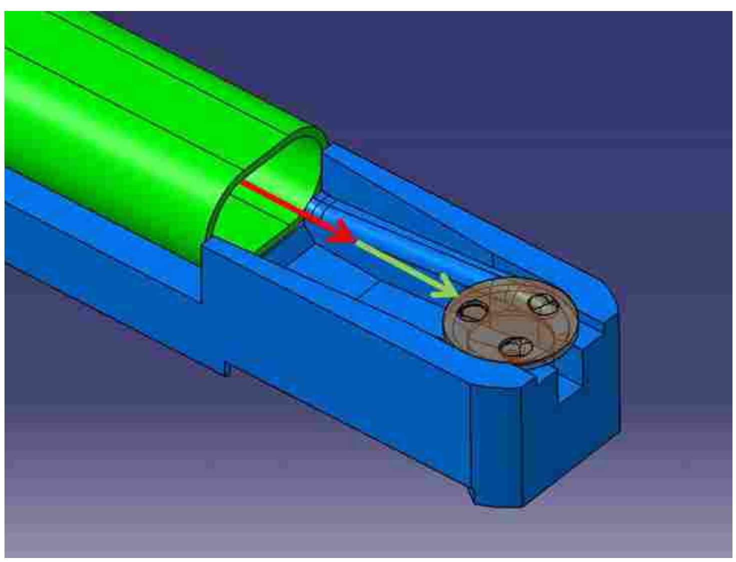

Figure 27 Closed-Open Jaw Technique, Bit is Caught (Red), then Located (Green)

4.3.2 Feed Tray Design

The transfer of the bit from the feed tube to the feed tray was by far the most sensitive and difficult part of the bit automation process. The rapid, and controlled, deceleration of the bit along with the accurate and repeatable locating of the bit in the X, Y and Z directions contributed to much of this difficulty. Three feed tray design iterations were made (Figure 30). Incremental changes in positioning for the feed tray were measured using an optical comparator (Figure 28). Trial runs were conducted with each feed tray with the feed system in the horizontal, 0 degree position with the feed system upright (Appendix B). 50 trials were conducted with each generation of feed tray and improvements were noted and implemented in the next generation. After the 50 trials were completed with the Gen 3 feed tray large trials of 200-250 trials were made with the Gen 3 feed tray to get a better understanding of the feed tray's characteristics over a larger sample set. After the horizontal (upright) trials were completed trials were conducted in the horizontal 90 degree (sideways), horizontal 180 degree (up-side-down), vertical up, and vertical down orientations (Figure 29).

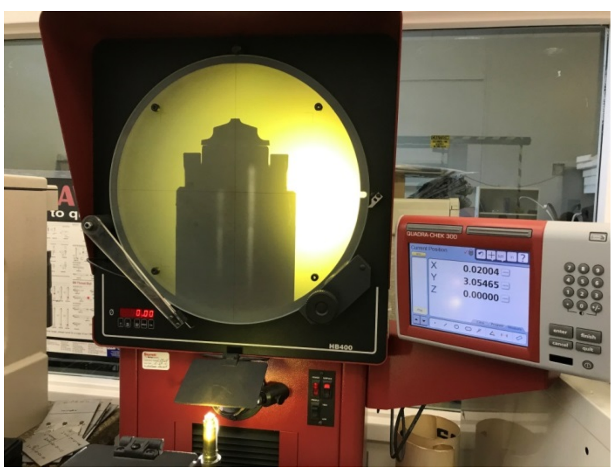

Figure 28 An Optical Comparator Measuring Bit Offset

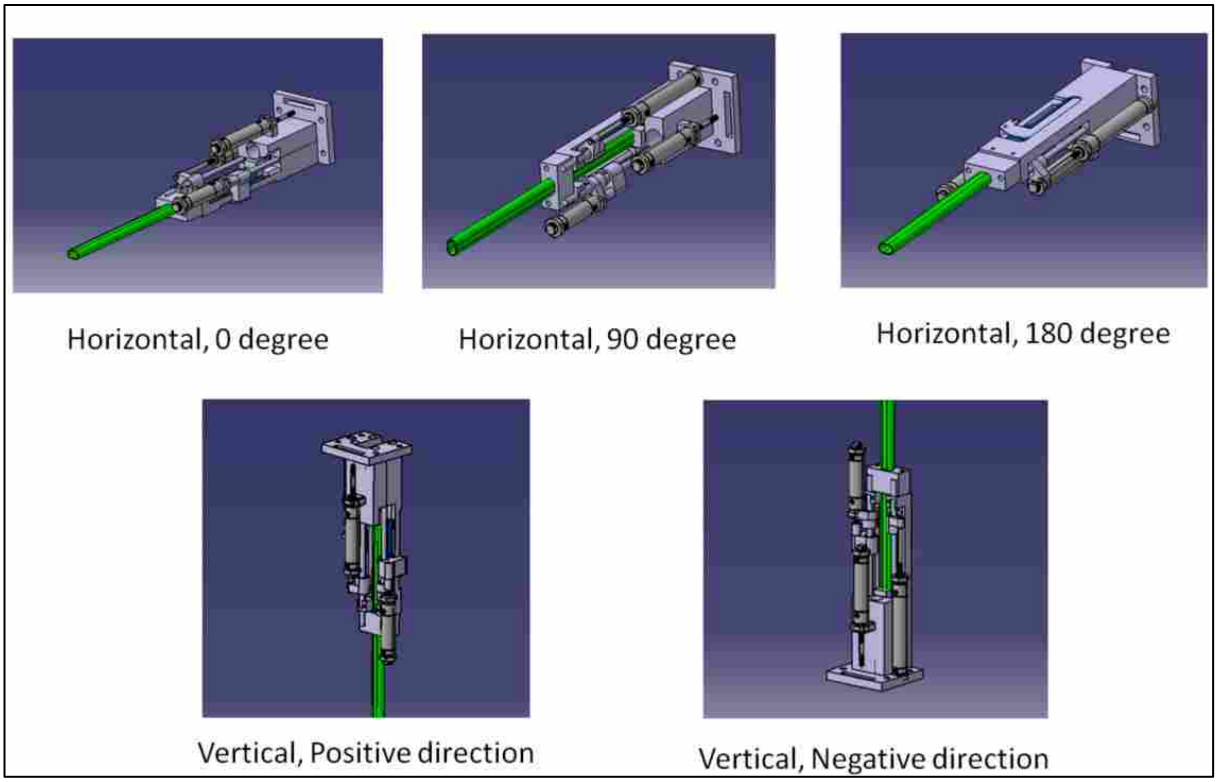

Figure 29 Feed System Orientations During Testing

Figure 30 Feed Tray Iterations: Gen 1 (Left), Gen 2 (Center), and Gen 3 (Right)

4.3.2.1 Gen 1 Feed Tray

The system with the Gen 1 feed tray was successful 47 out of 50 trials. The bit was found at an angle in the locating ramps or the bit wasn't clocked correctly. It was observed that the bit would hit the tapered walls of the feed tray and sometimes it would rebound back at the forward end of the locating features, near the feed tube opening (Figure 26). The funnel-like ramps appeared to be too steep to effectively guide the bit into the locating features. The feed tube air pressure for these trials was 586,054Pa (85 PSI), throughout the experiments the air pressure was steadily increased as the increased air flow was seen to have a greater ability to push the bit into the locating features.

Figure 31 Gen 1 Feed Tray

4.3.2.2 Gen 2 Feed Tray

The system with the Gen 2 feed tray was successful 44 out of 50 trials. 4 of the 6 failures were caused from the bit not making it all the way into the locating features of the feed tray. During two of these failures an attempt to fully locate the bit using another blast of compressed air was made and was successful. This suggested that there may not be enough air flow to fully seat the bit. This trial was run at 620,528Pa (90 PSI).

Figure 32 Gen 2 Feed Tray

4.3.2.3 Gen 3 Feed Tray

The Gen 3 feed tray really sought to control the air flow through the feed tray as the bit was being located. A notch cut out in the front of the feed tray provided a planned exit for the air flow which now flowed right through the locating features of the feed tray as opposed to over them as in the earlier generations of the feed tray. The Gen 3 tray worked 47 out of 50 times with the 3 malfunctions stemming from the bit not being sufficiently pushed into the locating features of the feed tray. This suggested that the bit was resting too high in the feed tray which lead to modifications in the skid plate design.

Figure 33 Gen 3 Feed Tray

4.3.3 Skid Plate Design

The skid plate is connected to the underside of the top block (Figure 35 and 36). Originally the surface of the skid plate was bare aluminum (Figure 34) but after several trials deep gouges started to appear on the surface of the skid plate. A steel skid was cut on the wire EDM and fitted to the top block for added protection. Initially the skid plate wasn’t a major design concern as it was thought that the feed tray was the main locator for the bit but after a several dozen tests it became apparent that the skid plate was partially responsible for decelerating, directing, and locating the bit in the Z axis (spindle axis of the FBJ welder) as it came out of the feed tube.

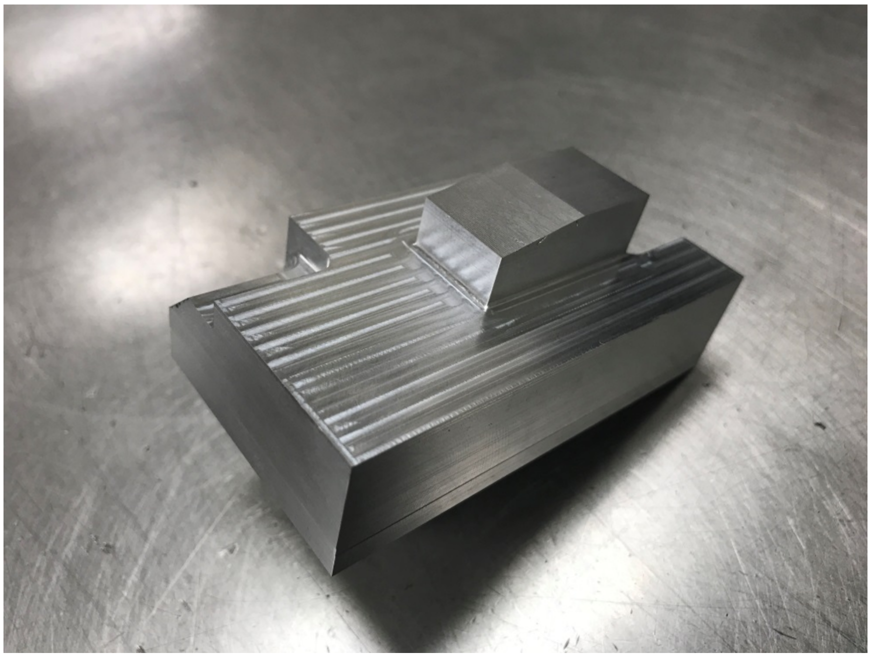

Figure 34 Original Top Clamp Block

At this time the Gen 1 feed tray was being tested and some of the bits had difficulty making it all the way into the locating features of the feed tray. It was thought that if the air flow was directed up and forward it would help the bit get into the proper position and increase the feed systems' ability to locate the bit properly. To do this a slot was made down the center of the skid plate to help the air go up and out the front of the feed tray (Figure 35). This change did help the bit get all the way to the front of the feed tray but because the air also directed the bits upward some bits would come out of the bit clamp because they were held by the very bottom edge of the bit head. Other bits would stay in the clamp but they would be held very loosely and would even come out as the feed tray extended to load the driver.

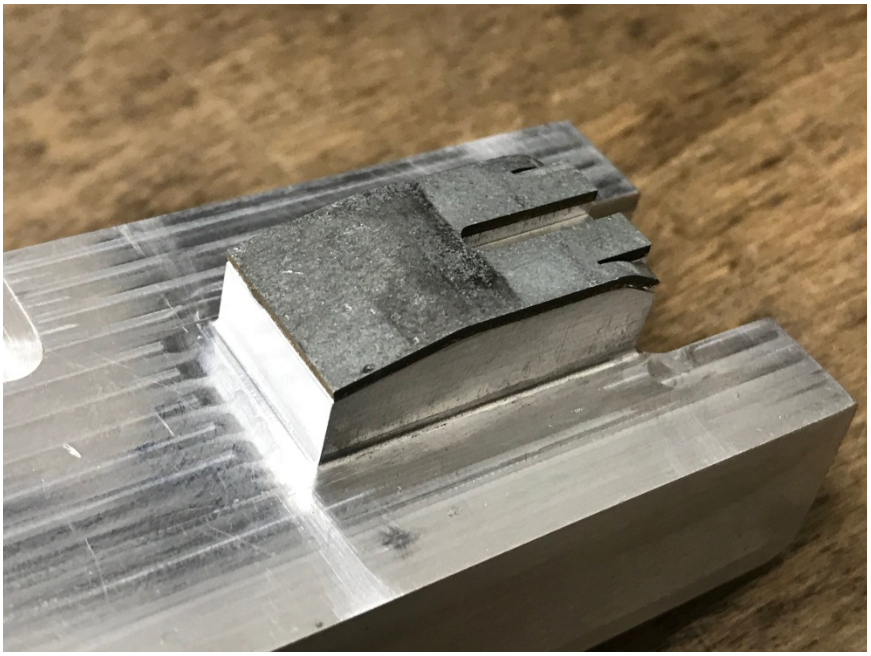

Figure 35 Slotted Skid Plate

The next iteration of the skid plate was a plate that had a small pin in the center of it (Figure 36). The pin was shaped so that it protruded out from the main surface of the skid plate (Figure 38). This pin held the bit down .64mm (.025 inches) into the feed tray jaws. This caused the bit to have more engagement with the feed tray and therefore have more holding power during the locating sequence (Figure 19).

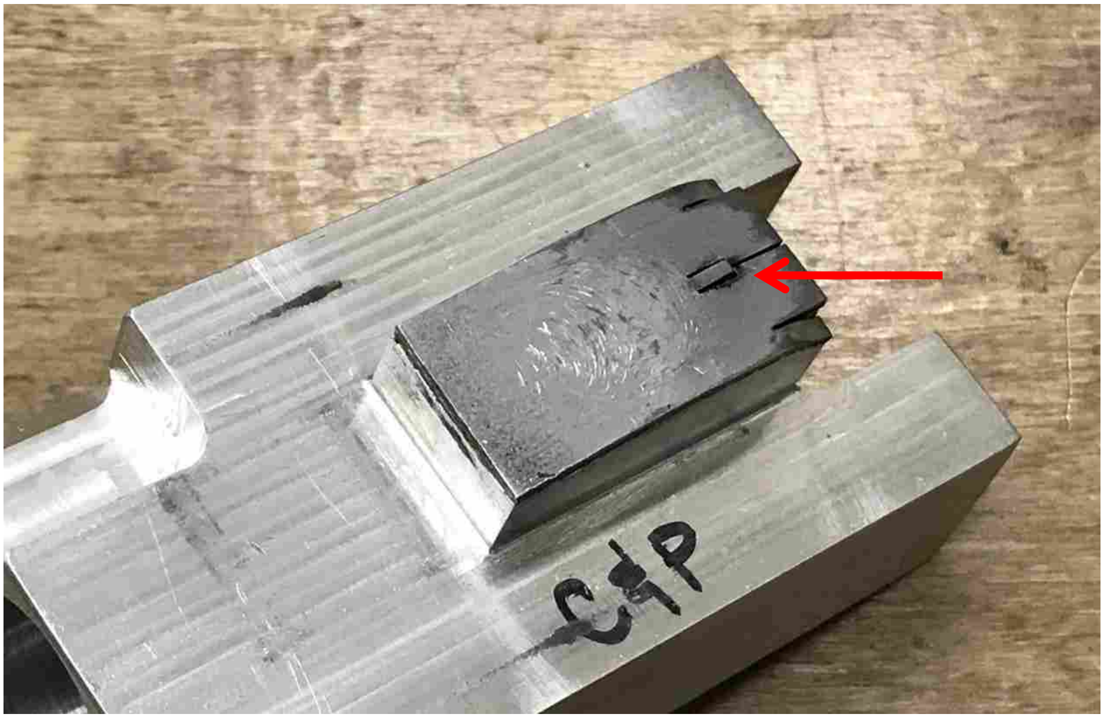

Figure 36 Pin Skid Plate Design, Pin Indicated by Arrow

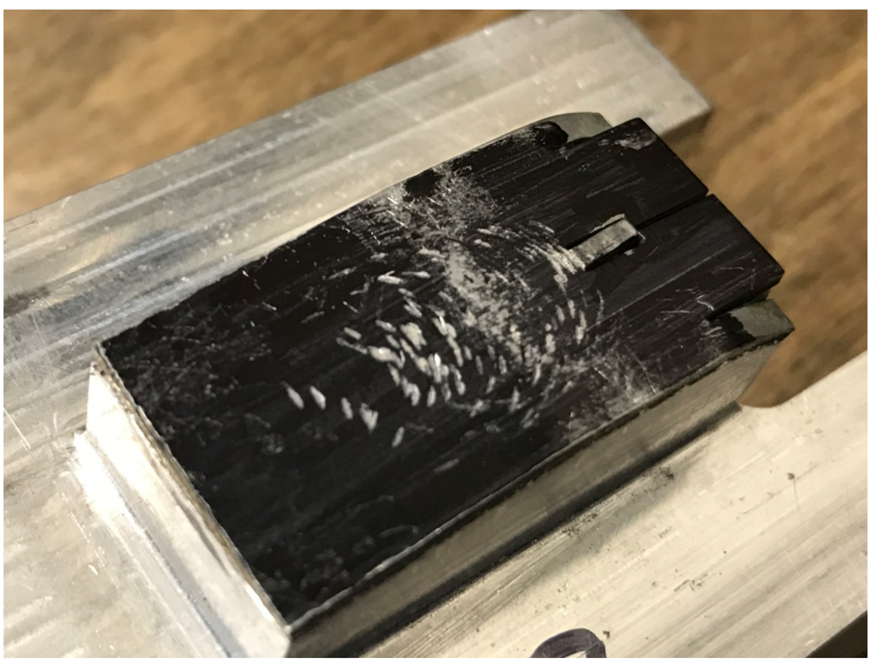

Figure 37 Pin Skid Plate Wear Pattern, Marked with Dye

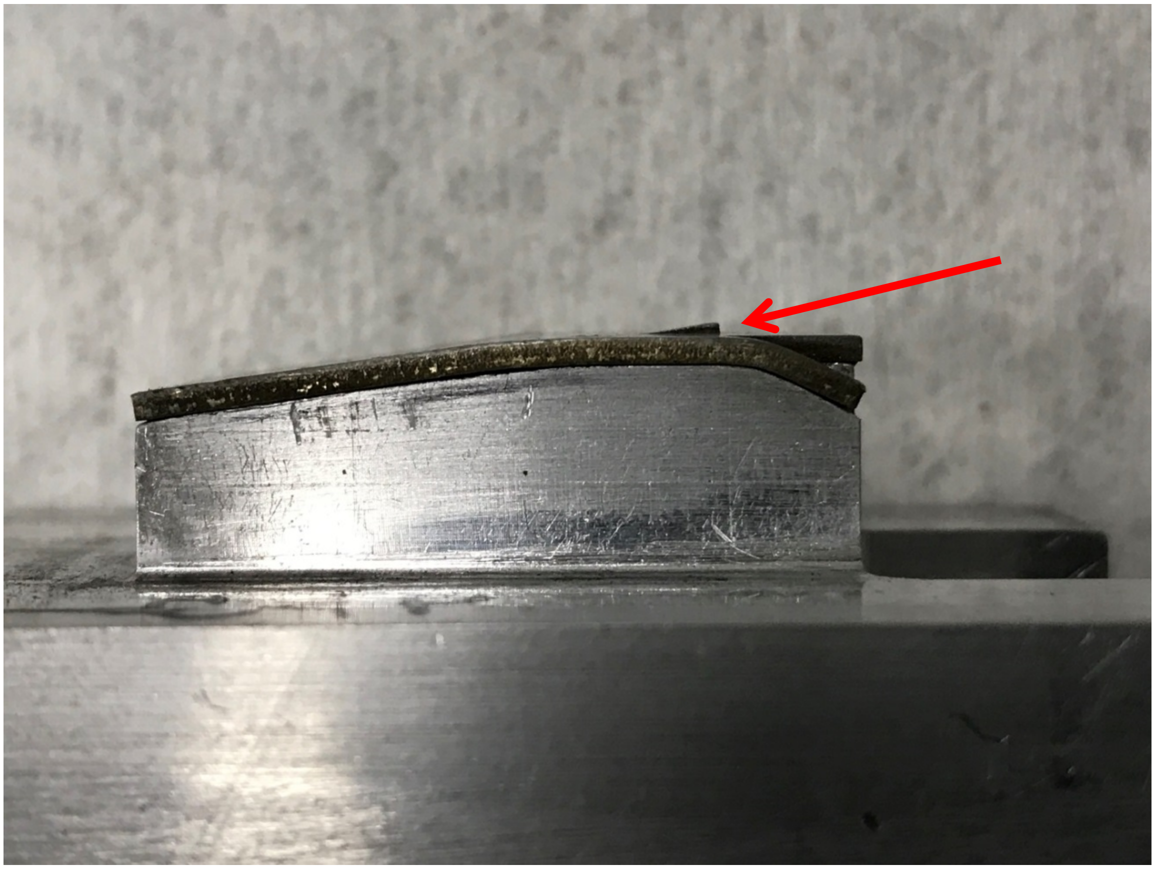

Figure 38 Skid Plate Pin (Red Arrow) Protruding .64mm (.025 Inch)

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research explored two hypotheses validating the mechanical conveyance and reloading performance of various systems that the research has design for the FBJ fastener.

1. Mechanical conveyance will be the most dependable method of conveyance for the FBJ fastener.

This research explored several different methods of conveyance and discovered that for bits of favorable geometry a feed tube system (pneumatic conveyance) can work quite well. The fasteners that did well in our testing were the bit variant 2 type. This type had no sharp external drive features and a low length to diameter ratio that helped the bit to not jam while traveling through a feed tube. These features combined proved to be favorable in terms of transportation. The results of this research rejected this hypothesis.

2. A type of mechanical jaw will provide the most repeatable reloading performance.

This research explored two main type of reloading devices and found that a reloading jaw gave more control that allowed the feed system to transfer bits with greater repeatability while holding them more securely. The bit reloading lever (Appendix A) did not have the holding power of the feed tray design; the bits in the reloading lever would often flip out of the front of the feed system when extended too fast or would prematurely release from their holding cup and mount incorrectly on the driver. The results of this research do not reject this hypothesis.

5.2 Recommendations

Further optimization could be done to the design of various components, namely the feed tube and the feed tray designs. The current feed tube is oversized, partially due to the length of the bit not being fully selected while the feed tube was made. The recommended feed tube would be closely contoured to the bit to reduce blow-by during bit transportation down the tube with pressurized air. However, it should be noted that the fit cannot be too as the cross sectional dimensions change as the tube is flexed and bent into different radiuses. Enough space around the bit is necessary to maintain proper tolerances throughout the tube while not too much space that the bit struggles to make it to the end of a 7-14 meter feed tube. The recommended feed tube could have a recess built into it to prevent the friction bit tip from digging into the plastic of the feed tube (Figure 39). While the newest feed tube did not have any jamming in over 1,200 trials experience with other designs suggests that the hardened bit will eventually dig into the softer plastic, especially when the bit is navigating tight radiuses in the feed system.

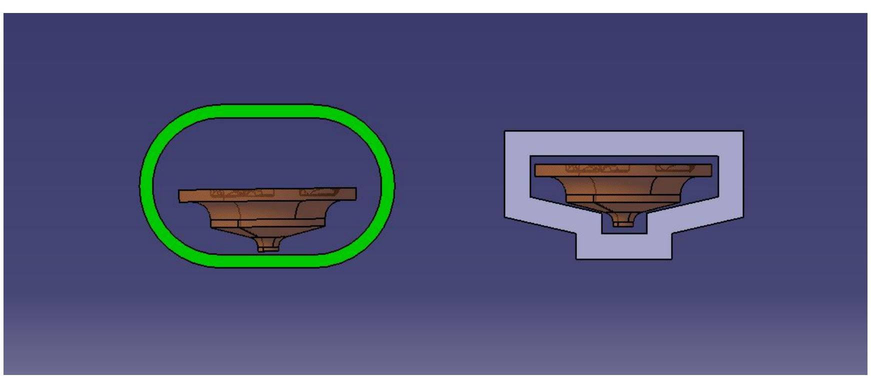

Figure 39 Current Feed Tube (Left) Recommended Feed Tube Design (Right)

The feed tray would greatly benefit from the use of superior jaw material. Feed ramp wear was a particular concern during testing. A properly heat treated D2 tool steel would probably do well for the feed ramp portion of the feed tray. The failure rate was also greatly reduced once the sharp edges of the bit head had been broken with sand paper and polished with a fine grit abrasive pad.

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APPENDICES

APPENDIX A

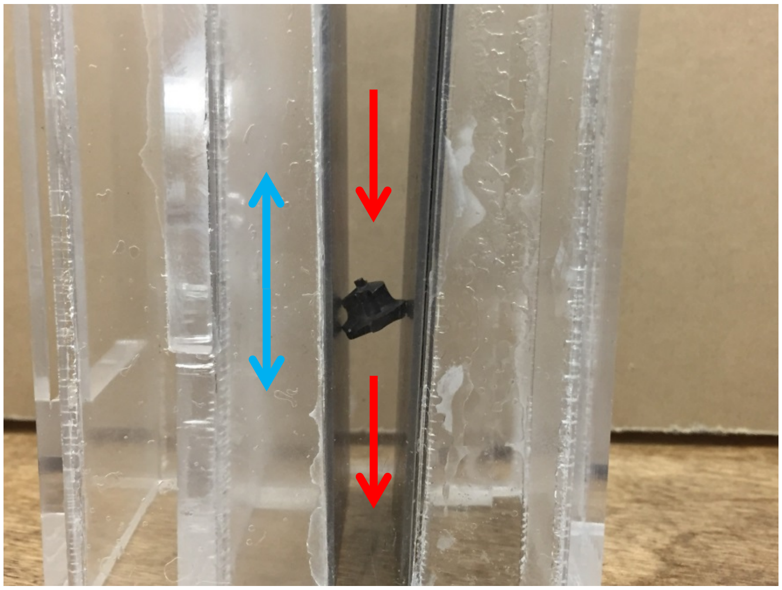
Initial Designs and Experiments

In the beginning it was important to understand the behavior of the bit. During this time we rolled the bit across flat surfaces, rolled and blew it through tubes, rolled it down ramps, and manipulated it with magnets.

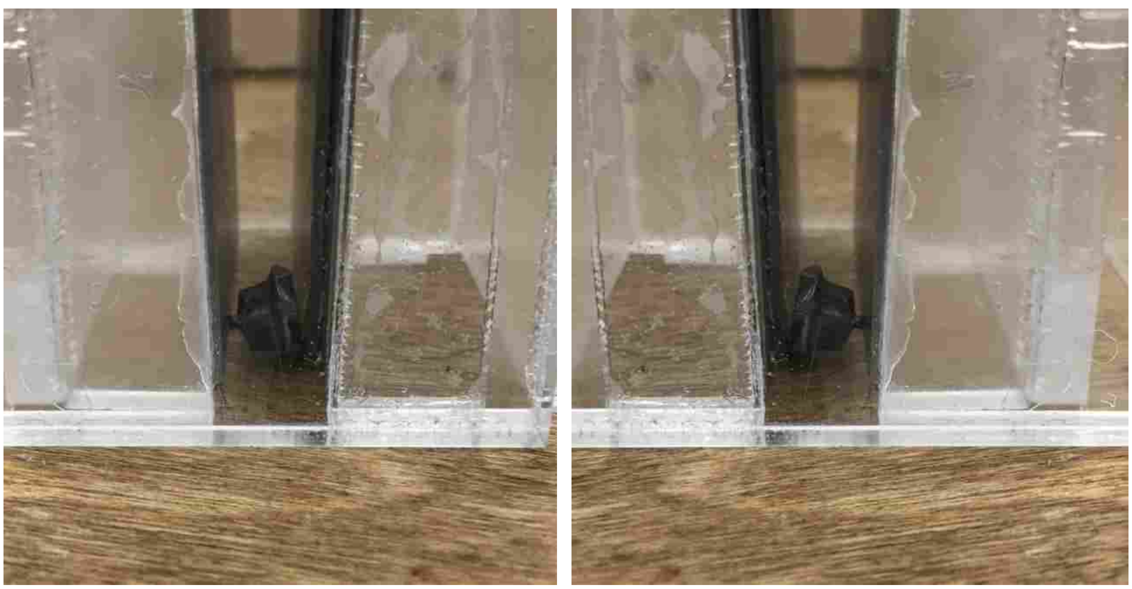
Textured Surface Used for Bit Orientation Testing

Magnetic Drag Experiment, Disoriented Bit left, Oriented Bit Right

We also wanted to explore orienting the bits to see if there was a way we could implement bit orientation into the feed system. At the time we were using bit variant 1 and using a blow feed tube was not feasible due to its tendency to tip over and jam in the feed tube. In one experiment we used two plates that formed a “V” shape to orient the bits. One plate was stationary and the other reciprocated up and down 6.35mm to increase the likelihood of orientation. This approach proved to be effective. It was able to orient 95%-98% of the bits that went into it during the trials. A major problem to the system was that sometimes, during the down stroke, a bit would be oriented in just the right way and jam the plates quite firmly. Some solutions to this problem were thought of but this design was discontinued due to a couple key concerns. The first being that the system relied heavily upon gravity, designs that used compressed air as a motive force were made but this added to the complexity to this design. The second concern was that the bit would come out in one of two orientations, either the head touching one plate or the other at the bottom of the device. So additional orientation would need to be done after going through this system, this added complexity proved to be the main reason that this system was discontinued.



Bit Orienting Plates, Bit Path in Red, Plate Movement in Blue

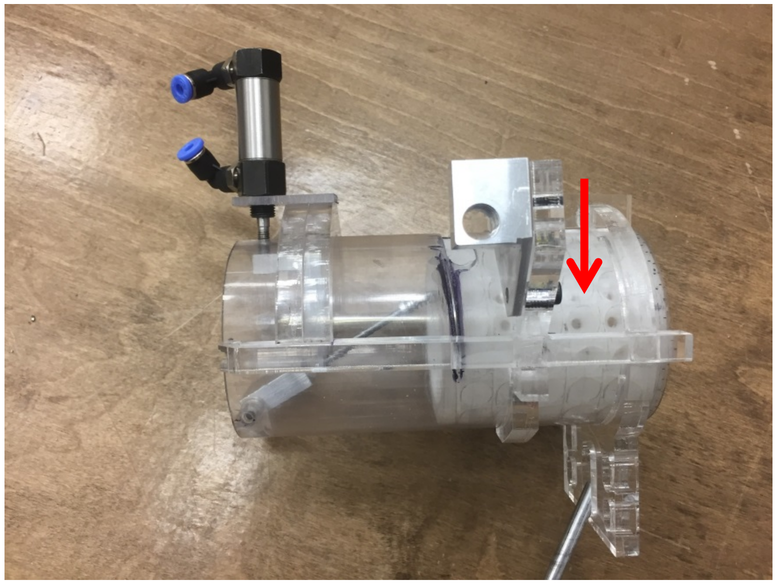


A Successful Orientation, Two Orientation Possibilities

We also explored the idea of storing the bits, already oriented correctly, in a magazine. We used a cylindrical magazine with a helical array of pockets that each held one bit.

Helical Magazine with Bits

This magazine was installed in an early feeder prototype that pushed out the bits from the inside of the cylinder to the outside. It used an armature powered by a pneumatic actuator with a small magnet attached at the end to pick up the bit in the magazine and push it through to a small carriage that would then take the bit to be loaded onto the driver. The small magnet securely holds the bit while the armature lowered the bit into the bit carriage. The helical magazine was indexed to the next bit by another pneumatic cylinder.

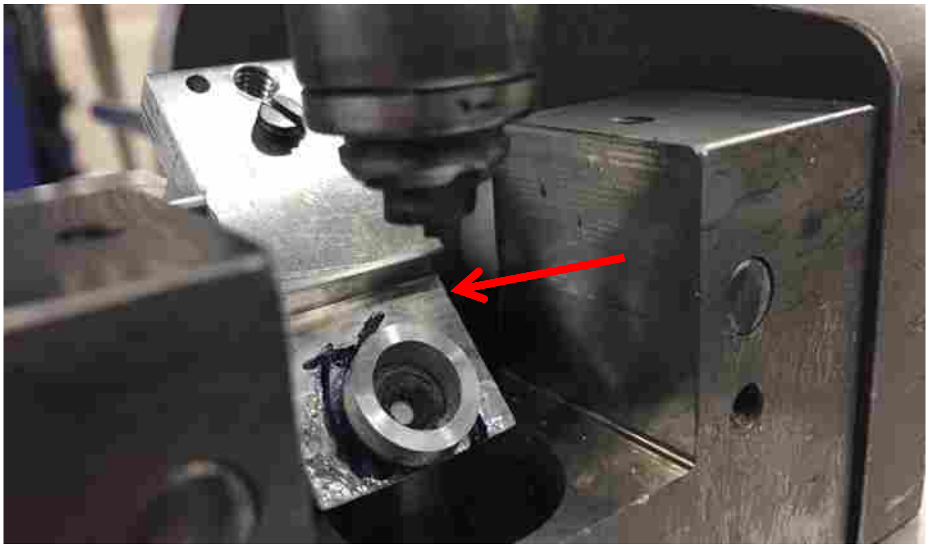


Early Feed System Prototype with Helical Magazine (Red Arrow)

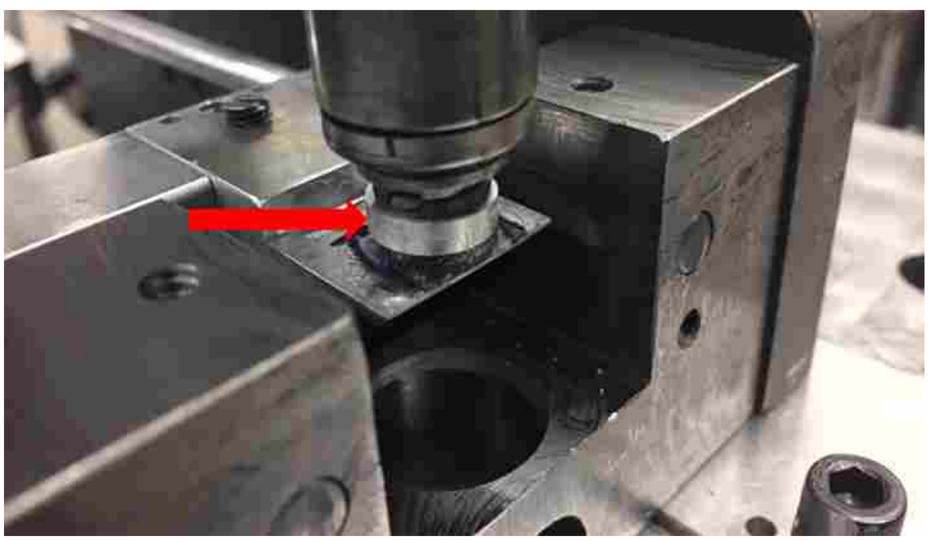
Inside the Early Prototype Feed System, Bit Armature (Red)

The Feed System in its Installed Position in the FBJ Welder

This system encountered a couple problems that eventually blocked its full implementation. First the system was quite large and difficult to fit in the space available in the FBJ welder. The helical magazine needs a hollow cavity to fit an armature to transport the bits to the bit carriage, this necessitated a larger diameter magazine to accommodate the travel of the armature per given diameter and wall thickness. Another problem with this design is the bit storage density, the system had a poor ability to store a large quantity of bits compared to the space it occupied as compared to the bits being aggregated together in a container. The helical magazine could only store bits in the outer wall; the cavity inside the magazine was needed for the armature that transported the bits to the bit carriage. We wanted a higher storage capacity to reduce the amount of reloading that needed to occur during use. And finally this system used magnets as the primary form of work holding. This became a problem as the bit was transferred from station to station within the feed system. Inconsistencies of bit location and environmental contamination caused variations in feed system performance. It was this experience that prompted the next iteration of bit holding that would eventually become the feed tray which uses mechanical grippers to firmly hold the bit.



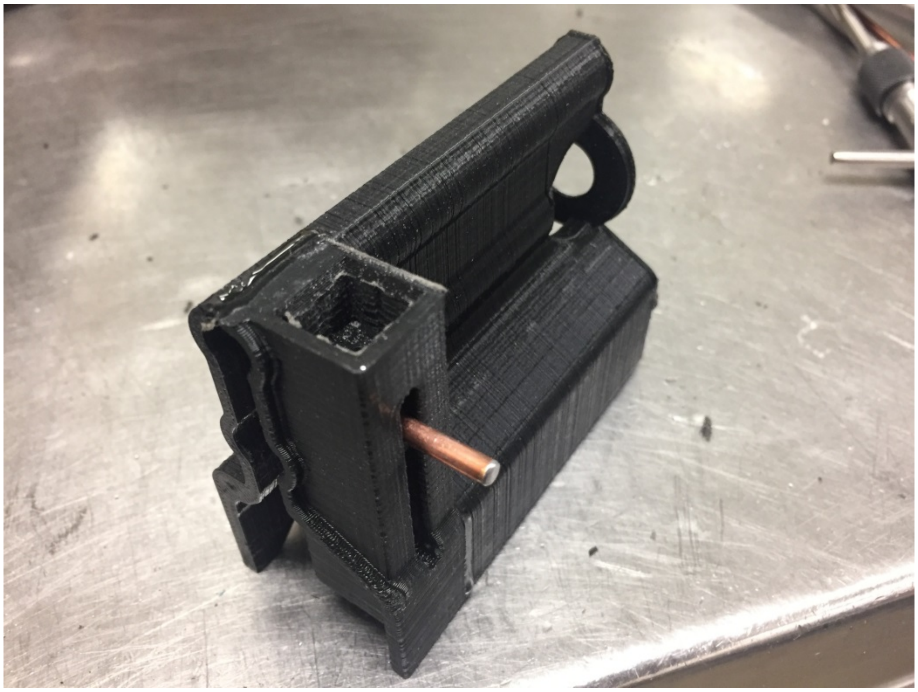
The Magnetic Loading Lever (Red) in the Down Position



Magnetic Loading Lever in the Up Position, Magnetic Cup Indicated by Red Arrow

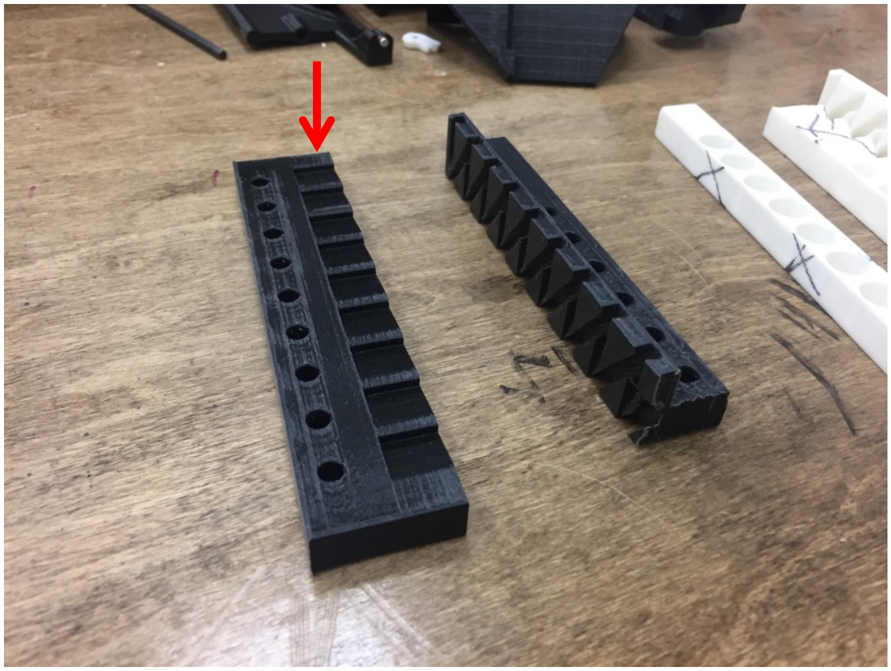
Inconsistencies in Magnets Caused Misfeeds

In order to try and simplify the helical magazine design straight magazines, and their accompanying frames, were made. These designs did work better than the helical magazine but they still relied on magnets which proved to be inconsistent at locating and holding onto the bit. The bits would often be attracted to the next magnet too early and attach to the magnet in an incorrect orientation.

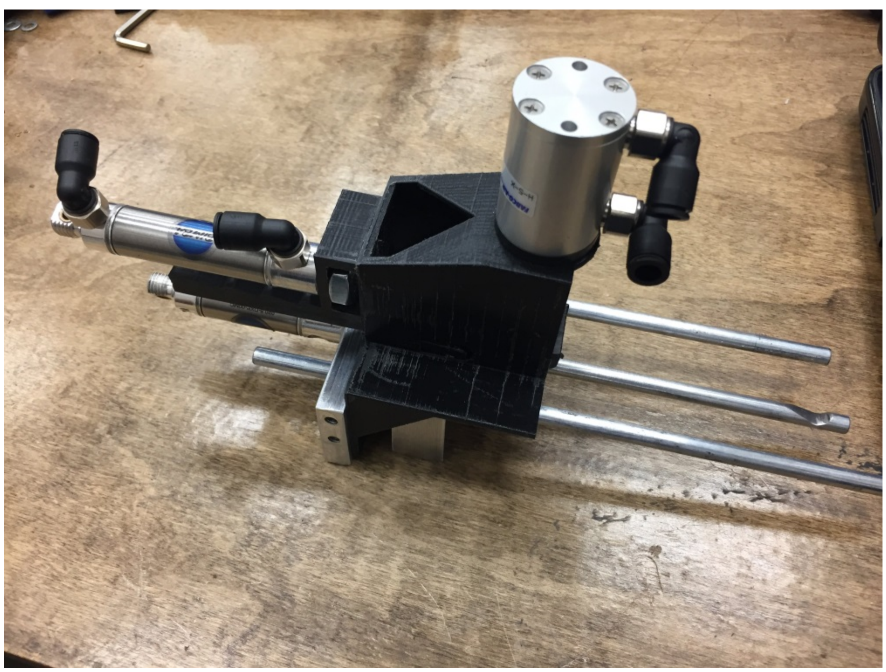


An Early Prototype Frame that Housed the Magazine and Bits

Various Frame and Magazine Designs



Early Straight Magazine Prototype, Ratchet Teeth Indicated by Red Arrow



Early Frame and Straight Magazine Prototype

APPENDIX B

Linear Actuator Pressure: 45 PSI (310264 Pa)			
Line Pressure 85 PSI (586054 Pa), steady at 60 PSI (413685 Pa) during use, 3 sec bursts			
90 degree spindle rotations			
Gen 1 feed tray			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	Yes		
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	No	Free tray ramp	Bit was found at an angle on the ramp
19	Yes		
20	Yes		
21	Yes		
22	Yes		
23	Yes		
24	Yes		
25	Yes		
26	Yes		
27	Yes		
28	No	Driver tip	Bit was not clocked correctly
29	Yes		
30	Yes		
31	Yes		
32	Yes		
33	No	Driver tip	Bit was not clocked correctly
34	Yes		
35	Yes		
36	Yes		
37	Yes		
38	Yes		
39	Yes		
40	Yes		
41	Yes		
42	Yes		
43	Yes		
44	Yes		
45	Yes		
46	Yes		
47	Yes		
48	Yes		
49	Yes		
50	Yes		
49	Yes		
50	Yes		

Linear Actuator Pressure: 45 PSI (310264 Pa)			
Feed Tube Pressure 90 PSI (620528 Pa), steady at 67 PSI (461949 Pa) during use, 4 sec bursts			
180 degree spindle rotation in closed position			
180 degree spindle rotation in open position			
Gen 2 feed tray			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	Yes		
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	No	Feed tray	Bit was not fully seated in tray locating features, the clamp block was replaced and a 2 sec blast of air seated it correctly, bit was successfully loaded on driver
19	Yes		
20	Yes		
21	Yes		
22	No	Feed tray	Bit was not fully seated in tray locating features, the clamp block was replaced and a 2 sec blast of air seated it correctly, bit was successfully loaded on driver
23	Yes		
24	Yes		
25	Yes		
26	Yes		
27	Yes		
28	Yes		
29	Yes		
30	Yes		
31	Yes		
32	Yes		
33	Yes		
34	No	Driver tip	Bit was not clocked correctly
35	Yes		
36	Yes		
37	No	Driver tip	Bit was not clocked correctly
38	Yes		
39	Yes		
40	Yes		
41	Yes		
42	Yes		
43	Yes		
44	Yes		
45	Yes		
46	No	Free tray ramp	Bit was found at an angle on the ramp
47	Yes		
48	Yes		
49	Yes		
50	No	Free tray ramp	Bit was found at an angle on the ramp

Linear Actuator Pressure: 55 PSI (379212 Pa)			
Feed Tube Pressure: 100 PSI (689476 Pa), steady at 73 PSI (503317 Pa) during use, 4 sec bursts			
360 degree spindle rotations for closed and open positions			
Extended steel pin skid plate, .026" high			
Gen 3 feed tray			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	No	Feed tray	Bit did not fully seat in locating features
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	Yes		
19	Yes		
20	Yes		
21	Yes		
22	Yes		
23	Yes		
24	Yes		
25	Yes		
26	Yes		
27	Yes		
28	Yes		
29	Yes		
30	No	Feed tray	Bit did not fully seat in locating features
31	Yes		
32	Yes		
33	Yes		
34	Yes		
35	Yes		
36	Yes		
37	Yes		
38	Yes		
39	Yes		
40	Yes		
41	Yes		
42	Yes		
43	Yes		
44	Yes		
45	Yes		
46	Yes		
47	Yes		
48	No	Feed tray	Bit did not fully seat in locating features
49	Yes		
50	Yes		

Linear Actuator Pressure: 55 PSI (379212 Pa)			
Feed Tube Pressure: 100 PSI (689476 Pa), steady at 73 PSI (503317 Pa) during use, 4 sec bursts			
360 degree spindle rotations			
Extended Steel Pin Skid Plate, .025" high			
Bit is Chamfered and lapped			
Bit tray closed-open technique			
Gen 3 feed tray			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	Yes		
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	Yes		
19	Yes		
20	Yes		
21	Yes		
22	Yes		
23	Yes		
24	Yes		
25	Yes		
26	Yes		
27	Yes		
28	Yes		
29	Yes		
30	Yes		
31	Yes		
32	Yes		
33	Yes		
34	Yes		
35	Yes		
36	Yes		
37	Yes		
38	Yes		
39	Yes		
40	Yes		
41	Yes		
42	Yes		
43	Yes		
44	Yes		
45	Yes		
46	Yes		
47	Yes		
48	Yes		
49	Yes		
50	Yes		
51	Yes		
52	Yes		
53	Yes		
54	Yes		
55	Yes		
56	Yes		
57	Yes		
58	Yes		
59	Yes		
60	Yes		
61	Yes		
62	Yes		
63	Yes		
64	Yes		
65	Yes		
66	Yes		
67	Yes		
68	Yes		
69	Yes		Ramp Sanded, extensive ramp surface degradation had occurred which may cause jamming
70	Yes		

71	No	Feed tray	Bit stuck to the side wall of feed tray.
72	Yes		
73	Yes		
74	Yes		
75	Yes		
76	Yes		
77	Yes		
78	Yes		
79	Yes		
80	Yes		
81	Yes		
82	Yes		
83	Yes		
84	Yes		
85	Yes		First picture of both tray and skid plate
86	Yes		
87	Yes		
88	Yes		
89	Yes		
90	Yes		
91	Yes		
92	Yes		
93	Yes		
94	Yes		
95	Yes		Black marker applied to ramp surfaces
96	Yes		
97	Yes		
98	Yes		
99	Yes		
100	Yes		
101	Yes		
102	Yes		
103	Yes		
104	Yes		
105	Yes		
106	Yes		
107	Yes		
108	Yes		
109	Yes		
110	Yes		
111	Yes		
112	Yes		
113	Yes		
114	Yes		
115	Yes		
116	Yes		
117	Yes		
118	Yes		
119	Yes		
120	Yes		
121	Yes		
122	Yes		
123	Yes		
124	Yes		
125	Yes		
126	Yes		
127	Yes		
128	Yes		
129	Yes		
130	Yes		
131	Yes		
132	Yes		
133	Yes		
134	Yes		
135	Yes		
136	Yes		
137	Yes		
138	Yes		
139	Yes		
140	Yes		
141	Yes		
142	Yes		
143	Yes		
144	Yes		
145	Yes		
146	Yes		
147	Yes		
148	Yes		
149	Yes		
150	Yes		

151	Yes		
152	Yes		
153	Yes		
154	Yes		
155	Yes		
156	Yes		
157	Yes		
158	Yes		
159	Yes		
160	Yes		
161	Yes		
162	Yes		
163	Yes		
164	Yes		
165	Yes		Bit re-greased
166	Yes		
167	Yes		
168	Yes		
169	Yes		
170	Yes		
171	Yes		
172	Yes		
173	Yes		
174	Yes		
175	Yes		
176	Yes		
177	Yes		
178	Yes		
179	Yes		
180	Yes		
181	Yes		
182	Yes		
183	Yes		Feed tray ramp resanded and remarked with marker
184	Yes		
185	Yes		
186	Yes		
187	Yes		
188	Yes		
189	Yes		

190	Yes		
191	Yes		
192	Yes		
193	Yes		
194	Yes		
195	Yes		
196	Yes		
197	Yes		
198	Yes		
199	Yes		
200	Yes		
201	Yes		
202	Yes		
203	Yes		
204	Yes		
205	Yes		
206	Yes		
207	Yes		
208	Yes		
209	Yes		
210	Yes		Bit re-greased, ramp and skid surfaces sanded
211	Yes		
212	Yes		
213	Yes		
214	Yes		
215	Yes		
216	Yes		
217	Yes		
218	Yes		
219	Yes		
220	Yes		
221	Yes		
222	Yes		
223	Yes		
224	Yes		
225	Yes		
226	Yes		
227	Yes		
228	Yes		
229	Yes		

230	Yes		
231	Yes		
232	Yes		
233	Yes		
234	Yes		
235	Yes		
236	Yes		
237	Yes		
238	Yes		
239	Yes		
240	Yes		
241	Yes		
242	Yes		
243	Yes		
244	Yes		
245	Yes		
246	Yes		
247	Yes		
248	Yes		
249	Yes		
250	Yes		

Linear Actuator Pressure: 55 PSI (379212 Pa)			
Feed Tube Pressure: 100 PSI (689476 Pa), steady at 73 PSI (503317 Pa) during use, 4 sec bursts			
360 degree spindle rotations in closed and open positions			
Extended Steel Pin Skid Plate, .025" high			
Bit is chamfered and lapped			
Bit tray closed-open technique			
Gen 3 feed tray			
Feed system in 90 degree orientation			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	Yes		
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	Yes		
19	Yes		
20	Yes		
21	Yes		
22	Yes		
23	Yes		
24	Yes		
25	Yes		
26	Yes		
27	Yes		
28	Yes		
29	Yes		
30	Yes		
31	Yes		
32	Yes		
33	Yes		
34	Yes		
35	Yes		
36	Yes		resanded feed ramp
37	Yes		
38	Yes		
39	Yes		
40	Yes		
41	Yes		
42	Yes		
43	Yes		
44	Yes		
45	Yes		
46	Yes		
47	Yes		
48	Yes		
49	Yes		
50	Yes		
51	Yes		
52	Yes		
53	Yes		
54	Yes		
55	Yes		
56	Yes		
57	Yes		
58	Yes		
59	Yes		
60	Yes		
61	Yes		
62	Yes		
63	Yes		
64	Yes		
65	Yes		
66	Yes		
67	Yes		resanded ramp, regreased bit
68	Yes		
69	Yes		
70	Yes		
71	Yes		
72	Yes		
73	Yes		
74	Yes		
75	Yes		

76	Yes		
77	Yes		
78	Yes		
79	Yes		
80	Yes		
81	Yes		
82	Yes		
83	Yes		
84	Yes		
85	Yes		
86	Yes		
87	Yes		
88	Yes		
89	Yes		
90	Yes		
91	Yes		
92	Yes		
93	Yes		
94	Yes		
95	Yes		
96	Yes		
97	Yes		
98	Yes		
99	Yes		
100	Yes		ramp resanded
101	Yes		
102	Yes		
103	Yes		
104	Yes		
105	Yes		
106	Yes		
107	Yes		
108	Yes		
109	Yes		
110	Yes		
111	Yes		
112	Yes		
113	Yes		
114	Yes		
115	Yes		
116	Yes		
117	Yes		
118	Yes		

119	Yes		
120	Yes		
121	Yes		
122	Yes		
123	Yes		
124	Yes		
125	Yes		
126	No	Feed tray	bit was not fully seated into locating features
127	Yes		
128	Yes		
129	Yes		
130	Yes		
131	Yes		
132	Yes		
133	Yes		
134	Yes		
135	Yes		
136	Yes		
137	Yes		
138	Yes		
139	Yes		
140	Yes		
141	Yes		
142	Yes		
143	Yes		
144	Yes		
145	Yes		
146	Yes		
147	Yes		
148	Yes		
149	Yes		
150	Yes		
151	Yes		
152	Yes		
153	Yes		
154	Yes		
155	Yes		
156	Yes		
157	Yes		
158	Yes		
159	Yes		

160	Yes		
161	Yes		
162	Yes		
163	Yes		
164	Yes		
165	Yes		
166	Yes		ramp resanded
167	Yes		
168	Yes		
169	Yes		
170	Yes		
171	Yes		
172	Yes		
173	Yes		
174	Yes		
175	Yes		
176	Yes		
177	Yes		
178	Yes		
179	Yes		
180	Yes		
181	Yes		
182	Yes		
183	Yes		
184	Yes		
185	Yes		
186	Yes		
187	Yes		
188	Yes		
189	Yes		
190	Yes		
191	Yes		
192	Yes		
193	Yes		
194	Yes		
195	Yes		
196	Yes		
197	Yes		
198	Yes		
199	Yes		
200	Yes		

Linear Actuator Pressure: 55 PSI (379,212 Pa)			
Feed Tube Pressure: 100 PSI (689,476 Pa), steady at 73 PSI (503,317 Pa) during use, 4 sec bursts			
360 degree spindle rotations in closed and open positions			
Extended Steel Pin Skid Plate, .025" high			
Bit is chamfered and lapped			
Bit tray closed-open technique			
Gen 3 feed tray			
Feed system in 180 degree orientation			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	Yes		
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	Yes		
19	Yes		
20	Yes		
21	Yes		
22	Yes		
23	Yes		
24	Yes		
25	Yes		
26	Yes		
27	Yes		
28	Yes		
29	Yes		
30	Yes		
31	Yes		
32	Yes		
33	Yes		
34	Yes		
35	Yes		
36	Yes		
37	Yes		
38	Yes		
39	Yes		
40	Yes		
41	Yes		
42	Yes		
43	Yes		
44	Yes		
45	Yes		
46	Yes		
47	Yes		
48	Yes		
49	Yes		
50	Yes		
51	Yes		
52	Yes		
53	Yes		
54	Yes		
55	Yes		
56	Yes		
57	Yes		
58	Yes		
59	Yes		
60	Yes		
61	Yes		
62	Yes		
63	Yes		
64	Yes		
65	Yes		
66	Yes		
67	Yes		
68	Yes		
69	Yes		
70	Yes		
71	No	Feed tray	Bit was not fully seated into locating features, bit was re located using air and the feed was successful
72	Yes		
73	Yes		

74	Yes		
75	Yes		
76	Yes		
77	Yes		
78	Yes		
79	No	Feed tray	Bit was not fully seated into locating features, bit was re located using air and the feed was successful
80	Yes		
81	Yes		
82	Yes		
83	Yes		
84	Yes		
85	Yes		
86	Yes		
87	No	Feed tray	Bit was not fully seated into locating features, bit was relocated using air and the feed was successful
88	Yes		Air line pressure turned up to 106 psi, 88psi during use
89	Yes		
90	Yes		
91	Yes		
92	Yes		
93	Yes		
94	Yes		
95	Yes		
96	Yes		
97	Yes		
98	Yes		
99	Yes		
100	Yes		
101	Yes		
102	Yes		
103	Yes		
104	Yes		
105	Yes		
106	Yes		
107	Yes		
108	Yes		
109	Yes		
110	Yes		
111	Yes		
112	Yes		
113	Yes		
114	Yes		
115	Yes		
116	Yes		
117	Yes		
118	Yes		
119	Yes		
120	Yes		
121	Yes		
122	Yes		
123	Yes		
124	Yes		
125	Yes		
126	Yes		
127	Yes		
128	Yes		
129	Yes		
130	Yes		
131	Yes		
132	Yes		
133	Yes		
134	Yes		
135	Yes		
136	Yes		
137	Yes		
138	Yes		
139	Yes		
140	Yes		
141	Yes		
142	Yes		
143	Yes		
144	Yes		
145	Yes		
146	Yes		
147	Yes		
148	Yes		
149	Yes		
150	Yes		

151	Yes		
152	Yes		
153	Yes		
154	Yes		
155	Yes		
156	Yes		
157	Yes		
158	Yes		
159	Yes		
160	Yes		
161	Yes		
162	Yes		
163	Yes		
164	Yes		
165	Yes		
166	Yes		
167	Yes		
168	Yes		
169	Yes		
170	Yes		
171	Yes		
172	Yes		
173	Yes		
174	Yes		
175	Yes		
176	Yes		
177	Yes		
178	Yes		
179	Yes		
180	Yes		
181	Yes		
182	Yes		
183	Yes		
184	Yes		
185	Yes		
186	No	Feed tray	Bit was not fully seated into locating features, bit was relocated using air and the feed was successful
187	Yes		
188	Yes		
189	Yes		
190	Yes		
191	Yes		
192	Yes		
193	Yes		
194	Yes		
195	Yes		
196	Yes		
197	Yes		
198	Yes		
199	Yes		
200	Yes		

Linear Actuator Pressure 55 PSI (379,212 Pa)			
Feed tube pressure: 106 PSI (730,844 Pa), 88 PSI (606,739 Pa) during use			
360 degree spindle rotations in closed and open positions			
Extended Steel Pin Skid Plate, .025" high			
Bit is chamfered and lapped			
Bit tray closed-open technique			
Gen 3 feed tray			
Z+ Orientation			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	Yes		
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	Yes		
19	Yes		
20	Yes		
21	Yes		
22	Yes		
23	Yes		
24	No	Driver tip	Bit not clocked correctly in driver tip, although it was aligned correctly, possibly a cause of "clutching"
25	Yes		
26	Yes		
27	Yes		
28	Yes		
29	Yes		
30	Yes		
31	Yes		
32	Yes		
33	Yes		
34	Yes		
35	Yes		
36	Yes		
37	Yes		
38	No	Driver tip	Bit not clocked correctly in driver tip, not located in the feed ramp
39	Yes		
40	Yes		
41	Yes		
42	Yes		
43	Yes		
44	Yes		
45	Yes		
46	Yes		
47	Yes		
48	Yes		
49	Yes		
50	Yes		
51	Yes		
52	Yes		
53	Yes		
54	Yes		
55	Yes		
56	Yes		
57	Yes		
58	Yes		
59	Yes		
60	Yes		
61	Yes		
62	Yes		
63	No	Driver tip	Bit not clocked correctly in driver tip, although it was aligned correctly, possibly a cause of "clutching"
64	Yes		

65	No	Feed ramp	When tray was extended the bit fell back down in the tube, the bit was re-blown and located correctly and was successfully loaded on the driver tip
66	Yes		
67	Yes		
68	Yes		
69	Yes		
70	Yes		
71	Yes		
72	Yes		
73	Yes		
74	Yes		
75	Yes		
76	Yes		
77	Yes		
78	Yes		
79	Yes		
80	Yes		
81	Yes		
82	Yes		
83	Yes		
84	Yes		
85	Yes		
86	Yes		
87	Yes		
88	Yes		
89	Yes		
90	Yes		
91	Yes		
92	Yes		
93	Yes		
94	Yes		
95	Yes		
96	Yes		
97	Yes		
98	Yes		
99	Yes		
100	Yes		
101	Yes		
102	Yes		

103	Yes		
104	Yes		
105	Yes		
106	Yes		
107	Yes		
108	Yes		
109	Yes		
110	Yes		
111	Yes		
112	Yes		
113	Yes		
114	Yes		
115	Yes		
116	Yes		
117	Yes		
118	Yes		
119	Yes		
120	Yes		
121	Yes		
122	Yes		
123	Yes		
124	Yes		
125	Yes		
126	Yes		
127	Yes		
128	Yes		
129	Yes		
130	Yes		
131	Yes		
132	Yes		
133	Yes		
134	Yes		
135	Yes		
136	Yes		
137	Yes		
138	Yes		
139	Yes		
140	Yes		
141	Yes		
142	Yes		
143	Yes		
144	Yes		
145	Yes		

146	Yes		
147	Yes		
148	Yes		
149	Yes		
150	Yes		
151	Yes		
152	Yes		
153	Yes		
154	Yes		
155	Yes		
156	Yes		
157	Yes		
158	Yes		
159	Yes		
160	Yes		
161	Yes		
162	Yes		
163	Yes		
164	Yes		
165	Yes		
166	No	Driver tip	Bit not clocked correctly in driver tip
167	Yes		
168	Yes		
169	Yes		
170	Yes		
171	Yes		
172	Yes		
173	Yes		
174	Yes		
175	Yes		
176	Yes		
177	Yes		
178	Yes		
179	Yes		
180	Yes		
181	Yes		
182	Yes		
183	Yes		
184	No	Feed ramp	When tray was extended the bit fell back down in the tube, the bit was re-blown and located correctly and was successfully loaded on the driver tip, a feedback loop could possibly correct most failure to feed scenarios
185	Yes		
186	Yes		
187	Yes		
188	Yes		
189	Yes		
190	Yes		
191	Yes		
192	Yes		
193	Yes		
194	Yes		
195	Yes		
196	Yes		
197	Yes		
198	Yes		
199	Yes		
200	Yes		

Linear Actuator Pressure 55 PSI (379,212 Pa)			
Feed tube pressure: 106 PSI (730,844 Pa), 88 PSI (606,739 Pa) during use			
360 degree spindle rotations in closed and open positions			
Extended steel pin skid plate, .025" high			
Bit is chamfered and lapped			
Bit tray closed-open technique			
Gen 3 feed tray			
Z- Orientation			
TRIAL	SUCCESS	FAILURE LOCATION	NOTES
1	Yes		
2	Yes		
3	Yes		
4	Yes		
5	Yes		
6	Yes		
7	Yes		
8	Yes		
9	Yes		
10	Yes		
11	Yes		
12	Yes		
13	Yes		
14	Yes		
15	Yes		
16	Yes		
17	Yes		
18	Yes		
19	Yes		
20	Yes		
21	Yes		
22	Yes		
23	Yes		
24	Yes		
25	Yes		
26	Yes		
27	Yes		
28	Yes		
29	Yes		
30	Yes		
31	Yes		
32	Yes		
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35	Yes		
36	Yes		
37	Yes		
38	Yes		
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42	Yes		
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63	Yes		
64	Yes		
65	Yes		
66	Yes		
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69	Yes		
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87	Yes		
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90	Yes		
91	Yes		
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93	Yes		
94	Yes		
95	Yes		
96	Yes		
97	Yes		
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102	Yes		
103	Yes		
104	Yes		
105	Yes		
106	Yes		
107	Yes		
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109	Yes		
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112	Yes		
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114	Yes		
115	Yes		
116	Yes		
117	Yes		
118	Yes		
119	Yes		
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121	Yes		
122	Yes		
123	Yes		
124	Yes		
125	Yes		
126	Yes		
127	Yes		
128	Yes		
129	Yes		
130	Yes		
131	Yes		
132	Yes		
133	Yes		
134	Yes		
135	Yes		
136	Yes		
137	Yes		
138	Yes		
139	Yes		
140	Yes		
141	Yes		
142	Yes		
143	Yes		
144	Yes		
145	Yes		
146	Yes		
147	Yes		
148	Yes		
149	Yes		
150	Yes		
151	Yes		
152	Yes		
153	Yes		
154	Yes		
155	Yes		
156	Yes		
157	Yes		
158	Yes		
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160	Yes		
161	Yes		
162	Yes		
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164	Yes		
165	Yes		
166	Yes		
167	Yes		
168	Yes		
169	Yes		
170	Yes		
171	Yes		
172	Yes		
173	Yes		
174	Yes		
175	Yes		
176	Yes		
177	Yes		
178	Yes		
179	Yes		
180	Yes		
181	Yes		
182	Yes		
183	Yes		
184	Yes		
185	Yes		
186	Yes		
187	Yes		
188	Yes		
189	Yes		
190	Yes		
191	Yes		
192	Yes		
193	Yes		
194	Yes		
195	Yes		
196	Yes		
197	Yes		
198	Yes		
199	Yes		
200	Yes		