Project Number: ME-CAB-SKI

MOTORIZED SKI GATE WRENCH

A Major Qualifying Project Report

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

In Mechanical Engineering

by

____

Ryan P. Foley

____

Benjamin G. Hawkins

Approved by:

____

Christopher A. Brown

Date: 30 April, 2010

Keywords:

1. Slalom ski pole
2. Static gate wrench
3. Powered open ended wrench
4. Gear Redundancies

Abstract

The objective of this project is to design, manufacture, and test an open-ended powered wrench to accelerate and aid the process of installing alpine racing slalom poles into the snow for alpine race course sets. Easy to find and purchase manual gate wrenches are slow and tiresome to use. Our final designed, constructed, and tested device will be a motorized slalom gate wrench with forward, neutral, and reverse. It utilizes an open gear for horizontal engagement of the slalom pole rather than axial.

Acknowledgements

We would like to thank:

Adam Sears (WPI)

Christopher A Brown (WPI Project Advisor)

Torbjorn S. Bergstrom (WPI)

Acclaro

HAAS

Esprit

SolidWorks

This project would not have been successfully completed without their support.

Table of Contents

Table of Figures

1 Introduction

1.1 Objective

To create a functional prototype that will quickly and easily install ski racing gates. We are going to design and build a prototype of the device, as well as test it in the field, and address any issues that may arise.

1.2 Rationale

Using current technology, setting a course can be very time-consuming and burdening on the course setters. This device has been designed and manufactured in order to improve on both of these issues, and provide a quicker method of installing ski gates while also using less effort.

1.3 State of the Art

The original method of installing gates is through the use of a manual gate wrench. It is a simple device that hooks onto the gate and is manually turned until the gate is installed. It is a simple design and relatively cheap to manufacture.

Another current method for installing gates is the ratcheting gate wrench. There is a previous MQP that designed a wrench that only requires the user to rotate the handles partially, and they can then be rotated back. Along with this MQP, there is a product called Ratchet Key, which is similar to the previous MQP, in that it is a ratcheting wrench. Both of these designs allow for a quicker installation than the manual wrench.

There is currently a patent for a powered ski gate wrench. It is a sketch of the basic concept for an open-ended gate wrench; simply an open drive gear with two driving gears. There are no bearing surfaces or ways to keep all moving parts in the correct position. The patent uses an outside power source to drive the device i.e. any kind of powered drill. There are, however, no current consumer products similar to this patent.

1.4 Approach

Current technology is a manual approach to installing ski gate poles. The ratcheting device, while easier than the static wrench, is still requires a lot of excess energy to install a pole into the snow. The motorized ski gate wrench looks to eliminate unnecessary use of energy in the installation of ski gate poles by requiring the user to simply hold the device in place while it screws the pole into the snow.

The process of axiomatic design was utilized to complete the design portion of this project. This follows two basic axioms:

1. Maximize the independence
2. Minimize the information

Axiomatic design consists of breaking down a task into functional requirements. These functional requirements need to be collectively exhaustive and mutually exclusive. This maximizes the independence. By breaking down what the design needs to accomplish, axiomatic design is able to show the designer the finer details of the task. This also helps to make designs that are more readily changed because changing one piece of it will not affect the requirements. This is called decoupling (Suh).

Each functional requirement is assigned one, and only one, design parameter. A design parameter is basically the physical piece that satisfies the functional requirement. Each design parameter only fulfills one functional requirement as well. This minimizes the information content. A design with more design parameters than functional requirements will just have more pieces that could fail and do not add the functionality of the device (Suh).

2 Design Decomposition and Constraints

The primary functional requirement of the design is to install and uninstall alpine slalom racing poles. This is FR0. This was further broken down into three upper-level functional requirements that are necessary for the task. The first, FR1, is to apply a vertical force to the top of the slalom pole base. The second, FR2, is to apply a torque to the slalom pole base. And third, FR3 is to allow for horizontal engagement of the pole so the user does not have to lift the device up over the top of the slalom pole. The constraint that affected the outcome of the design is the budget of the project because it limited the material selection. See Figure 1 for an example of where some FRs have been physically integrated.

2.1 FR1: Apply Vertical Force

The vertical force on the base of the slalom initiates the threads tapping and screwing into the snow. FR1 is broken down into two sub-functional requirements. The first is to have the user to provide the vertical force, and the second is to have the device transmit the force to the top of the slalom pole base. In doing this the device will need to transmit a vertical force from static parts to a rotating shaft.

2.2 FR2 Apply a Torque to Base of Slalom Pole

The application of a torque is slightly more complicated than the application of the vertical force. First a power source is needed that is mobile. This will power a torque supply system, such as an electric motor. This needs to be able to be controlled by the user. The amount of torque applied needs to be adjustable and the torque needs to be supplied in forward and reverse.

The torque supply needs to be attached to the device. This device needs to be lightweight while maintain structural integrity. The geometry needs to match that of the frame tube to be able to be attached to it. To make everything line up easier, the position should be adjustable relative to the frame tube. The torque supply needs to be securely attached to this device.

The torque from the supply needs to be applied to the main shaft. This can be done with a gearbox. Inside the gearbox the friction of moving parts needs to be minimized. Also the gears need to be lined up, as well as the shafts. Also the right amount of torque necessary to screw in the base needs to be applied. This is done with a gear reduction explained in the physical integration section. The final part of FR2 is to transfer the torque from the main shaft to the base of the slalom pole.

2.3 FR3 Allow for Horizontal Engagement of the Slalom Pole

Static wrenches have the ability to engage the slalom pole from the side. This is very important for the design to compete with the traditional gate wrenches. The first portion of this FR is to allow the pole to engage the entire device horizontally. All the parts from the main shaft out will need to be able to allow the pole to travel through it. The second portion is to allow full rotation of the main drive shaft with the slot in it.

To accomplish this, the gearbox needs to apply torque to the drive gear of the main shaft at all times. This piece of the FR is the key to the fully functional design. This portion of the design also couples most of the design. Although the key to axiomatic design is to decouple all of the functional requirements, this part of the functional requirement coupled the engaging parts of the design together.

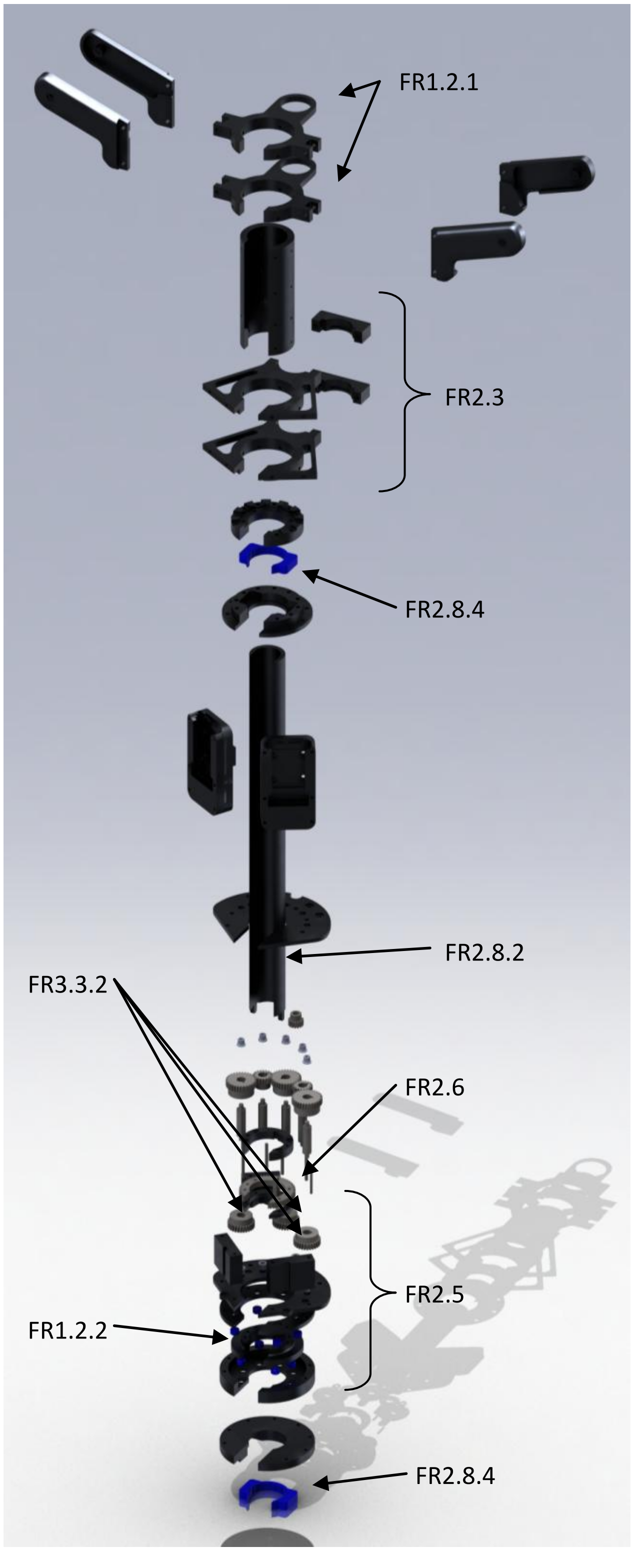


Figure 1: Exploded view of device with some FRs labeled

3 Physical Integration

Once the functional requirements and design parameters have been established they need to be integrated into a physical design. Using SolidWorks Computer Aided Drafting (CAD), the design parameters were assimilated into all the various parts that make up the assembly of the entire device that fulfills FR0. With CAD it is very easy to see how the parts will mate together before production begins, thereby avoiding parts not fitting together and work properly. SolidWorks also has useful tools like a simplified Finite Element Analysis tool to easily determine if a part will fail under given loads, and the dimension tools that allow tolerances to be added to the nominal dimension based on fit types.

3.1 Vertical Force Transmission

The first upper level functional requirement is to transmit a vertical force from the user to the top of the base of the slalom pole. The user will interface with the parts that make up the handle. Here the user will provide a downward force from the palms of his hands to the device.

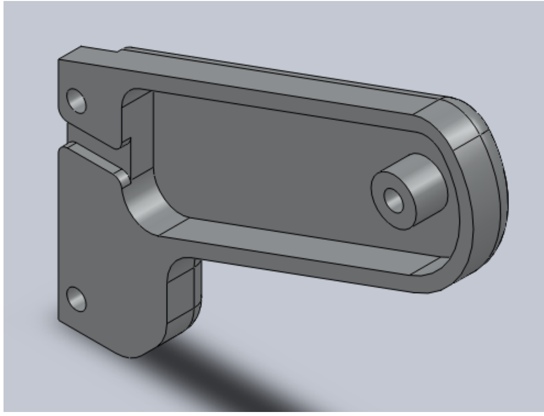


Figure 2: Isometric view of half of non-trigger handle

The handles are designed to be gripped by the human hand with a glove on it. Each handle is made from two pieces of aluminum. The pieces have pockets that make a hollow core in the handle to allow for the wiring, ground and trigger mechanism as seen in Figure 2 above. The handle with the trigger has an extra area that has been removed to allow for the trigger to protrude from the underside of the handle (See Figure 3 below).

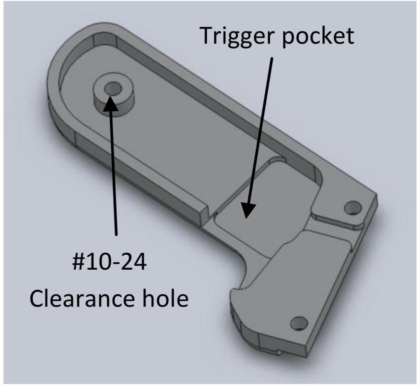


Figure 3: Half of trigger handle

Because of the size of the trigger housing, the handles needed to be designed a little larger than the dimensions initially required by the design. There is a 0.201in diameter (#7 Drill) through hole (which is a clearance hole for a #10-24 bolt) in roughly the middle of one of the halves, shown in Figure 3, that corresponds with a #10-24 threaded through hole in the other half. This, along with a counterbore on the clearance hole half, allows for a #10-24 button head cap screw to hold the halves of the handles together.

The handles have a tongue on the side that faces the device to correspond with a groove in each of the two handle mounts as seen in Figure 4, Figure 5 and Figure 6.

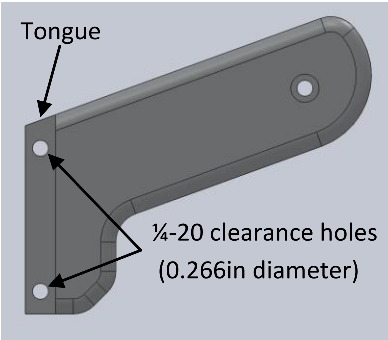


Figure 4: Front view of handle half

Figure 5: Bottom view of handle half

This is where the handles transfer the vertical force to the frame components. Two (2) 0.266in diameter (H Drill) holes through the sides of the groove on the motor mount and the tongue of the handle halves allow for a ¼-20 bolt to hold everything together with a corresponding nut (See Figure 6). These bolts also help keep the halves of the handles aligned with each other.

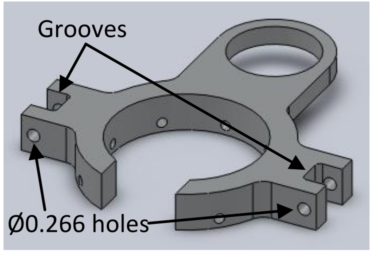


Figure 6: Isometric view of one handle mount

Each of the two handle mounts has three additional features necessary for them to fulfill the functional requirements as shown in Figure 7 below.

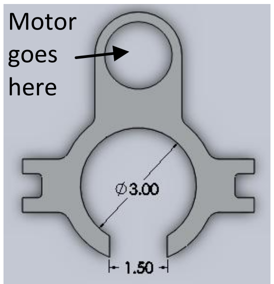


Figure 7: Top view of one handle mount

The internal diameter of the handle mount has a nominal diameter of 3.000in. However, in order to fit onto the frame tube it needed a clearance fit, so the lower limit of the dimension is actually 3.000+0.005in. This will allow for the handle mounts to slide onto the frame tube. There are seven (7) 0.201in through holes (visible in Figure 6) that are equally spaced at 45° intervals that correspond to #10-24 threaded holes in the frame tube. These will be used to fasten the handle mounts to the frame tube. The 1.500in slot allows the slalom pole to be engaged horizontally. The feature opposite the slot is a skeleton frame that wraps around the motor to provide support for a fiberglass or plastic outer shell. The handle mounts transfer the vertical load from the handles to the frame tube as shown in Figure 8 below.

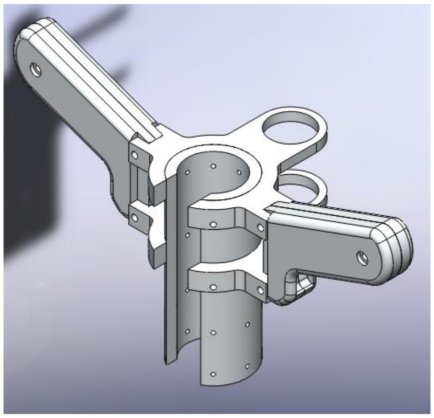


Figure 8: Assembly of handles, handle mounts, and frame tube

The vertical force initially from the user travels down through the frame tube and other frame components that make up the device to the vertical thrust bearing shown in Figure 12. The top most part of this bearing assembly is the upper bearing button ring (See Figure 9). This part is round with a 1.5in slot to allow for the horizontal engagement. It also has an inner diameter of 3.00in for clearance around the rings that surround the main shaft. The part is fastened to the other parts of the thrust bearing and other parts of the device with long #10-24 button head cap bolts going through 0.201in clearance holes ending in #10-24 tapped holes in the lower bearing holster. These bolts sandwich all of the stationary aluminum parts of the vertical bearing together. The upper bearing button ring has seven (7) 0.500in through holes that provide an interference fit with the 0.005in nylon button bearing surfaces. These buttons surround the inner diameter at equal intervals of 45°.

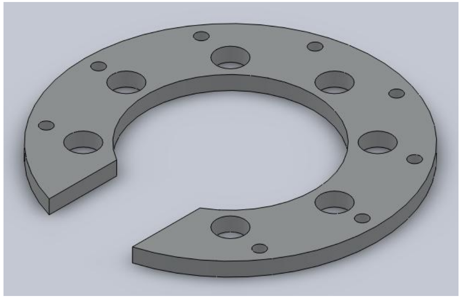


Figure 9: Isometric view of upper bearing button ring

The bottom part of the vertical thrust bearing is the lower bearing button ring. This part is similar to the upper bearing button ring. An additional feature included is a thin wall with a thickness of 0.469in that enclose the vertical bearing surface as well as provide the space necessary for the nylon button bearing surfaces and the vertical force ring on the main shaft.

There is also 0.010in of clearance to allow a very loose fit between the nylon button bearing surfaces and the vertical force wring.

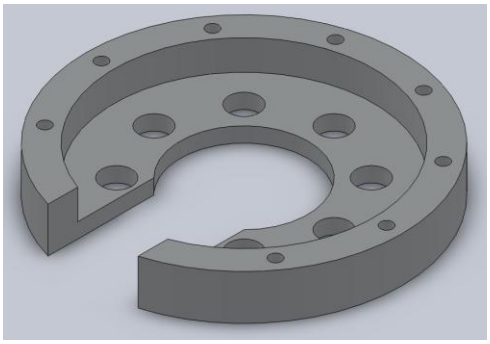


Figure 10: Isometric view of lower bearing button ring

The vertical thrust bearing has a total of fourteen (14) nylon button bearing surfaces. These nylon buttons provide the low friction surface that the vertical force ring slides against as the main shaft rotates. They protrude from both the upper and lower bearing button rings to keep the aluminum parts from contacting each other. By having multiple small bearing surfaces, the area of contact is reduced, theoretically reducing the overall force of friction.

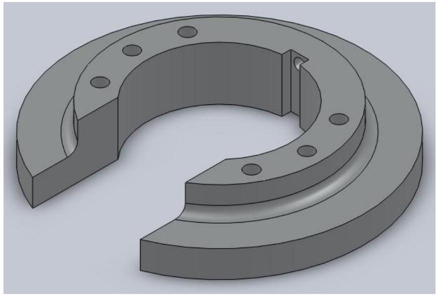


Figure 11: Isometric view of vertical force ring

The vertical force from the static portion of the vertical thrust bearing is applied to the vertical force ring (Figure 11) attached to the main shaft as shown in Figure 12 below. From here the main shaft transfers the force to the top of the base of the slalom pole. This fulfills functional requirement 1.

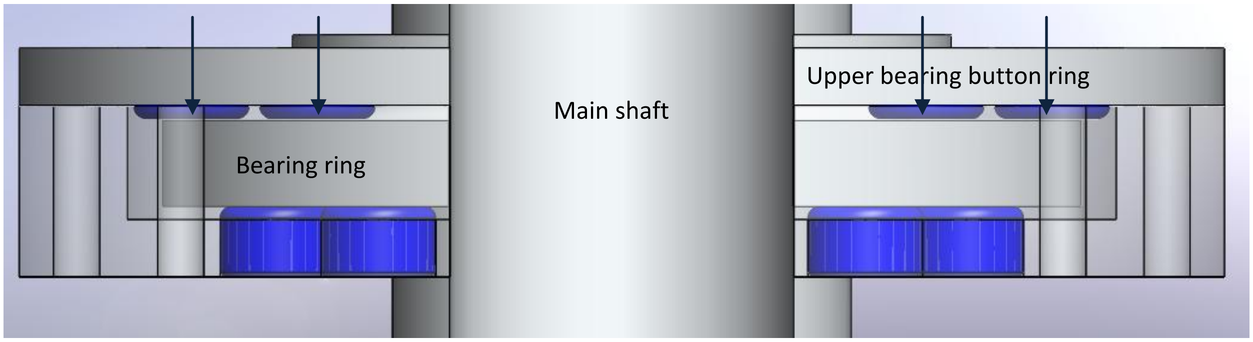


Figure 12: Front view of thrust bearing assembly

3.2 Torque Transmission

Functional requirement 2 is to apply a torque to the base of the slalom pole, thereby screwing it into the hole predrilled in the snow. The lowest required ideal torque (neglecting all losses in drive train and bearing surfaces) that was decided upon was 1800in-lb at the base as described later in this section.

The torque is being provided from an 18V motor and transmission from a Black & Decker Drill. Also being used from the same drill, are the 18V batteries to provide the energy for the motor. To allow the user to control the rotational velocity and direction of the motor, the device utilizes the Black & Decker trigger mechanism and a dual action switch. The clutch built into the transmission is used to adjust the maximum torque the motor can apply without overloading the motor and transmission.

All these parts needed to be mounted to the frame. The motor mounts are designed similar to the handle mounts in that they have an internal diameter fit to the frame tube, a slot to allow horizontal engagement, and radial holes to fasten through to the frame tube as seen in Figure 14. The feature opposite the slot is a radius matching that of the transmission. This, and the notches, provide for half of the clamping mechanism used to mount the motor and transmission to the motor mounts. The other half of the clamp is a mirror of these features that fastens using ¼-20 socket head cap screws shown in Figure 13.

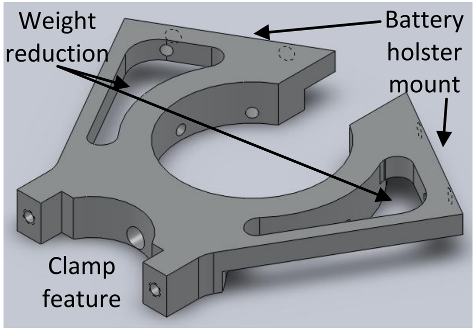


Figure 14: Isometric view of motor mount

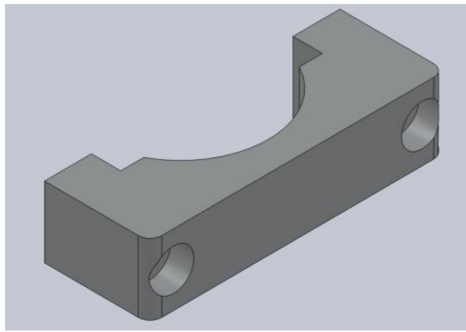


Figure 13: Isometric view of motor clamp

The motor mounts also have features to reduce weight. These pockets reduce the overall weight of the part but still have enough material and stiffness to hold the battery holsters and batteries on each side of the 1.5in slot. These are also angled so the batteries help funnel the pole into the slot. The choice to put two (2) batteries on the device was both for balancing the weight across the device and to provide a location for an extra battery.

A pinion gear with a pitch diameter of 0.750in has an internal bore that is threaded to match the ½-20 thread on the hub of the motor. The reverse thread bolt is used with washers to lock the pinion on gear on the hub. This pinion gear transfers the torque from the motor to the gearbox. The gearbox structure consists of a top and bottom of similar shape shown in Figure 16 and Figure 15. The top has a 2.125in inner diameter to clear the main shaft and the bottom has a 3.000in inner diameter to clear the main shaft and the rings surrounding it. There are 5 holes on both the top and bottom with collinear axes. These have a 0.375in diameter to mate with the purchased nylon sleeve bearings. There are two sets of two (2) 0.266in diameter holes to provide for ¼-20 bolts to attach to the gearbox back spacers. There are also two sets of two (2) 0.201in diameter holes for #10-24 bolts for the front spacers.

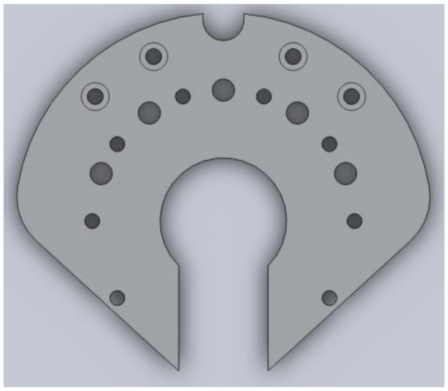


Figure 16: Top view of gearbox top

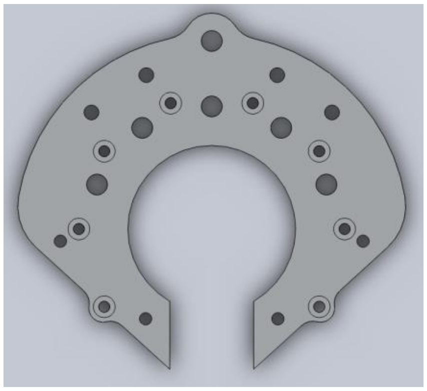


Figure 15: Top view of gearbox bottom

The spacers have tapped holes corresponding to each set of clearance holes. The spacers are designed to provide enough clearance to allow the shafts and to rotate, but not fall out or move along their axes of rotation. The back spacers (Figure 17) are angled into wedges to provide clearance for the gears. The front spacers (Figure 18) have a slot in them to allow an Allen wrench to fit into the button head cap screw that fastens all the bottom parts to the device.

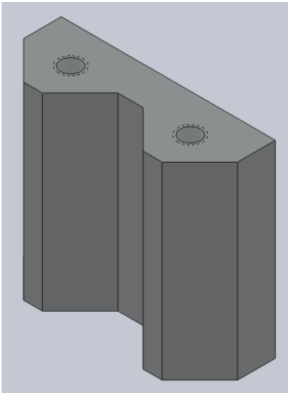


Figure 17: Isometric view of back spacer

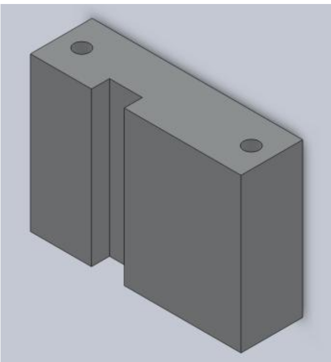


Figure 18: Isometric view of front spacer

The shafts, shown in Figure 19, have an outer diameter of 0.500in. There is a 0.125in wide key cut down the outside 0.0625in deep. This is the keyway that corresponds to a key and keyways in the gears. The key stock was purchased undersized to fit into the keyways. The keys and keyways allow the torque to be transmitted from one gear on the shaft to the other gear on the shaft. The ends of the shafts have a smaller outside diameter of 0.250in to have a clearance fit with the nylon sleeve bearings. The larger outer diameter portion of the shaft is 1.750in to provide clearance for the rotating gears. The shoulder created by the smaller outer diameter portion of the shaft rubs against the flange on the nylon bearing sleeve.

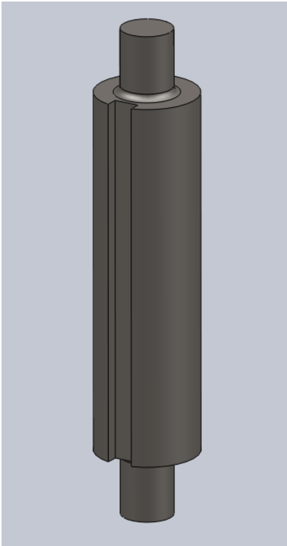


Figure 19: View of gear shaft

The motor purchased does not produce the required torque necessary to screw the base into the snow. It was estimated by Lyons and Riley that 110ft-lb of torque could be applied by a human to a static gate wrench and that this would be enough to screw a base into the snow. This device was designed to produce a minimum of 150ft-lb or 1800in-lb of torque in an ideal situation to make up for the losses due to friction in the drive train and the bearing surfaces of the device (Lyons and Riley).

Using gear sizes easily purchasable the gearbox is able to produce 1901in-lb at the shaft with the gearbox having a ratio of 4.57:1. The 0.75 pitch diameter pinion gear is connected to a gear with a pitch diameter of 1.6in. This rotates the shaft and a gear with a 1.4in pitch diameter. The 1.4in gear then turns the main drive gear of the shaft which has a pitch diameter of 3.0in.

The following equation shows how the torque output is determined from the ratios of the pitch diameters of the gears.

$$\tau_{out} = \left[\tau_{in} * \left(\frac{1.6}{0.75}\right)\right] * \left(\frac{3.0}{1.4}\right) = \left[420in - lb * \left(\frac{1.6}{0.75}\right)\right] * \left(\frac{3.0}{1.4}\right) = 1920in - lb$$

Equation 1: Equation to determine ideal toque output of gearbox.

Total torque output in an ideal situation with no friction is represented by τ_{out}, where τ_{in} is the 420in-lb of torque input by the motor. The gear ratio is determined by the driven gear pitch diameter divided by the drive gear pitch diameter as shown.

To keep the gears aligned with the 3.0in gear on the shaft, the vertical bearing ring is spaced 0.625in from the 3.0in gear. As said before the, 3.0in gear is attached to the main shaft. The torque outputted by the gearbox is transferred to the main shaft by a 0.250in keyway and corresponding key in the 3.0in gear and the shaft. This key stock was also purchased undersized like the 0.125in key stock to have a clearance fit. All keys and keyways have set screws of various sizes holding them together.

The main shaft transmits the torque through the aluminum down into the dogs at the bottom of the shaft. These dogs were designed to fit into the pockets on the top side of the base of the slalom pole. The torque from the dogs is transmitted from the faces to the faces of the pocket, thereby screwing the base into the snow. The design of the dogs follows the same design made by Lyons and Riley to reduce stress concentrations in the corners of the traditional gate wrench dogs (Lyons and Riley).

One degree of freedom – rotation around the axis of the pole – is achieved by Delrin bearing surfaces on the outside diameter of the main shaft. These are held in place by the upper and lower bearing holsters that are made out of aluminum. They are kept from spinning by the tabs on each side of them. The inner diameter of the bearing is a clearance fit with the shaft to allow for a low friction sliding interface.

3.3 Horizontal Engagement of Slalom Pole

The key to the gate wrench is its ability to engage the slalom pole from this side. This means the user does not have to reach up over his head and slide the wrench over the pole to engage the base of the slalom pole. Instead he can place the gate around the pole because of the slot in the side. This is a very simple design feature in a static gate wrench. However, once there are rotating parts and static parts or parts that rotate separate from one another, such as in a ratcheting or motorized gate wrench the design becomes much more complicated. After considering the slalom poles geometry, the necessary slot size to have clearance and allow easy engagement of the pole is around 1.5in in size. This is the size of the slot in all the parts that are coupled with the functional requirement of horizontal engagement (See Figure 20).

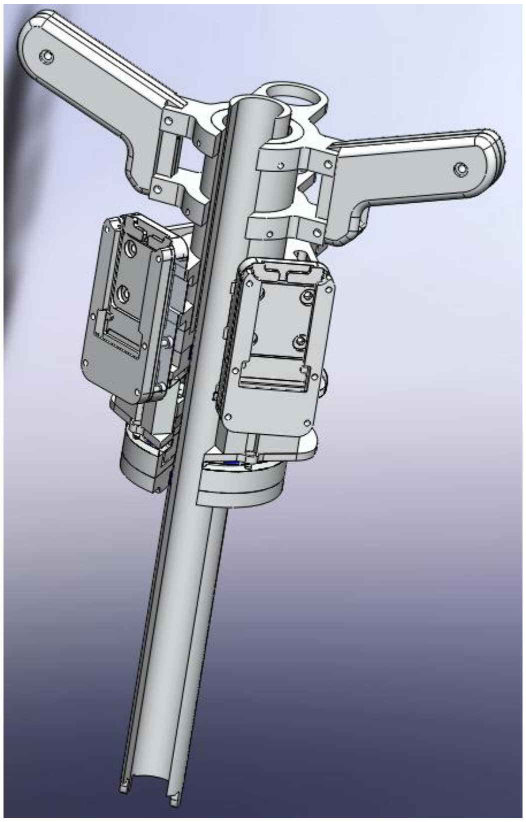


Figure 20: View of slot in assembly of motorized gate wrench

The main shaft as well as the 3.0in gear and the rings around the main shaft have a 1.5in slot to allow the slalom pole to be engaged from the side. Also, all parts of the frame have a 1.5in slot feature to fulfill the functional requirement. These parts include all motor and handle mounts, frame tube, upper and lower bearing holsters, gearbox top and bottom, upper and lower bearing button rings, and all pieces connecting them.

Because of the slot, traditional bearing systems could not be used with this design. A normal thrust bearing does not have the ability of having a slot it in so the nylon button bearing set up with the vertical bearing ring was designed to replace the traditional thrust bearing as described in the vertical force transmission section. Also ball bearings could not be used because they also cannot have a slot in them. This is the reason Delrin was chosen to create bearing surfaces above and below the gearbox that could have a slot in it as shown in Figure 21. Although there is more friction seen at these areas than in more traditional bearings they are useless for the fulfillment of this functional requirement.

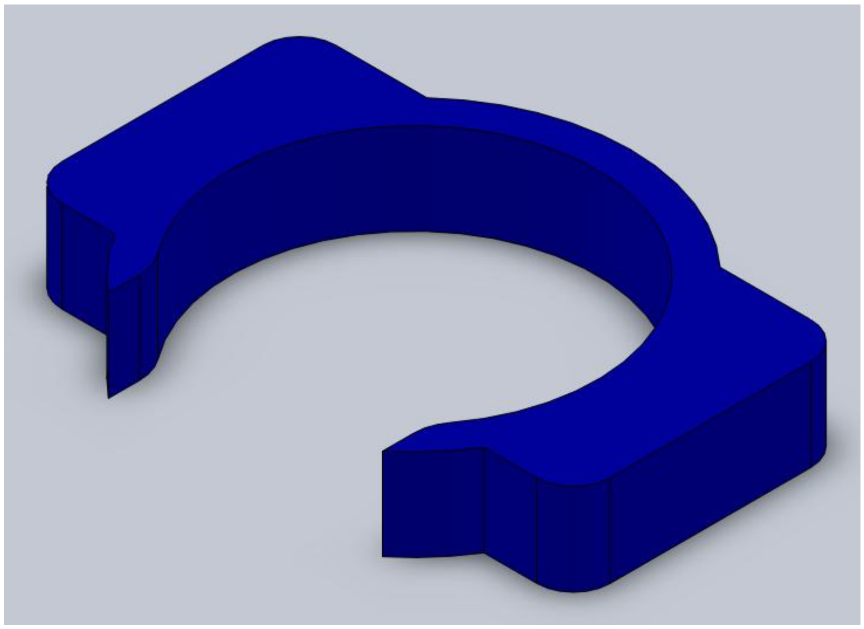
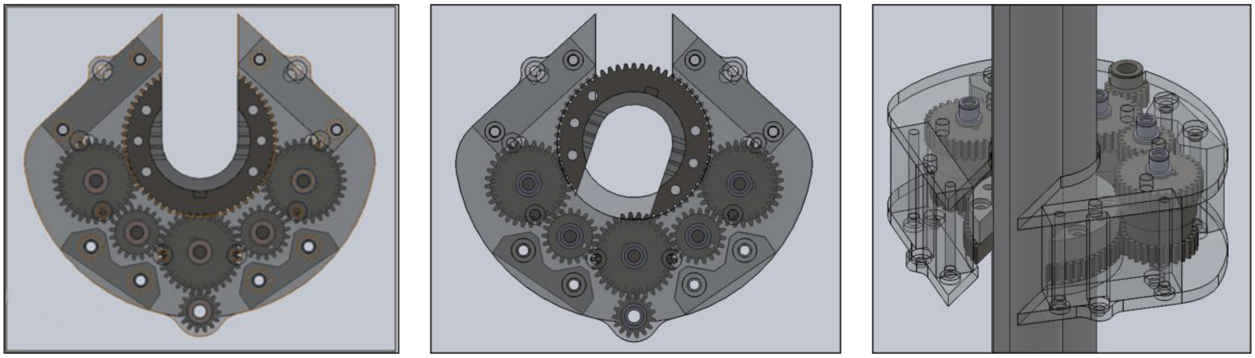


Figure 21: Isometric view of Delrin bearing with slot

Another issue to tackle with this functional requirement is how to provide constant torque to a gear with a slot in it from another traditional gear. Because there is a gap in the teeth, the concept of the gearbox design was to have two (2) redundancies in the gear train so that at any given time in the rotation there were at least two (2) gears driving the 3.0in gear with the slot in it. This was the key, along with the bearings, to the design fulfilling all the functional requirements (See Figure 22).



Bottom view of gearbox with slot aligned | Bottom of gearbox with shaft rotated | Trimetric view of gearbox

Figure 22: Views of designed gearbox

3.4 Finite Element Analysis

The finite element analysis (FEA) was minimal on this project. With only two people working on the project and the long list of parts, it would have been impossible to do finite element analysis and then optimize every part for mass versus strength. Most designs incorporate a factor of safety of at least 2 or 3. Using the built in FEA tools in SolidWorks, we were able to determine the lowest factor of safety in each of the parts and simulate it to show where the low points actually were located in the part.

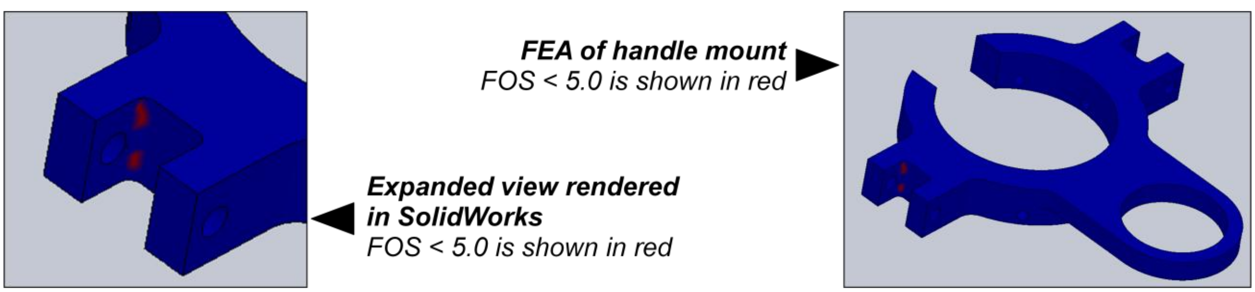


Figure 23: FEA of handle mount

Most of the parts came out having a lowest factor of safety well over 100 or even 200. This means are parts are sure not to break because they are way overbuilt. Some parts did have material machined away just to make them lighter, and thereby lowering the factor of safety, but most parts did not because there was no time to go through each part and optimize the design. The primary focus of the design was to fulfill the functional requirements rather than on a mass or weight constraint. The parts with the lowest factor of safety were the handle mounts having a factor of safety around 4.5 around the groove the handle tongue fits into. The simulation was set to show where the factor of safety was less than 5.

3.5 Tolerances

The two main types of fit were clearance fits and interference fits. Clearance fits allow mating parts to slide against one another, while interference fits, or press fits, allow no movement and do not require fasteners to hold the mating parts together. All fits were determined from tables in the *Machinery's Handbook* (Oberg, Jones and Horton). See Appendix B for examples of fits.

4 Prototype Production

Prototype production took up the majority of the time in the project. The first step for the individual aluminum and steel parts was to generate tool paths using the computer aided manufacturing (CAM) software Esprit. Fixtures were also created the same way to hold various parts. Then the CNC machines were used to machine the parts. Speed and feed rates, as well as incremental cut depth and step over, were determined using the recommended speeds and feeds from the tool manufacturer's website for a tool of a given size. In most cases Kennametal was the manufacturer (See Appendix C for examples). The nylon pieces used a CNC machine to be manufactured. The Delrin pieces were cut using a laser. There were also some parts machined using manually controlled machines.

After the parts were made the project was assembled. This included press fitting, orienting, and fastening parts together. While the prototype was being assembled the wiring was also done. Minor adjustments were made to some parts with a file, sander, or grinder to fit the parts at assembly.

4.1 Manufacturing Parts

The motor mounts and handle mounts had similar features throughout their design. This allows for the parts to have similar manufacturing steps. In fact they used the same fixtures and jigs. The only difference in the process was the tool paths to create the different geometries between the two different part types. In total two (2) of each were manufactured.

The first tool paths in created in Esprit were a tool path that programmed the HAAS VF4 Milling Machine to cut a chamfer around the profile of the part. The tool made a 90° groove 0.050in deep, centered 0.050in outside the actual part profile. There were also eight (8) clearance holes for ¼-20 socket head button cap screws in 2.000in radius equally spaced at 45° intervals in the material that would eventually be removed for the inner diameter of the part. This along with a .500in hole cut in the center of this circle make up the holes that would be used to correspond to the jig to drill the radial holes needed in all four parts. The 0.500in hole will also be used as the zero point for the x and y axis in the machine. The stock aluminum was then taken out of the machine and cut close to the profile's chamfer on the band saw. Some stock was left behind.

Each part was then bolted to a fixture and the HAAS VF4 was used to clean up the material left behind by the band saw, giving the part a smooth machined surface. Then each part was mounted to the jig using 3 of ¼-20 clearance holes. As the radial holes were drilled around the lower lip of each part, it was rotated around the 0.500in by changing which holes were used to bolt the part down. By having these holes at 45° increments, the radial holes ended up at the same increment. The parts were then bolted to the fixture that was placed square on the table of the mill. Then the machining straps were used to strap it down in the correct orientation and the bolts were removed. After probing the 0.500in hole as the zero for the x and y axes, the internal profile of the slot and radius were cut out, removing all of the indexing holes and the 0.500in hole.

The motor mounts had to have a feature to support the battery holsters. This produced a lot of extra material, so the motor mounts had material removed on the mill that made it more of a frame rather than a plate of aluminum. The handle mounts also needed material machined away in the middle of the groove to give clearance for the head of a socket head cap screw that would be used in assembly.

The frame tube was made from a piece of 3.000in outer diameter aluminum pipe with a wall thickness of 0.375in. A cap was manufactured to be fastened to one end so that the HAAS Fourth Axis could be used with the VF4. This cap was necessary to mount the tube on the fourth axis. The fourth axis allowed us to rotate the part in 45° increments. Seven (7) sets of four (4) #25 holes were drilled. These have a diameter of 0.1495in and are the correct tap drill size for a #10-24 thread.

On the last 45° turn, the 1.5in slot was cut to the length that the finished frame tube would be cut too. Extra material was left at either end to first, allow the 0.500in square end mill room to not run into the work holding devices, and second to reduce the amount of chatter that the part would encounter if the entire length was cut open. The extra material was then cut off with the band saw and smoothed with the sander.

The four (4) parts that make up the two (2) handles of the device. All of the parts were machined out of one (1) piece of 1.000in aluminum stock. The tool path was set up in esprit so that the parts would all fit inside the dimensions of the stock piece and oriented so all the internal pocketing operations will be done from one side of the stock. The pockets were machined out using Esprit's pocketing operation. There was an island feature left in the largest pocket to provide for the clearance corresponding tapped hole for a #10-24 bolt to hole the halves together. The trigger handle had an extra pocketing operation to remove the wall material where the trigger would protrude out.

After the pocketing operations were completed, the holes were drilled to the specified sizes for either the clearance holes or threaded holes. The two exterior sides perpendicular to each other were machined through the stock piece of material to provide for two points of contact for the fixture for the last operation on each handle. The stock sheet was then flipped and probed off the same corner as before. A facing operation was used to machine down to the specified thickness for the handles.

The handles were then cut out with a band saw to the rough dimensions necessary. Using the two outer surfaces machined to the specified dimensions, the handles are each placed on the handle fixture constructed and strapped down to the table of the HAAS VF4. Three machining operations were completed on each handle half on this fixture. The first was to machine down the flat side to make half of the tongue. The next operation machined the exterior of the handle halves to the specified dimensions. The last operation machined the rounded edge tangent to the side and front of the handle half all around the profile of the part.

Many of the parts had very similar geometry for an inside profile. The geometry consisted of a 1.5in slot to a radius of varying sizes from 2.000in to 3.000in. This made it possible to create a fixture that met the largest size radius to locate the parts with the largest radius and features to clock the parts in the correct orientation for the tool paths. As the parts were completed, the fixture had material removed to match smaller radii on the other parts. The parts using this fixture included the lower and upper bearing holsters, upper bearing holster support, main shaft vertical bearing ring, main shaft spacer rings, upper and lower bearing button rings, and gearbox top and bottom.

The gearbox top and bottom were described earlier in the section. The other parts started in a sheet of aluminum of various thicknesses up to 0.75in. The inside profile used for the fixture described before was machine out, as well as any other geometry internal to the part. The parts were not machined out of the stock material. Instead a drill mill was used to cut a chamfer outlining the part profile. The band saw was used to cut close to this profile. The outside profile was then machined to the specified dimensions on the fixture.

The vertical bearing surfaces which were comprised of the nylon buttons were cut with a quick operation in the HAAS SL-10 Lathe. The operation consisted of a chamfer and a cut out operation. The Delrin parts that made up the axial bearing surfaces had a two-dimensional profile that was cut with the laser out of 0.250in sheets. Since the design called for 0.500in thick bearings, they needed to be double stacked. The laser could only cut through a thickness of 0.250in.

4.2 Assembly

All aluminum and steel parts were fastened together using socket head cap screws, button head cap screws, and set screws. The wiring, trigger mechanism, and the battery connection were reused from the Black and Decker drill. Some parts needed minor modifications to fit with the other parts. These parts were fit at assembly by using the sander, grinder, various files, and sand paper. Since the tolerances were not met as designed the main shaft did not rotate in the bearing surfaces at first so the Delrin needed to be sanded down for instance.

5 Testing

Testing of the design was fairly straightforward. On April 20th, 2010, Ben Hawkins travelled to Mt. Sunapee, in Sunapee New Hampshire to test the motorized ski gate wrench. The testing was witnessed and videotaped by his father, Ralph Hawkins. A hole was drilled into the snow and the device was used to insert the pole into the snow. The testing conditions were very similar to actual conditions that the device would have to endure in order to simulate how the device would have to perform when put into use. The only difference between the testing and possible real-world scenarios would be that during the ski season, the snow may be harder than the snow that was used in testing.

The time it took to insert a gate into the snow was recorded and discovered to be comparable to that of a pole inserted using either a static or ratcheting wrench. The difference in the use of the three devices is that the powered gate wrench will take less effort to insert a pole, and therefore the user will more likely be able to keep insert a pole at that same speed after setting up an entire course, where as the other two options will experience a growth in time to use due to user fatigue.

Some things noted during the testing of the device is that the aluminum drive shaft had started to grind away at the Delrin bearing surfaces. The tolerances o the Delrin parts were too tight, while the edges of the drive shaft were too sharp. Another notable deficiency in the prototype was that there was no mechanism to keep the pole inside of the drive shaft. If the device was not help directly in line with the pole, the pole would partially slip out and jam up the device.

6 Discussion

6.1 Future Work

The application of our device to the specific job of installing ski gate poles would not be very lucrative. The skiing community does not have the same kind of money that other sports have, so many smaller mountains would not have the money to buy a device such as this, or would want to spend the money if they had it. While larger mountains, or ones that would hold national or international competitions, would possibly want a device such as this. The only drawback is there are not enough of them to make the device worth marketing.

If this device were to be produced, several other changes in skiing equipment could be made to make it much more marketable. As of right now, someone has to go ahead and drill a hole into the ground that the pole will be screwed into. This requires at least two people to set a course, one to drill the hole, and one to insert the pole. If the screw top at the base of the pole had a portion of it that had cutters and possibly flutes to expel the borrowed snow, the poles could be screwed into the snow in one step. Using this powered device, a hole drilled into the snow would not be necessary for setting a course, and therefore a single person could set a course in the amount of time that it takes to just drill the holes using the current method.

6.2 Weight

Since what was manufactured was a prototype, there are many things that could have been improved upon, due to the fact that this project was simply trying to make a device that works in order to prove a concept. There were many places that where weight reduction could have been applied. The main drive shaft could have been machined so that it has holes in it, but was still able to apply the torque through the shaft, possibly in a helical pattern. The frame tube was purchased the size that it was because it was cheap and it was known that it would be strong enough for the job it needed to perform. Therefore, there was a lot of extra material, a lot of which could have been machined out in order to make the part much lighter. The handles did not have to be as bulky as they were. They were made the size that they were in order to accept the trigger from the drill that was purchased. The trigger did not take up the entire handle though, and the handle could have slimmed down where it did not have to have the trigger inside of it. In addition to these specific changes, many of the other parts could have had various holes put into them in parts where there are not excessive stresses in order to make them lighter.

6.3 Material Selection

Although this device would not be extremely lucrative to market, it would still be useful for people who set courses, and there are people who would be interested in it. If our device were to be produced, it would almost certainly look very different from our prototype. The device would be made of some sort of injection-molded plastic, very similar to how drills are made. It would be two half shells, and each side would have multiple features that would hold everything, including the gearbox, transmission, motor, and would also have features that would accept the battery or batteries. The gears themselves would be made of a material much less dense than steel, the material choice for our gears because of price and availability. Perhaps a lighter metal or even a strong plastic could be used, dramatically decreasing the weight of the gearbox, and therefore, the weight of the entire device.

6.4 What Could Have Been Done Different

There certainly is a learning curve in the design and manufacturing methods. During the beginning stages of the process, all machining steps were done on a milling machine, which required many iterations of machining, each with multiple stages of fixturing and clamping. A much faster and easier process entails machining the interior features of the part, as well as a simple chamfer to denote the outer features of the part. The part can then be cut on the band saw, re-fixtured once, and then all out facing operations can be run. This dramatically decreases the amount of fixturing, clamping and re-clamping of each part, which in turn decreases machining time and speeds up the manufacturing process. If this had been thought of this at the beginning of the process, machining time could have been cut considerably.

Other changes done to methods included a more design for manufacturing approach. In the early stages, parts were designed mainly so that they performed the task needed to perform, and manufacturability was a second thought, so they were relatively easy to manufacture, but it could have been easier. Toward the end of the process, function and manufacturability became equally important, so that parts performed the required task, but were also easy to manufacture. This made machining of the parts easier and quicker, resulting in an earlier finish to the project.

6.5 Improvements on Prior Art

The Original gate wrench is very lightweight and very simple to use. It does not take any training, and there is no learning curve to use it. The problem with this design is that it requires a sufficient amount of manual work from the user I order to use the wrench and insert and remove a pole from the ground. This is where the ratcheting ski gate wrench improves upon this design. It has a ratcheting feature so that the user does not use as much effort to insert a pole. With the simple wrench, there is a lot of wasted energy that goes into letting go of the handles and reaching around in order to grab the other handles and continue turning the wrench. The ratcheting wrench reduces this wasted energy. There is still wasted energy, however, and the user needs to put in a decent amount of energy to insert a pole. A powered wrench greatly reduces the amount of energy required to insert a ski gate pole, as well as completely eliminated the wasted energy involved. With the powered wrench, the only energy put into inserting a pole into the snow is carrying the device and holding it in place while the pole is screwed in. While it may be more complicated than the simple static wrench, it is still fairly easy to use, and operates almost exactly like a drill.

6.6 Marketability and Value

A powered ski gate wrench may not be the most lucrative device, but the idea of a powered, open-ended wrench has many different applications. Anything that is either too long or tall, or simply does not have an end would be able to be installed using this device. The installation of things such as turnbuckles for telephone poles, any type of piping or things such as brake lines would be made much easier through the use of this device. Patenting this gearbox design would be the next step in our process. If a patent on this design is obtained, there are many devices that could use this idea, making the basic concept of this design a valuable and marketable idea.

7 Conclusions

The installation of slalom race poles is a very time consuming and burdening process. A powered wrench to install these poles would alleviate both of these problems. Rather than a simple axial engagement of the pole, which would necessitate lifting the device upwards of 7 feet into the air, a more complicated, horizontal engagement device was conceived. Using axiomatic design, a prototype of one such wrench was designed. Through the use of CAD and CAM software, and machining done on CNC machines, the prototype went from a simple idea to a physical prototype that was tested in a real-world setting to test the functionality of the design.

While this design may be very useful in this particular application, due to a small market, the idea is not very lucrative. The underlying principle of an open-ended, powered wrench, however, has many different applications. It is for this reason that the pursuit of a patent could be advantageous.

Works Cited

Discount Tools. 2010 <http://www.discount-tools.com/drillsspeeds.htm>.

Lyons, Gregory D and Mitchell B Riley. Alpine Slalom Pole Wrench. Major Qualifying Project. Worcester: Worcester Polytechnic Institute, 2009.

Oberg, Erik, et al. Machinery's Handbook (27th Edition) & Guide to Machinery's Handbook. Industrial Press, 2004.

Suh, Nam. Principles of Design. New York: Oxford University Press, 1990.

Appendix A

Axiomatic Design Decomposition

Functional Requirements	Design Parameters
FR0: Install/uninstall slalom poles from snow	DP0: Motorized Gate Wrench
FR1: Apply vertical force to base of slalom pole	DP1: Vertical Force System
FR1.1: Allow for human to provide vertical force	DP1.1: Human vertical force interface
FR1.2: Allow for force provided by human to be transmitted to top of slalom pole base	DP1.2: Vertical force transmitter
FR1.2.1: Transmit force from handles to frame	DP1.2.1: Handles attached into frame
FR1.2.2: Allow for vertical force to be applied to shaft	DP1.2.2: Thrust bearing on shaft
FR1.2.3: Minimize friction	DP1.2.3: Nylon surfaces
FR2: Apply 1800 in-lb of torque to base of slalom pole	DP2: Torque Supply System
FR2.1: Supply power in order to supply torque	DP2.1:18V Black&Decker Battery
FR2.2: Supply torque	DP2.2: Black&Decker 18V drill motor
FR2.2.1: Allow human control of motor	DP2.2.1: Displacement sensitive trigger placed on handle
FR2.2.2: Allow control of torque applied	DP2.2.2: Black&Decker torque limiter
FR2.2.3: Allow for two-directional rotation	DP1.3: Reversal switch
FR2.3: Attach power source to device	DP2.3 Motor mounting system
FR2.3.1: Securing device to be minimum weight while still maintaining structural integrity	DP2.3.1: Motor mount has pockets machined out.
FR2.3.2: Securing device within tolerance for fit onto frame tube.	DP2.3.2: Hole in motor mount has 3.005" clearance.
FR2.3.3: Allow for slight adjustments in mounts	DP2.3.3: Slots for screws
FR2.4: Secure motor to motor mounts	DP2.4: Clamping system
FR2.5: Transmit force from power supply to shaft	DP2.5: Set of gears
FR2.5.1: Reduce Friction	DP2.5.1: Nylon sleeve bearing with flange
FR2.5.2: Position gears	DP2.5.2: Shaft with key/keyway
FR2.5.3: Secure gears	DP2.5.3: Set screw
FR2.5.4: Keep shaft aligned	DP2.5.4: Smaller diameter shaft end to sit in nylon sleeve bearing
FR2.6: Keep gears aligned	DP2.6: Vertical force ring
FR2.6.1: Prevent vertical motion of main gear	DP2.6.1: Nylon buttons above and below main gear
FR2.6.2: Minimize friction	DP2.6.2: Nylon surface interfacing with flange
FR2.6.2.1: Prevent rotation of nylon bearing surface	DP2.6.2.1: Notches on nylon pieces
FR2.6.2.2: Attach nylon bearing surface to frame	DP2.6.2.2: Press-fit into frame
FR2.7: Supply adequate force to pole	DP2.7: Gear box supplying 1920 in-lbs
FR2.8: Transmit torque to base of slalom pole	DP2.8: Torque transmission system
FR2.8.1: Transmit force to main drive shaft producing 1800 in-lb of torque on main drive shaft	DP2.8.1: Gear box
FR2.8.2: Transmit torque through device	DP2.8.2: Main drive shaft
FR2.8.2.1: Keep drive shaft positioned within device	DP2.8.2.1: Flanges on drive shaft

FR2.8.2.2: Attach flanges to shaft	DP2.8.2.2: Screws that go through flange and thread into drive shaft.
FR2.8.2.3: Reduce friction	DP2.8.2.3: Nylon surfaces for flange to ride on
FR2.8.3: Transmit force from main drive shaft to slalom pole base	DP2.8.3: Dogs on bottom of drive shaft
FR2.8.4: Allow one degree of freedom for main drive shaft (rotation around y-axis)	DP2.8.4: Bearing(s) on inside of shell
FR2.8.5: Maximize life of material in gearbox	DP2.8.5: Nylon Bushings
FR2.9: Keep device stationary while pole turns	DP2.9: Handles for user to hold on to
FR2.9.1: Attach handles to device	DP2.9.1: Handle mount system
FR2.9.2: Secure handle mount within tolerance for fit onto frame tube	DP2.9.2: Hole in handle mount to have 3.005" clearance
FR2.9.3: Allow for adjustment of handle mounts	DP2.9.3: Slots for screws
FR3: Horizontal engagement with slalom pole	DP3: Slot system
FR3.1: Allow for horizontal engagement of pole with main shaft	DP3.1: Slot in main shaft (1.5in)
FR3.2: Allow for horizontal engagement with main drive gear	DP3.2: Slot in main gear (1.5in)
FR3.3: Allow full rotation of pole	DP3.3: Drive system
FR3.3.1: Transmit torque from main drive gear to main drive shaft	DP3.3.1: Keyway and keys (with slots aligned)
FR3.3.2: Transmit torque to main drive gear at all times	DP3.3.2: Gear box with three gears driving main drive gear
FR3.4: Allow for horizontal engagement of pole with frame	DP3.4: Slot along entire device (1.5 in)
FR3.5: Align frame and main drive shaft slot after installation/removal of pole	DP3.5: Alignment system
FR3.5.1: Allow main drive shaft to rotate freely inside frame	DP3.5.1: Free rotation of motor
FR3.5.2: Stop rotation when slots are aligned	DP3.5.2: Viewing slot to show user when slots line up
FR3.6: Keep gear box and shaft aligned through the vertical axis	DP3.6: Delrin bearing surface
FR3.6.1: Minimize friction	DP3.6.1: Delrin surface against shaft
FR3.6.2: Provide stability to drive shaft	DP3.6.3: Two bearing surfaces separated by a distance

FR1 Vertical Load Application

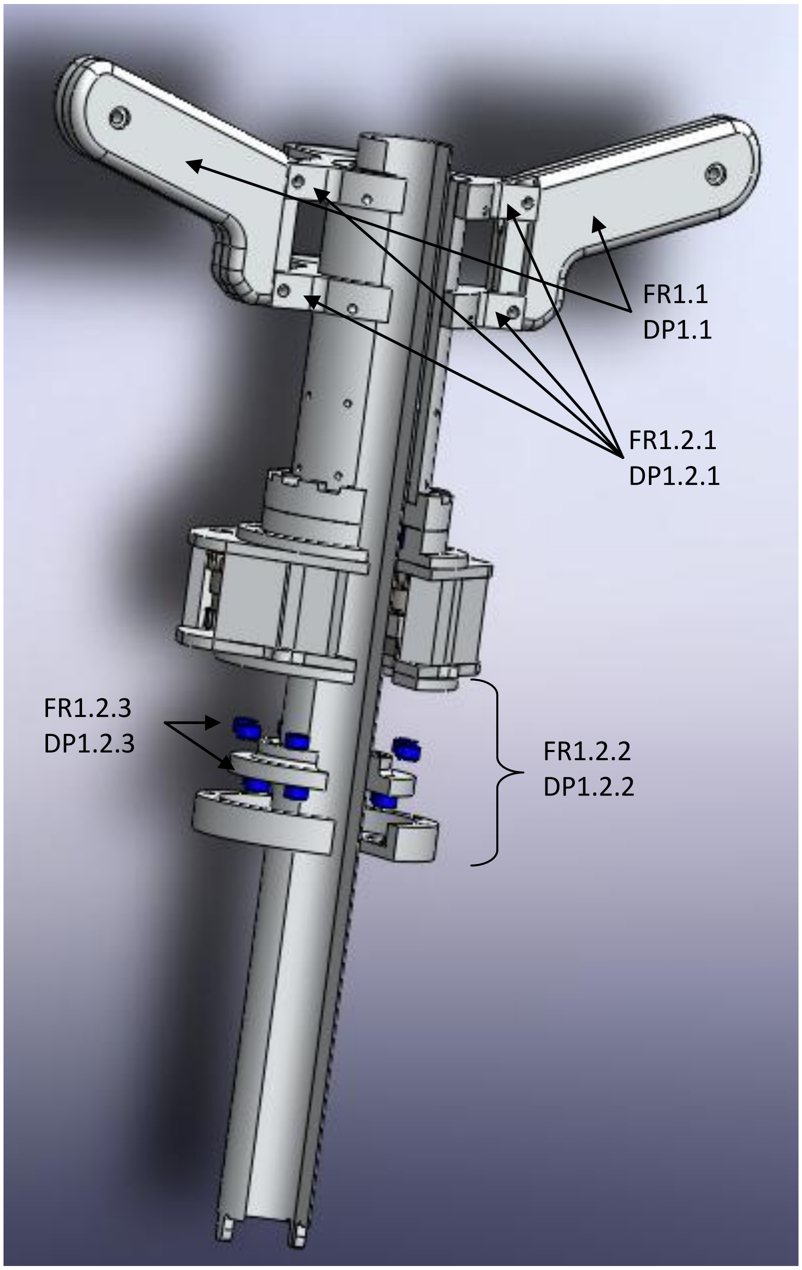


Figure 24: Vertical force components with exploded thrust bearing

Gearbox

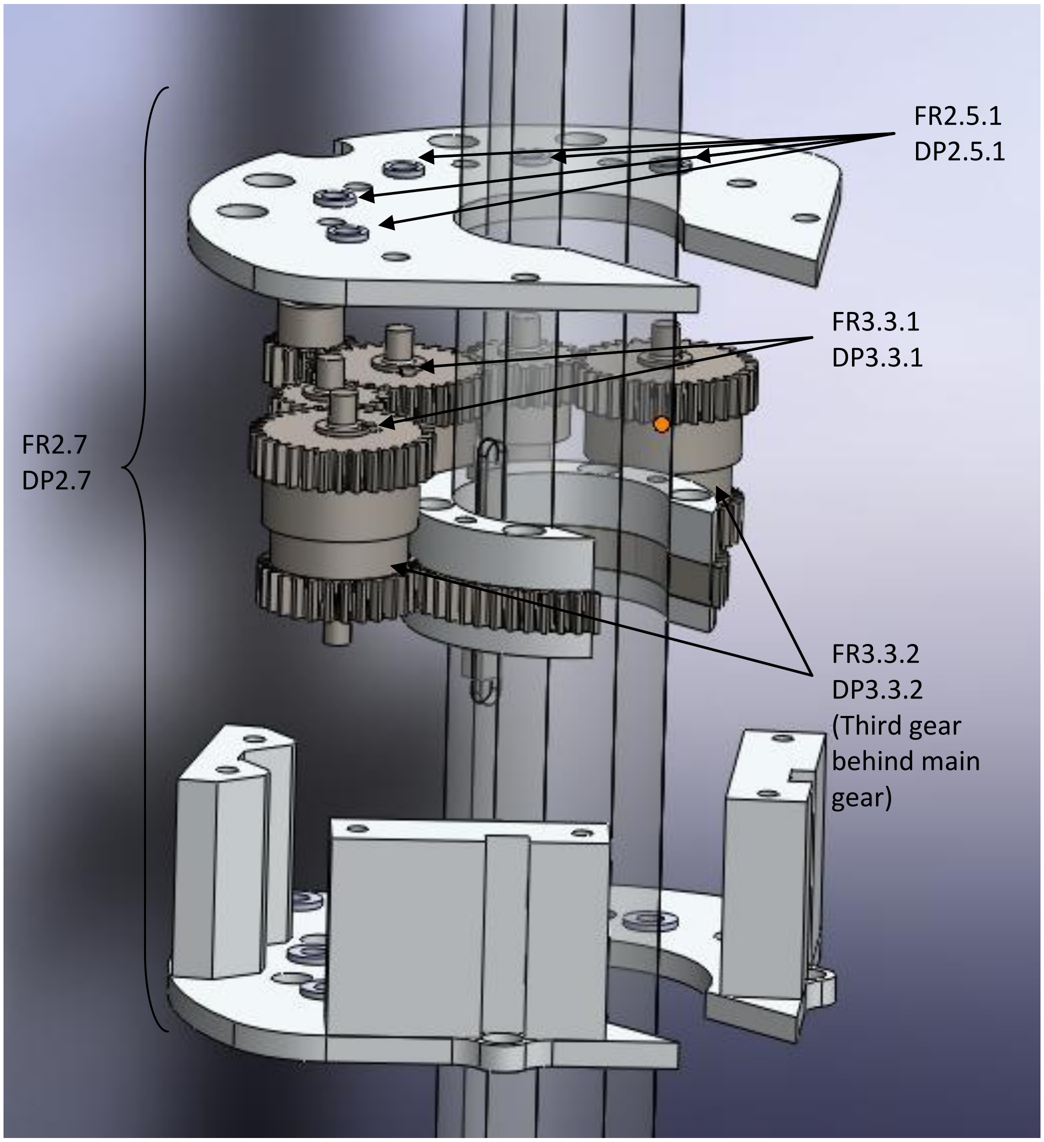


Figure 25: Gearbox exploded view

Appendix B

Running Sliding Fits

Nominal Size Range, Inches	Class RC 1			Class RC 2			Class RC 3			Class RC 4		
	Clearance[a]	Standard Tolerance Limits		Clearance[a]	Standard Tolerance Limits		Clearance[a]	Standard Tolerance Limits		Clearance[a]	Standard Tolerance Limits	
		Hole H5	Shaft g4		Hole H6	Shaft g5		Hole H7	Shaft f6		Hole H8	Shaft f7
Over To	Values shown below are in thousandths of an inch											
0 – 0.12	0.1	+0.2	−0.1	0.1	+0.25	−0.1	0.3	+0.4	−0.3	0.3	+0.6	−0.3
	0.45	0	−0.25	0.55	0	−0.3	0.95	0	−0.55	1.3	0	−0.7
0.12 – 0.24	0.15	+0.2	−0.15	0.15	+0.3	−0.15	0.4	+0.5	−0.4	0.4	+0.7	−0.4
	0.5	0	−0.3	0.65	0	−0.35	1.12	0	−0.7	1.6	0	−0.9
0.24 – 0.40	0.2	+0.25	−0.2	0.2	+0.4	−0.2	0.5	+0.6	−0.5	0.5	+0.9	−0.5
	0.6	0	−0.35	0.85	0	−0.45	1.5	0	−0.9	2.0	0	−1.1
0.40 – 0.71	0.25	+0.3	−0.25	0.25	+0.4	−0.25	0.6	+0.7	−0.6	0.6	+1.0	−0.6
	0.75	0	−0.45	0.95	0	−0.55	1.7	0	−1.0	2.3	0	−1.3
0.71 – 1.19	0.3	+0.4	−0.3	0.3	+0.5	−0.3	0.8	+0.8	−0.8	0.8	+1.2	−0.8
	0.95	0	−0.55	1.2	0	−0.7	2.1	0	−1.3	2.8	0	−1.6
1.19 – 1.97	0.4	+0.4	−0.4	0.4	+0.6	−0.4	1.0	+1.0	−1.0	1.0	+1.6	−1.0
	1.1	0	−0.7	1.4	0	−0.8	2.6	0	−1.6	3.6	0	−2.0
1.97 – 3.15	0.4	+0.5	−0.4	0.4	+0.7	−0.4	1.2	+1.2	−1.2	1.2	+1.8	−1.2
	1.2	0	−0.7	1.6	0	−0.9	3.1	0	−1.9	4.2	0	−2.4
3.15 – 4.73	0.5	+0.6	−0.5	0.5	+0.9	−0.5	1.4	+1.4	−1.4	1.4	+2.2	−1.4
	1.5	0	−0.9	2.0	0	−1.1	3.7	0	−2.3	5.0	0	−2.8
4.73 – 7.09	0.6	+0.7	−0.6	0.6	+1.0	−0.6	1.6	+1.6	−1.6	1.6	+2.5	−1.6
	1.8	0	−1.1	2.3	0	−1.3	4.2	0	−2.6	5.7	0	−3.2
7.09 – 9.85	0.6	+0.8	−0.6	0.6	+1.2	−0.6	2.0	+1.8	−2.0	2.0	+2.8	−2.0
	2.0	0	−1.2	2.6	0	−1.4	5.0	0	−3.2	6.6	0	−3.8
9.85 – 12.41	0.8	+0.9	−0.8	0.8	+1.2	−0.8	2.5	+2.0	−2.5	2.5	+3.0	−2.5
	2.3	0	−1.4	2.9	0	−1.7	5.7	0	−3.7	7.5	0	−4.5
12.41 – 15.75	1.0	+1.0	−1.0	1.0	+1.4	−1.0	3.0	+2.2	−3.0	3.0	+3.5	−3.0
	2.7	0	−1.7	3.4	0	−2.0	6.6	0	−4.4	8.7	0	−5.2
15.75 – 19.69	1.2	+1.0	−1.2	1.2	+1.6	−1.2	4.0	+2.5	−4.0	4.0	+4.0	−4.0
	3.0	0	−2.0	3.8	0	−2.2	8.1	0	−5.6	10.5	0	−6.5

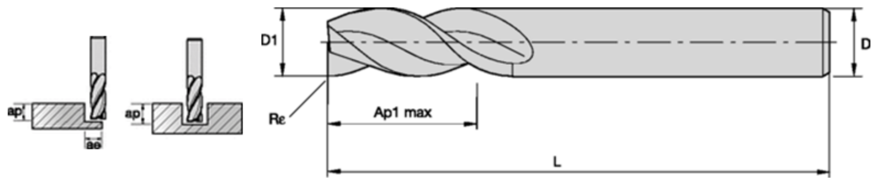
Table taken from Machinery's Handbook (Oberg, Jones and Horton).

Appendix C

Square End Mill Feeds and Speeds for Aluminum

AADE - K600 **AADF - K600**

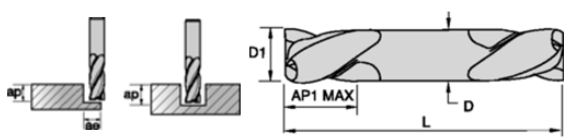
3-Flute, 37° Helix **2-Flute, 45° Helix**



Diameter (D)	Length of Cut (AP1max)	Total Length (L)	Radius (Re)	Catalog Number	Incremental Depth (ap)	Step Over (ae)	SFM (ft/min)	Feed PT (in)
0.5	0.625	2	0.03	AADE0500J3ARB	0.5	0.25	Up to 6000	0.0055
0.5	1.25	3	0.03	AADE0500J3BRB	0.25	0.25	Up to 6000	0.0055
0.5	2	4	0.03	AADE0500J3CRB	0.05	0.25	Up to 6000	0.0040
0.375	0.5	2	0	AADE0375J3A	0.375	0.1875	Up to 6000	0.0035
0.375	1.5	4	0.03	AADE0375J3CRB	0.0375	0.1875	Up to 6000	0.0035
0.25	0.375	2	0.03	AADE0250J3ARB	0.25	0.125	Up to 6000	0.0018
0.25	0.75	2.5	0.03	AADE0250J3BRB	0.025	0.125	Up to 6000	0.0018
0.1875	0.3125	1.5	0	AADF0188J2A	0.1875	0.09375	Up to 6000	0.0015
0.125	0.375	1.5	0	AADF0125J2A	0.125	0.0625	Up to 6000	0.0010

Square End Mill Feeds and Speeds for Steel

4-Flute, 30° Helix



For Slotting reduce Speed by 20% — Feed in Inches per Flute (PT) by Tool Diameter -- For Slotting Reduce Feed by 20%

MTL Group	Material	SFM	Incremental Depth (ap)	Step Over (ae)	1/16"	1/8"	3/16"	1/4"	3/8"	1/2"
P2	Medium and high carbon steels > 0.3% C	350~450	1XD	0.1XD	0.0004	0.0006	0.001	0.0015	0.0025	0.003
P3	Alloy steels and Tool steels <330HB, <35HRC	250~350	1XD	0.1XD	0.0003	0.0005	0.0007	0.001	0.002	0.0024
P4	Alloy steels and Tool steels 340-450HB, 36-48HRC	175~325	1XD	0.1XD	0.0002	0.0004	0.0005	0.001	0.0015	0.002
P5	Ferritic, Martensitic and PH Stainless steels <330HB, <35HRC	250~450	1XD	0.1XD	0.0002	0.0004	0.0006	0.001	0.002	0.0024
M1	Austenitic stainless steel (302, 303, 304)	275~500	1XD	0.1XD	0.0004	0.0006	0.0008	0.0012	0.002	0.0025
M2	Austenitic stainless steel (316, 316L)	200~450	1XD	0.1XD	0.0002	0.0003	0.0004	0.0007	0.0015	0.0017
M3	Austenitic stainless steel: Duplex (Ferritic and Austenitic Mixture)	175~400	1XD	0.1XD	0.0002	0.0003	0.0004	0.0007	0.0015	0.0017
K1	Grey Cast Iron (GG)	425~725	1XD	0.1XD	0.0005	0.0007	0.0015	0.002	0.003	0.004
K2	Ductile, CGI and Malleable cast iron <80KSI	400~600	1XD	0.1XD	0.0005	0.0007	0.0015	0.002	0.003	0.004
				Catalog #	DHEC062S4	DHEC125S4025	DHEC188S4	DHEC250S4	DHEC375S4056	DHEC500S4
			Length of Cut	(AP1 max)	0.125	0.25	0.375	0.5	0.5625	1
			Total Length	(L)	1.5	1.5	2	2.5	2.5	3

Drill Feeds and Speeds

Material	Speed	Feed	Rate	(I.P.R)		
	SFM	1/16"	1/8"	1/4"	1/2"	3/4"
Aluminum / Aluminum Alloys	300-600	.0008	.003	.007	.012	.015
Aluminum Alloyed Si > 10%	150-400	.0008	.002	.006	.01	.012
Soft Cast Irons	200-300	.001	.003	.005	.01	.012
Medium Cast Irons	125-225	.001	.003	.005	.008	.01
Malleable Cast Irons	65-200	.0005	.002	.004	.007	.01
Brass	200-300	.0007	.002	.003	.004	.006
Bronze	150-250	.0007	.002	.003	.004	.006
Coppers / Copper Alloys	150-300	.001	.003	.006	.01	.012
Magnesium	300-600	.001	.003	.007	.012	.015
Nickel Alloys	75-200	.001	.003	.005	.009	.012
Free Machining Stainless Steels	100-150	.001	.003	.005	.008	.012
Work Hardening Stainless Steels	50-100	.0005	.002	.004	.006	.01
Low Carbon Steels	150-300	.001	.002	.004	.007	.012
Medium Carbon Steels	100-200	.001	.002	.003	.006	.01
High Tensile (35-40 Rc) Steels	75-150	.001	.002	.003	.004	.005
High Tensile (40-45 Rc) Steels	50-100	.0007	.001	.002	.003	.004
High Tensile (45 Rc+) Steels	25-75	.0005	.0007	.001	.002	.003
Tool Steels	40-100	.001	.0015	.003	.005	.008
Soft Titanium	80-125	.001	.002	.004	.006	.01
Hard Titanium	40-100	.0007	.001	.002	.005	.008

Appendix D

Design Alterations

Transmission/Motor Assembly Housing

The transmission/motor housing for our design originally consisted of a box, made up of several different plates, which would encompass most of the motor and transmission assembly. This housing would then fit into pieces that would fit into a receiver portion of a mounting piece that would then be secured to the frame tube. The machining of this housing would have been, while simple, very time consuming, considering the amount of pieces that it contains. In addition to the time-consuming nature of this design, it would have been very bulky, used unnecessary material, and would have weighed the entire device down significantly more than necessary.

After thinking about the time it would take, and the weight it would have if we decided to use this design, we came up with a much simpler and smaller and therefore, lighter, design. Our new design uses a clamping fixture to hold the motor/transmission assembly in place, and only surrounds the assembly where it is clamping onto it, not entirely surrounding the assembly. In addition to making the device lighter and easier and faster to machine, this new design will allow the motor and transmission to have more airflow, because it is not enclosed, keeping it cooler.

After doing a finite element analysis on these new parts, we realized that it had a safety factor that was much higher than necessary. We then decided to remove un-needed material from areas that had excess, making our part about half the weight, but still maintaining a safety factor that is high enough that we are confident that it is strong enough to withstand any forces that an operator will be applying to it under any normal use.

Frame Tube Holster

The frame tube holster is a part of the system that connects the gearbox to the frame tube. This part designed to be fairly bulky so that we could bolt the gearbox to it, and then that assembly to our frame tube. While trying to figure out the best way to machine this part, we realized that we could modify other existing parts, and remove this one altogether. Using the holster, we would have had to machine a groove around the circumference of the tube, and then a matching tongue to fit into that groove. This would have been very difficult, as well as time-consuming, to machine. With the realization that we could completely remove this part, and slightly modify our frame tube holster it could perform the same job, and we would not have to machine a tongue and groove across a curved surface. We made the part slightly thicker, and created an inner diameter that will accept the frame tube. We also drilled holes straight up through the part so that we could secure it to the bottom of the frame tube, and these screws would perform the task the tongue and groove would have; securing the part to the frame tube. We could then fasten flange of the improved frame tube holster to the top of the gearbox. This would then secure the frame tube to the gearbox, using one whole part less than we originally designed.

Delrin Bearing Surface Holder

The original Delrin bearing surface holder consisted of a piece of round stock that we would have had to turn down and then cut I half, turn onto its side and machine a pocket into it, using very small diameter, yet long, machine tools. This would have proved very difficult, both to fixture and to machine. After consideration of these factors, we came up with a better design of these parts. We decided to machine these parts out of plate stock, made up of two 2-D parts, making machining much easier. The set-up would still b two parts, but it would be two parts that would stack vertically, rather than sitting side-by-side. This made the machining of the pocket for the Delrin surface much easier, and therefore the machining of the entire part much easier.