SunTrac Design Team

Operation and Assembly Manual

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DISCLAIMER

This manual was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this manual should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

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1. Introduction

This operation and assembly manual consists of the step-by-step process taken to manufacture the teams final design, as well as operate, maintain, and troubleshoot the braze-welding jig. The completed CAD model is shown in [Fig. 1].

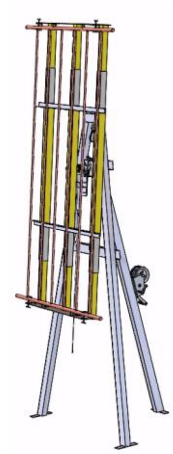

Figure 1. Complete CAD Model

Due to Covid-19, the physical prototype shown in [Fig. 2] has not been constructed to the final state of [Fig. 1].

Figure 2a. Jig Frame Figure 2b. Jig Face

The frame has been completed, although the face in [Fig. 2b] still requires welding the telescoping tubes to the end plates, along with the final weld onto the frame. Note that due to Covid-19 complications, some of the manufacturing steps laid out in this manual have not been performed by the SunTrac design team. Part numbers are often referenced throughout this manual, refer to the Appendix (Appendix A) for this information contained within the Bill of Materials.

2. Manufacturing

The braze-welding Jig manufacturing process is split into two components: the Jig Frame and Face. These two subassemblies can be constructed simultaneously or individually as the final step in the manufacturing process is to join these two systems; First to be considered is the jig frame.

2.1. Jig Frame

The following steps taken in manufacturing the jig frame are listed generically and elaborated on in the following sections.

1) Cut 20' steel beams to length
2) Cut steel beam end angles
3) Drill guide rail and pulley holes
4) Weld steel beams together
5) Attach winch, pulley, guide rail, and locking assembly

2.1.1 Cut Beams to Length

The two 20' carbon steel beams are to be cut by bandsaw into six lengths: a top, middle, and lower horizontal beam, along with the three tripod legs. The two identical front tripod legs are to be cut at 108'', while the back tripod leg is cut at 94''. The top horizontal bar is cut to 10'', the middle to 16.5'', and the lower to 29''

2.1.2 Cut Beam Angles

The horizontal beams are to be cut in the shape of a trapezoid while the tripod legs are to be cut into a sort of stretched rhombus. Using a chop saw, cut two 12° angles at the end of the top horizontal beam (10'' length) as shown in [Fig. 3] below.

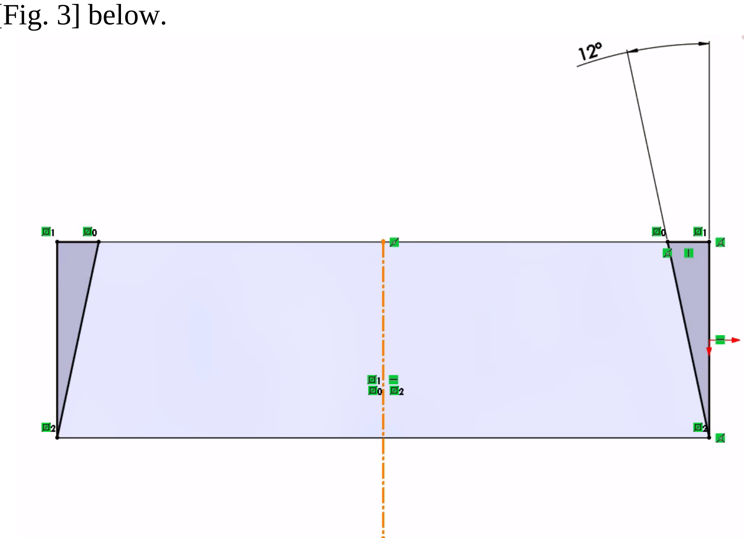

Figure 3. Top Horizontal Beam Angle Cut

Cut the same 12° angles into the middle and lower horizontal supports, resulting in three trapezoids total.

The cuts corresponding to the three tripod legs are more involved than that of the horizontal beams as there are multi-plane cuts. The CAD drawings for the left, right, and back tripod beams are provided in the Appendix (Appendix B). The two main considerations are the left and right tripod legs being unique as they are reflective mirrors of each other. Given either the right or left leg, cut 12° on both sides to form an extended rhombus as shown in the Appendix (Appendix B). Next, make the 7° cut outlined by detail C in these drawings; making sure to be mindful of the orientation as this cut must be on the bottom half of the beams. A portable bandsaw has been used by the SunTrac team to make the difficult multi-plane cuts. The next angles to be made are 12° and 19° on either side of the back leg beam. The 12° cut must be made where the beam mounts to the floor, while the 19° cut along where the back leg will connect to the middle horizontal beam.

2.1.3 Drill Guide Rail and Pulley Holes

Before assembling the formed steel sections, drill holes for the pulley and guide rail connections. To do this, 3 holes of 0.18’’ diameter are drilled, one in each of the horizontal beams. The top beam drill location is shown in [Fig. 4].

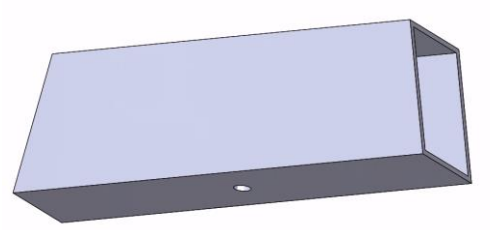

Figure 4. Top Beam Drill Location

The location of this 0.18’’ through hole is not critical so long as it is located near the center as shown. The positioning of the other 2 holes are more significant as they must accurately align with the pulley. This step may be revised according to the manufacturers preference, perhaps stationing the guide rail first, then drilling holes to ensure accuracy. This step decides the jig’s operating height, making it critical to consider the positioning of these next holes. [Fig. 5] and [Fig. 6] are the required guide rail connection hole required positioning to achieve a range of operating heights from 38’’ to 42’’.

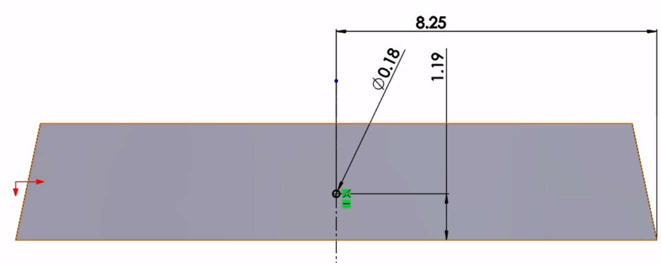

Figure 5. Middle Beam Drill Location

The through hole for the middle horizontal beam is located in the center of the beam, width-wise. While there is 1.2’’ distance from the bottom, this is important for the guide rail to properly align. [Fig. 6] shows the drill hole for the bottom horizontal beam.

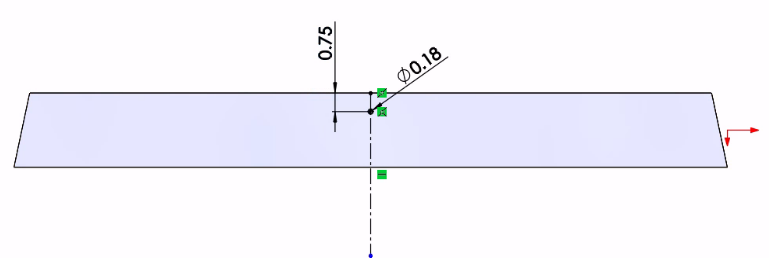

Figure 6. Bottom Beam Drill Location

Once again the hole is located in the center along the horizontal axis, and 0.75'' from the upper surface.

2.1.4 Weld Beams and Supports

Once all beams are cut to length, angled, and connection holes drilled, they are ready to be assembled. The first step is to weld the top horizontal beam and two front tripod legs. Lay the top horizontal beam on a flat surface and position the left and right tripod legs in an A formation as shown in [Fig. 7].


Figure 7. Weld A-Formation

Note that the sub-processes taken in the construction of the prototype are subject to manufacturers preference, for example the top horizontal beam could have been left as an extrusion with no cuts, to be cut to a trapezoid shape at this step. This is not the process taken by the SunTrac team and is based on the manufacturer's discretion and resources. Next, weld the middle and lower beams onto the current A-frame. The dimensions are shown in [Fig. 8] below.

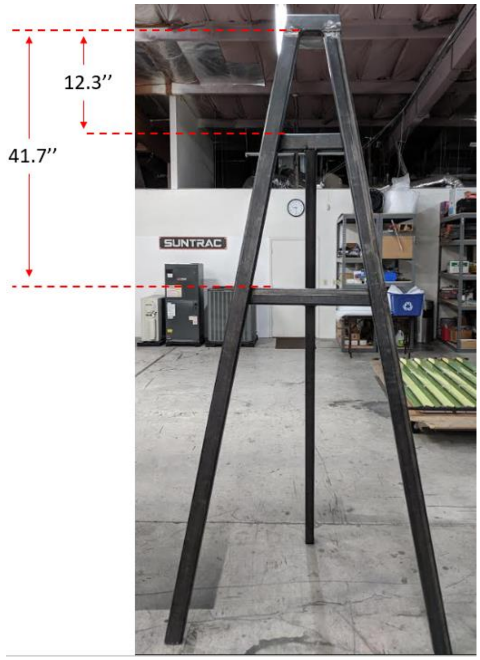

Figure 8. Frame Beam Welds

Note that the horizontal beams are positioned on the back of the A-frame, rather than in the middle. This is to allow for the guide rail to be positioned directly beneath the pulley for solely lifting applications. As mentioned previously, one could take the approach to attach these beams first, then to cut angles and drill holes. The back leg in [Fig. 8] hasn't yet been attached, this is the next step. Cut two 9'' sections of angle iron (part #4) to be used as a support for the back leg shown in [Fig. 9].

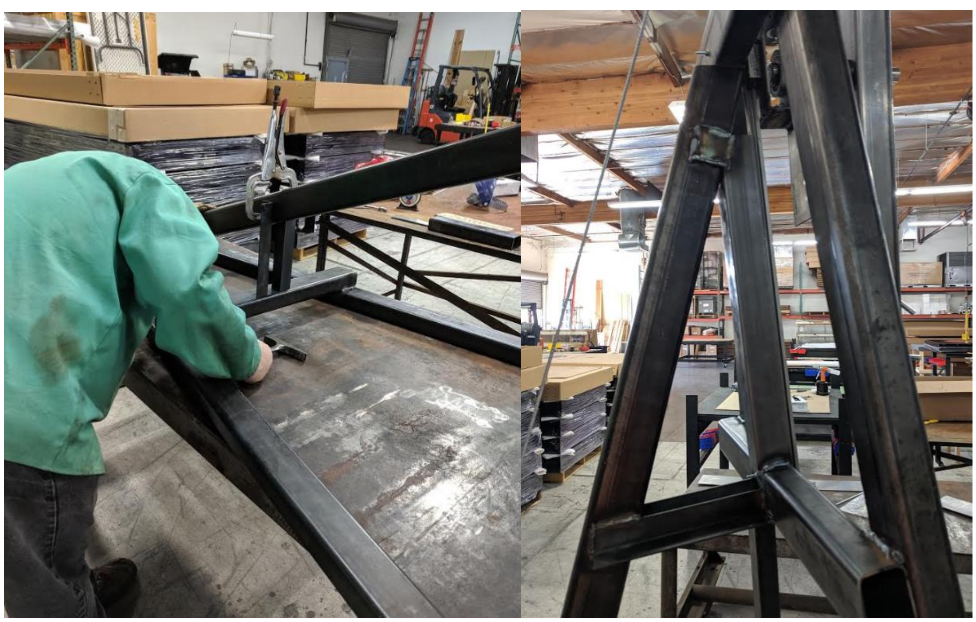

Figure 9. Back Leg Attachment

Using vice grips to secure the back leg, position it such that the 19° angle connects to the bottom of the middle horizontal beam, weld this in place.
Next, cut a 26.5'' section of the telescoping tube 2x2's (part #3). This support is to be added between the middle and lower horizontal beams to restrict guide rail deflection as shown in [Fig. 9] above. One side of this support is to have a section cut out to allow for a weldment along the tripod back leg, this is illustrated in [Fig. 10].

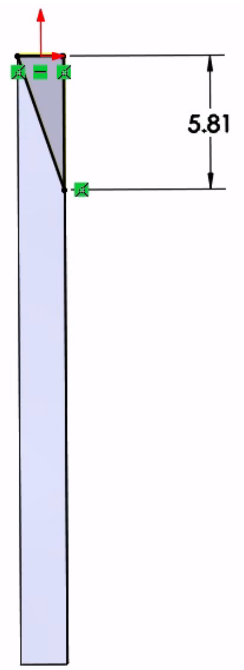

Figure 10. Guide Rail Support

Position this support between the middle and lower beams and weld in place. Add an extra support if necessary; the team used 2x2'' sections of sheet metal left over from part #6 to further secure the support to the tripod back leg as seen in [Fig. 9]

2.1.5 Construct Locking Mechanism

The locking mechanism is an assembly within the sub-assembly of the Jig Frame, the final form of the mechanism is shown in [Fig. 11]. The purpose of this sub-assembly is to support the rotational motion of the jig face via two bearings while also allowing a changing height of the center of rotation via a pulley connection.

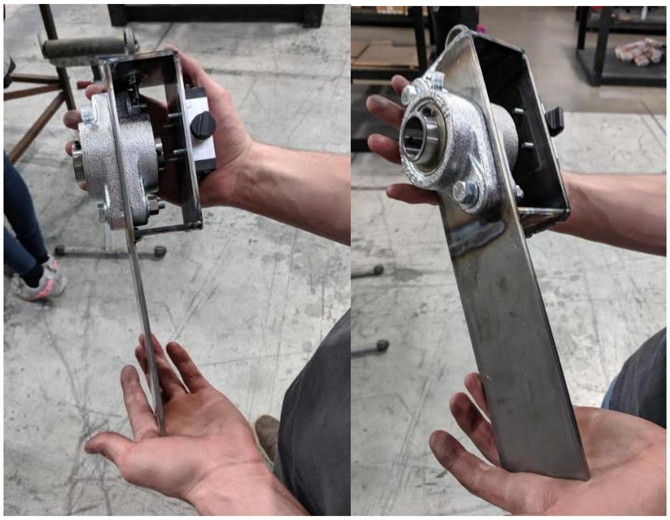

Figure 11. Complete Locking Mechanism

As seen in figure 11 above, the locking mechanism featured four plates of metal that were welded in a rectangle with one extruding edge. Within the rectangular shape, two bearings were bolted to either side of a plate with the intention of housing the rotational shaft that connects to the jig face. At the top of the figures above there is an eyebolt that when connected to a winch assembly allows the shaft and jig face to actuate vertically. The back plate which can be seen on the right side of the figures above is attached to a guide rail that keeps the entire assembly on the same plane and horizontally attached to the jig stand.

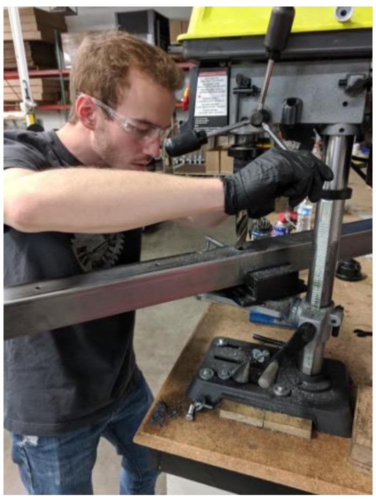

Figure 12. Complete Locking Mechanism

Figure 12 details some of the first steps involved in making the locking mechanism assembly. After cutting the strips of metal down to their desired sizes as detailed in the CAD drawings, the next step was to cut the eight holes that are used to mount both the bearings, the carriage system, and the eyebolt. After cutting and drilling all the pieces of strip metal, the next step was to weld all the pieces of metal together using a MIG welder. Tolerances were held in the pieces of metal by first tack welding each piece together before welding them solid.

2.1.6 Attach Components

Next, attach the winch, pulley, guide rail, carriage, and locking mechanism to the frame. Starting with the winch, cut two sections of 8'' angle iron left over from part #4 and weld them onto the back tripod leg as shown in [Fig. 10].

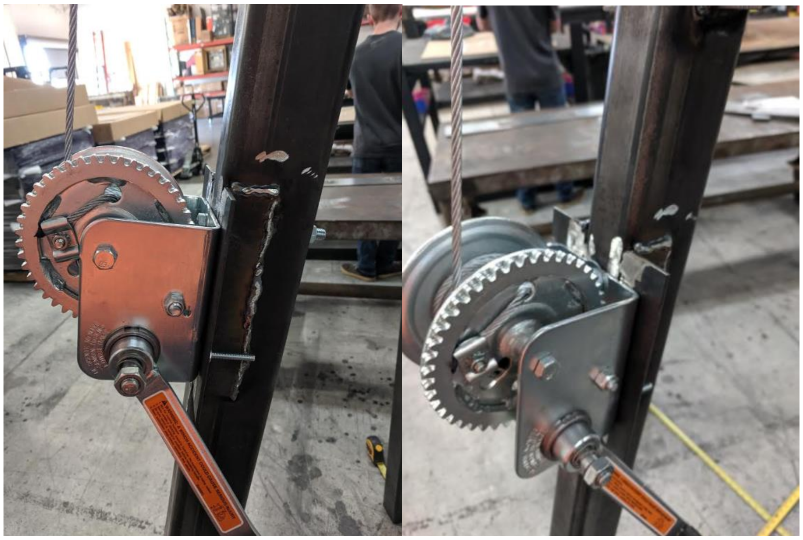

Figure 13. Winch Connection

These two angle irons are then drilled in two locations to allow for a bolted connection, while the back tripod leg has one bolted connection also seen in this figure. The winch can be positioned in any reasonable location along the back tripod leg, this is left for manufacturers preference. The SunTrac design team has set this at the working height of around 40''. Next, attach the pulley using the eyebolt of part #12. Simply using the eyebolt and nut provided, connect the pulley to the top horizontal bar seen in the bottom of [Fig. 11].

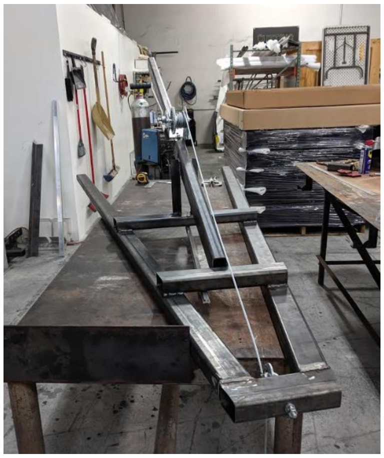

Figure 14. Winch & Pulley Additions

After this step, the wire rope can be connected as seen in the figure, although it’s recommended to save this step for the end. Next attach the guide rail shown in [Fig. 12].

Figure 15. Guide Rail Attachment

Don’t consider the already attached locking assembly in this figure. The guide rail is seen to span the distance between the middle and lower horizontal beams, this is as this picture was taken before discovering the need for the additional guide rail support. Using the M4 mounting fasteners of part #4 in the BOM, attach the guide rail to the previously drilled holes in the middle and lower beams. Next, using the same 0.18’’ drill bit (or nearest under) as before, drill two more holes through the guide rail and added 2x2’’ support. Secure the guide rail with two more M4 mounting fasteners (part #4) to minimize deflection. Next slide the carriage (with locking mechanism attached) onto the guide rail before attaching the wire rope as shown in [Fig. 12]. This concludes the manufacturing of the Jig Frame and respective sub-systems. Next, the Jig Face is constructed and attached to the Jig Frame to complete the prototype.

2.2. Jig Face

The following steps taken in manufacturing the jig face are listed generically and elaborated on in the following sections.

1) Cut 2.00" DIA to desired length
2) Cut 2.25" DIA to desired length
3) Cut 2.50" DIA to desired length
4) Drill center shaft hole
5) Drill pin holes
6) Smooth pin holes
7) Weld plates to endplate
8) Weld telescoping tubes to endplate
9) Weld Jig face to shaft

All the steps listed above were completed in the manufacturing facility at SunTrac USA except the final two steps which were delayed due to the COVID-19 crisis.

2.2.1 Cut 2.00" DIA square tubing to desired length

The smallest diameter square tubing first needs to be cut to their desired dimensions as detailed in the CAD package drawings. The length of the tubes should be 23" with a total of six tubes being cut.

2.2.2 Cut 2.25" DIA square tubing to desired length

The medium diameter square tubing second needs to be cut to their desired dimensions as detailed in the CAD package drawings. The length of the tubes should be 20" with a total of six tubes being cut.

2.2.3 Cut 2.50" DIA square tubing to desired length

The large diameter square tubing third needs to be cut to their desired dimensions as detailed in the CAD package drawings. The length of the tubes should be 42.125" with a total of three tubes being cut.

2.2.4 Drill center shaft hole

The center hole needs to be drilled to eventually be welded to the shaft of the rotational sub-assembly. The hole should be drilled in the center of one of the three largest DIA square tubes and extrude cut through both sides of the tubing.

2.2.5 Drill pin holes

The pinholes need to be drilled at multiple locations depending on the diameter of the square tubing. The small telescoping tube needs to have ⅜" holes drilled at 5.00", 9.00", 17.00", and 21.00" from the leading edge. The medium telescoping tubes need to have holes drilled at 2.00", 6.00", 14.00", and 18.00" from the leading edge. The large telescoping tube needs to have holes drilled at 2.00", 6.00", and 14.00" from the leading edge on both sides of the length of the tube.

2.2.6 Smooth pin holes
Once all the holes are drilled, the next step is to bore out the holes to clear out burrs and make the pins fit smoothly. This can be done using any form of scraping tool.

2.2.7 Weld plates to endplate
In order to prep the endplate, two pieces of metal strip were welded to the 6” x 36” endplate to provide manual stops for the brass standoffs. These pieces of metal need to be welded using lap welds on all sides of the metal slabs except the inside edge to provide a definite edge for tolerances.

2.2.8 Weld telescoping tubes to endplate
Once all telescoping tubes are prepped and ready, the next step is to weld all telescoping tubes to both edges and the middle of the endplate. This is done using corner welds on a MIG welder.

2.2.9 Weld Jig face to shaft
The last step is to weld the jig face to the shaft. This is done by inserting the shaft inside the 1.00” hole in the center large telescoping tube and welding both sides using corner welds. This weld supports the entire weight of the jig face so it is imperative that it is secure and solid.

3. Operation
The device is operated by utilizing the multiple features that it offers. First, the jig face needs to be adjusted to the required height, whether it’s a 4’, 6’, or 8’ configuration. This is done by adjusting the pins to slide the telescoping tubes and securing them in their rightful positions. The pins are shown in [Fig. 16].

Figure 16: Telescoping Tubes Height Adjustment

When the required height is obtained, the copper pipes are to be aligned in their respective positions on the jig’s face. The vertical pipes are supported by the brackets and the horizontal pipes are secured through the power screws. The brass brackets are then placed in the slot indentations beneath the horizontal copper tubing. Once all the copper manifold's components are placed and locked in their correct position, the user may adjust the working height of the jig's face. The winch is used to hoist the jig face vertically across the guide rail. When an appropriate height is obtained, the operator pulls the string attached to the rod that locks the jig face to rotate the device. This operation ensures the copper manifold joints are accessible to the welder. When all the welds are completed, the user can remove the manifold by unlocking the copper tubes from the power screw assembly. This concludes the operation of the welding jig.

4. Maintenance

Proper maintenance of the braze-welding jig is significant as incorrect operating conditions may lead to severe user harm. The components with considerable Risk Priority Number (RPN) from the Failure Modes and Effects Analysis (FMEA) are the guide rail, locking mechanism steel sheet, and pulley eyebolt. Overtime, the guide rail will experience abrasive wear and high cycle fatigue as the carriage and locking mechanism are continually raised and lowered during operation. To ensure the durability of the prototype, the guide rail carriage is to be disassembled from the locking mechanism and replaced as soon as the carriage teflon pads are seen to be worn.

The locking mechanism is another risky component as the moment applied to it from the Jig Face creates regions of concentrated stress along the steel sheet where the locking mechanism attaches to the carriage. These stresses may carry over to the fasteners which connect the carriage, requiring periodic supervision. If the fasteners are seen to be worn or stripped, they are to be replaced. If this occurs frequently, the locking mechanism itself may require a redesign.

Last to be considered is the eyebolt which holds the pulley in place. This eyebolt (part #12) has a lifting capacity of 1,200 lbs, which will not be reached during the operation of the device. Although, the failure of this eyebolt means the failure of the pulley, and the entire Jig Face will drop (potentially in the direction of the operator). It is this reason why the team has used two spacers as well as two nuts to fasten the eyebolt. These fasteners are to be continually monitored and replaced if a fault is found.

5. Troubleshooting

Since the device will be extensively used on a daily basis, some potential failures are expected. The first failure to be expected is from the guide rail. The guide rail carries a huge weight from the jig face and the copper manifold. This weight might apply enough stress on the guide rail that causes its failure. To mitigate this problem, the guide rail must be occasionally inspected for signs of fatigue or failure on the metal. Constant maintenance is also required to make sure the guide rail does not fracture. The second potential failure is from the power screw assembly. Heat expands the copper tubes, therefore if enough heat is transmitted, the horizontal pipes can be stuck in the power screw. To avoid this failure, the pipes should be allowed proper time to cool down before the manifold is dismounted from the jig face. A third potential failure is from tolerancing. Using the jig extensively can cause the jig's mechanisms to wear which causes an error in the manifolds tolerancing. This failure can be mitigated by maintaining the device and by adding another support behind the jig's face to make it sturdier. The last potential failure can be seen from the eyebolt that carries the pulley and jig face. If the eyebolt wears and breaks, the whole system is expected to fall down which can cause serious harm and injury, thus violating safety regulations. To avoid this failure, it is advised that no additional weight is to be applied on the jig and that routine checks are conducted occasionally to look for wear on the eyebolt.

References

[1] S. Siebens, Interviewee, *Ideal Characteristics for Revised Braze Welding Jig.* [Interview]. 30September 2019

[2] K. Alhossaini, N. Firor, E. Smith, E. Vieane, “SunTrac Final Report,” N/A, Flagstaff, 2020

[3] K. Alhossaini, N. Firor, E. Smith, E. Vieane, “SunTrac Final CAD Package,” N/A, Flagstaff, 2020

6 Appendices

Appendix A - Bill of Materials

Part #	Part Name	Location	Qty	Description	Functions	Material	Dimensions	Link to Cost estimate	Part ID	Unit Price	Cost ($)	Subassembly
1	Steel tube	SunTrac	1	4 foot center	Comprises of the stationary middle skeleton structure	Carbon Steel	2.5" x 2.5" x 12'	https://www.mcmaster.com/steel-tubing	4931T146	86.07	$86.07	Jig Face
2	Steel tube	SunTrac	1	Medium Telescoping Tube	Slides in part # 1 to allow for manifold length variation	Carbon Steel	2.25" x 2.25" x 12'	https://www.mcmaster.com/steel-tubing	4931T145	81.43	$81.43	
3	Steel tube	SunTrac	1	Small Telescoping Tube	Slides in part # 2 to allow for manifold length variation	Carbon Steel	2" x 2" x 12 '	https://www.mcmaster.com/steel-tubing	4931T144	75.12	$75.12	
4	Angle Iron	SP Engineering	2	Vertical Pipe Supports	Positions the Vertical Copper Pipes/ Rotation Subassembly support	Low-Carbon Steel	1.5" x 1.5" x 6'	https://www.mcmaster.com/angle-iron	9017K484	16.95	$33.90	
5	Bent-Pull Clevis Pin	SunTrac	24	Bent to lock, included cotter pin	Secures position of sliding tubes	Zinc- Plated Carbon Steel	3/8" Diameter, 3" Usable Length	https://www.mcmaster.com/pins	90146A071	3.86	$92.64	
6	Carbon Steel Strip	SunTrac	1	3' piece of low carbon strip	Used to provide more surface area to each tripod leg	Carbon Steel	2.0" x 1/8" x 3'	https://www.mcmaster.com/steel-strips	6511K511	16.45	$16.45	Jig Frame
7	Steel beam	SunTrac	2	Tripod / A - Frame	Holds welding jig upright	Hot-Rolled Carbon Steel	2" x 3" x 20' x Wall Thick: 0.12"	https://www.industrialmetalsupply.com/hot-rolled-steel-rectangle-tube/rt20030012	RT20030012	62.62	$125.24	
8	Hand Winch	SunTrac	1	Winch for lifting Cap: 800lb	Raise lower and support Jig Face	Steel	3 5/8" x 5 1/8" x 5 1/2" Handle 7"	https://www.mcmaster.com/winches	3196T56	69.51	$69.51	Guide Rail and Winch Assembly
9	Wire Rope	SunTrac	1	Winch rope with hook Cap: 800lb	Connects jig face to winch	Galvanized Steel	Dia: (3/16)" Lngth:15' Hook Open: 7/8"	https://www.mcmaster.com/wire-rope	3308T53	34.6	$34.60	
10	Hanging Pulley	SunTrac	1	Hooked single pulley Cap: 675lb	Guides the 1/4" Wire	Steel	5/8" x 5 3/4" OD 2 1/2" For Rope Dia 1/4"	https://www.mcmaster.com/catalog/126/1614	3099T53	22.21	$22.21	
11	Guide Rail	SunTrac	1	Guide Rail	Sets path for jig movement	Anodized Aluminum	(23 x 15 x 1000)mm	https://www.mcmaster.com/guide-rails	9867K12	70	$70.00	
12	Eyebolt 1	SunTrac	1	Eyebolt for lifting capacity with nut Cap: 1200lb	Mounts pully from A frame	Galvanized Steel	3/8" Dia 16TPI 4" Shank 5 1/2" Total	https://www.mcmaster.com/3016t34	3016T34	7.02	$7.02	
13	Screw	Ace Hardware	4	Long, thin structural support screws	Attach Guide Rail to Support	Stainless Steel	M4 x 70 mm	https://www.mcmaster.com/m4-x-70/flat-head-screws/phillips-flat-head-screws/metric-steel-phillips-flat-head-screws/	9867K12	7.00	$7.00	
14	Carriage	SunTrac	1	Guide Rail Carriage	Travels along guide rail	Aluminum	(68mm H) (47mm W)	https://www.mcmaster.com/guide-rails	9867K12	56.25	$56.25	
15	Steel Sheet	SunTrac	2	Top and Bottom Sheet of Metal	End Plate for tellescoping tubes and Power Screws	4130 Alloy Steel	36" x 6" x 1/8"	https://www.mcmaster.com/4459t188	4459T188	47.35	$94.70	Power Screw/Shelf
16	Steel Sheet	SunTrac	1	Square Sheet	All 4 Power Screw brackets	Ground Low Carbon	8" x 8" x 1/4"	https://www.mcmaster.com/squares	1388K121	54.77	$54.77	
17	Threaded Screw	SunTrac	1	1 foot length to cut	Power Screw	Low-Carbon Steel	3/8" Dia x 1' Long x 16 TPI	https://www.mcmaster.com/standard-threaded-rods	98957A132	3.62	$3.62	
18	Steel Rod	SunTrac	1	1 foot length to cut	Handles for Power Screws	Low-Carbon Steel	1/4" Dia x 1' Long	https://www.mcmaster.com/steel-rods	8920K115	1.19	$1.19	
19	Carbon Steel Strip	SP Engineering	1	Used as surface of shaft subassembly	Secures pillow block bearings to locking mechanism	Low Carbon Steel	3" x 3/16" x 3'	https://www.mcmaster.com/8910k542-8910K544	8910K542	18.4	$18.40	Block and Locking Mechanism
20	Roller Bearing	SunTrac	2	For Axis of Rotation	Connects shaft to A-Frame	Nickel-Plated Cast Iron	2 11/16" x 5 1/8" x 1 13/32"	https://www.mcmaster.com/bushings	6494K43	39.74	$79.48	
21	Metal Wire	SunTrac	1	Stainless Steel Wire	Connects grip to gear lock pin	Multipurpose 304 Stainless Steel Wire	0.162" x 14'	https://www.mcmaster.com/metal-wire	8860K24	12.06	$12.06	
22	Spring	SunTrac	1	Rotational Subassembly Spring	Lock the jig in place	301 Stainless Steel	2" Long, 0.938" OD, 0.778" ID	https://www.mcmaster.com/springs	9657K27	5.14	$5.14	
23	Rod	SunTrac	1	Rotational Subassembly Rod	Locks rotation of gear	4130Alloy Steel	D = 0.75" L = 1'	https://www.mcmaster.com/6673t25	6673T25	12.04	$12.04	
24	Gear	SunTrac	1	Locking Mechanism	Allows rotation of skeleton frame	1144 Carbon Steel	OD = 2.67", 14 teeth	https://www.mcmaster.com/gears	6867K1	103.3	$103.30	
25	Shaft	SunTrac	1	Carbon Steel Shaft	Connect jig to ball bearing and stand	1045 Carbon Steel	1" Diameter, 9" Long	https://www.mcmaster.com/precision-shafts	1497K145	26.06	$26.06	
26	Key	SunTrac	1	Key for gear and shaft	Restricts rotation of gear relative to shaft	Zinc Plated 1018-1045 Carbon Steel	12" x 0.25" x 0.25"	https://www.mcmaster.com/catalog/126/3579	98510A136	1.62	$1.62	
27	Eyebolt 2	SunTrac	1	Eyebolt for lifting capacity with nut Cap: 500lb	Connects Rotational Assembly to metal wire	Steel	1/4" Dia 20TPI 1" Shank 2 1/2" Total	https://www.mcmaster.com/eye	3014T45	3.21	$3.21	
28	Angle Iron	SunTrac	1	Angle Iron used in locking subassembly	Supports rod that interferes with gear	Low Carbon Steel	3" tall, 2" wide, 3/16" thick, 1' long	https://www.mcmaster.com/9017k3	9017K3	7.1	$7.10	
										Total Cost Estimate:	$1,200.13	(Before Shipping)
										$200 shipping	$1,400.13	(After Shipping)

Appendix B - Tripod Leg Beam Drawings

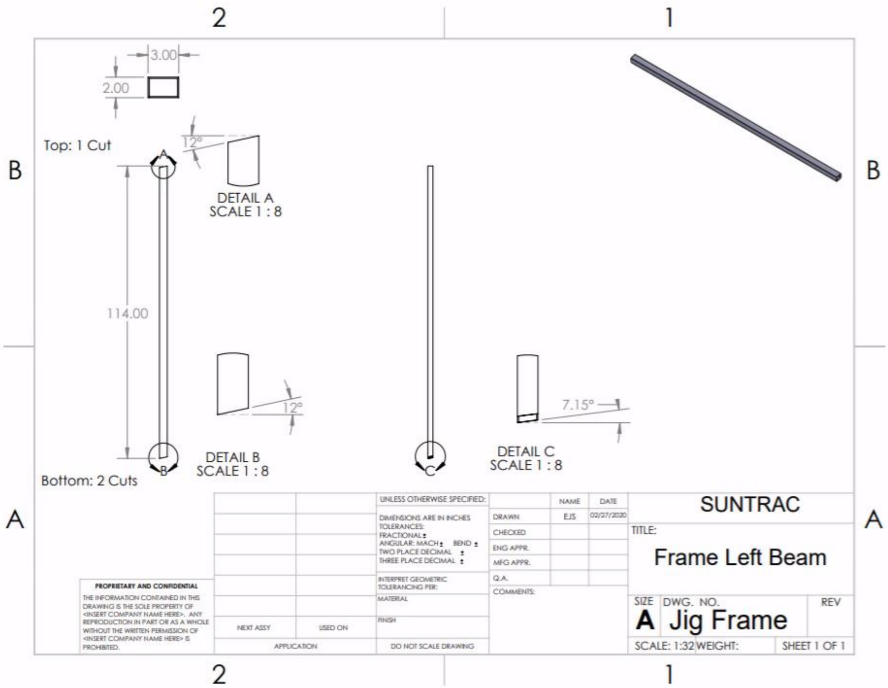

Figure 17. Tripod Frame Left Beam

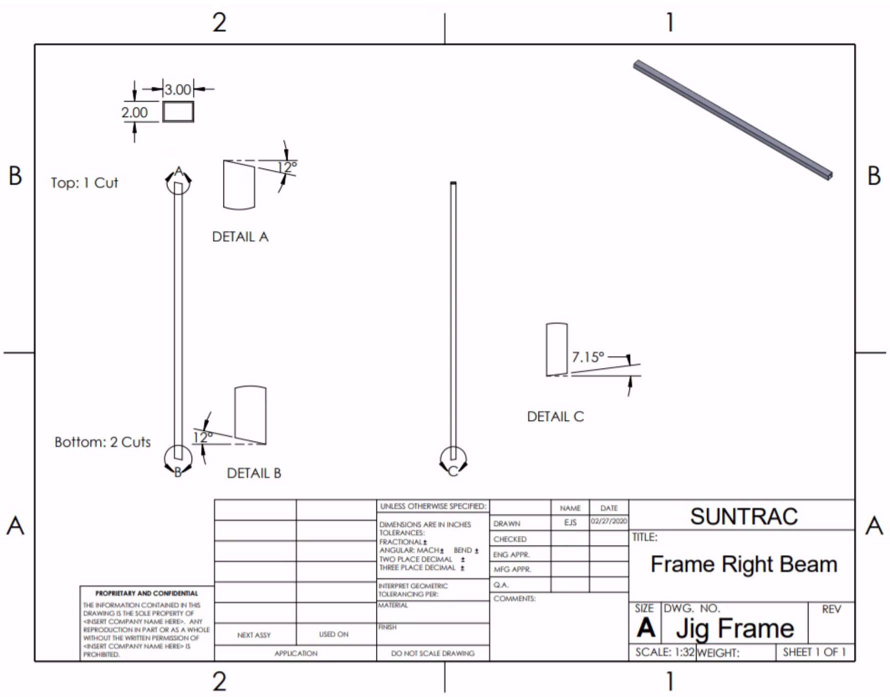

Figure 18. Tripod Frame Right Beam

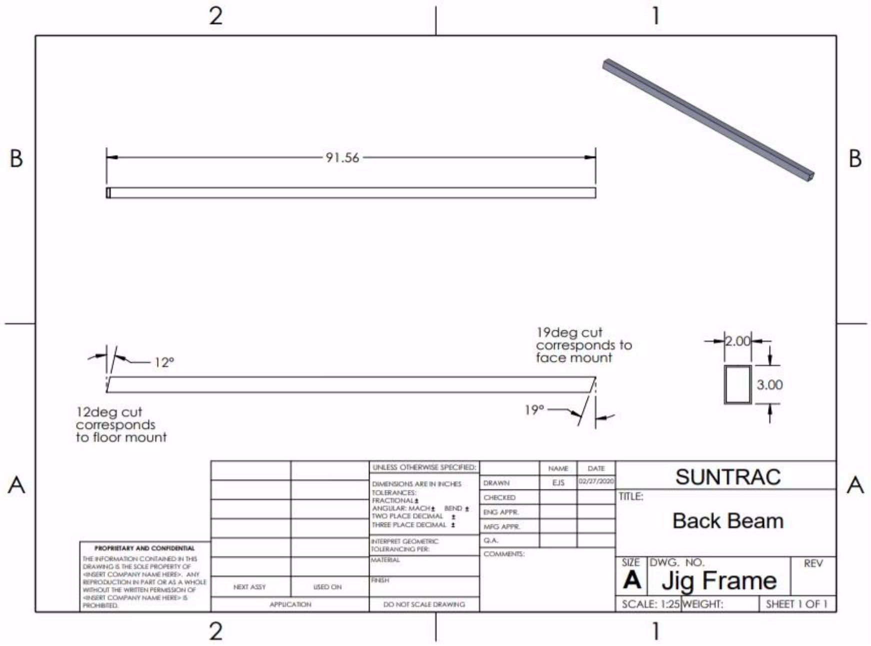

Figure 19. Tripod Frame Back Beam