Summer 2023

JME 4110: Remote Rail Switch

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Joint Engineering Program

University of Missouri–St. Louis ▪ Washington University in St. Louis

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When a rail line splits into 2 lines going in different directions, a switch must be manually thrown to determine which way the train goes. Our task was to create a device that would attach to the existing switch and be capable of throwing said switch remotely while still allowing for manual throwing if necessary.

JME 4110
Mechanical Engineering
Design Project

Remote Rail Switch

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Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Value proposition / project suggestion

Intramotev is a company developing battery operated automated railway vehicles to increase the efficiency, safety, and effectiveness of traditional rolling stock. An important element of their system is the ability to navigate railway systems efficiently and their vehicles to carry out the tasks assigned to them. The efficiency of this process is greatly reduced if there are manually actuated rail switches in the rail network the vehicles are operating on. The goal of this project was to develop a remotely actuated rail switch for use with their vehicles. This would involve retrofitting an existing switch with some sort of electro-mechanical actuator capable of throwing the switch when commanded.

1.2 List of team members

Tyler Teague
Kameron Ripple
Nolan Celestine
Dylan Light

2 Background Information Study

2.1 Design Brief

The goal of this project is to develop a remotely actuated rail switch for Intramotev to use with their rail cars. This mechanism will fully switch between tracks in a two-rail junction. To accomplish this, we must design a system that can produce enough force to turn the lever arm into switch positions, or push the switch bar to full extension and pull to full retraction. Intramotev requests this be more of an attachment to an existing switch rather than a complete overhaul, therefore complete demolition of the original is not recommended. Furthermore, there must be a control system that tells the system to activate after pressing a remote from a set distance (requirements given by Inrtamotev). Given the system will be outside we also need to weatherproof the system. Finally, the switch needs to have some sort of locking mechanism to comply with legal safety precautions.

2.2 Background summary

When researching other products people have created to throw a track remotely nearly every design we found resulted in a complete tear away of the old system and the building of a more advanced one. There seemed to be no other companies (that we could find) that built an attachment on the old system to make it function remotely. However, perhaps we can use some of their switching methods for our system while keeping the original switch functional. It seems the two main methods companies use for switching the track remotely are electrical motors and hydraulics, with motors being more popular. We believe this is due to the simplicity of using a fully electrical system rather than hydraulics or pneumatics. Although, finding a motor with enough torque to turn the lever within a reasonable price range is difficult. If we took a hydraulic approach getting the amount of force we require would be very simple but managing the fluid would add additional complexity.

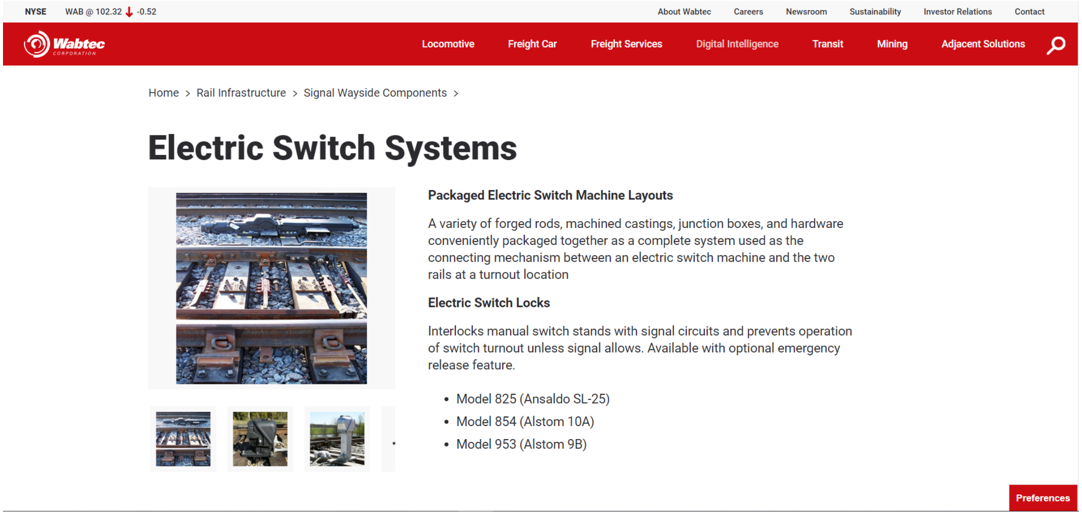


Figure 1: BIS Source 1.

This company sells an "all-in-one" system that connects an electric switch machine to the switch junction. The electric switch locks to prevent the train switch from being used unless a certain signal is used. This is somewhat similar to what we would need, as we want something that is electrically operated and allows the use of a signal to activate or lock the rails. This design not only requires an electric switch machine to be installed but the junction itself. Using this design would require an entirely new system to be installed.

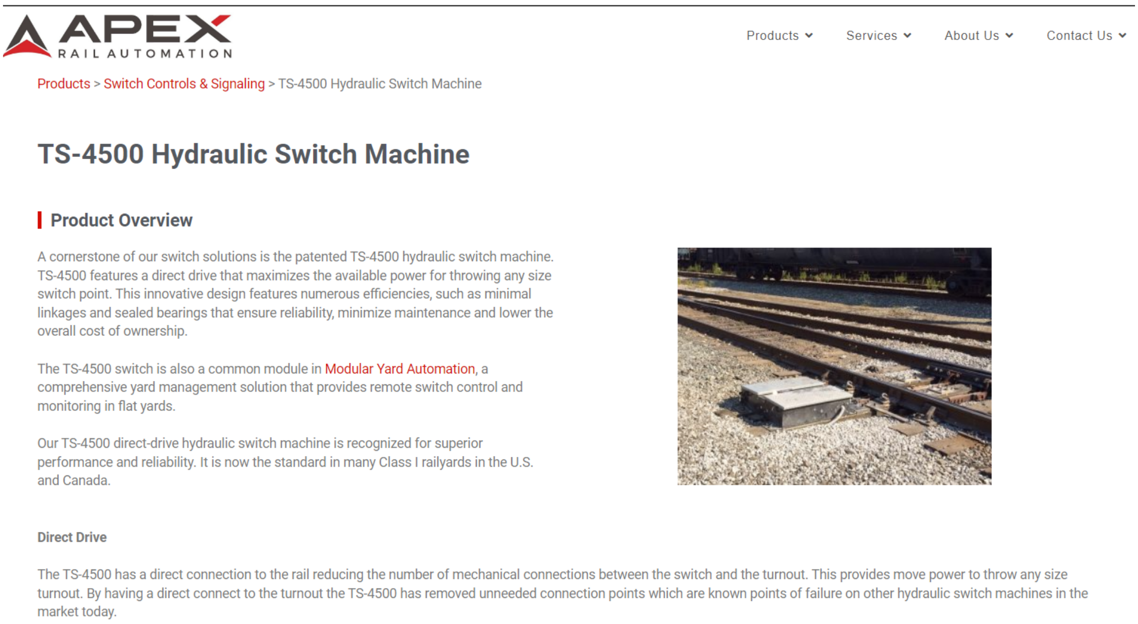


Figure 2: BIS Source 2.

This company specializes in railroad automation and has many products dedicated to automating rail switches. This is a switch system that uses hydraulics to move the throwing arm instead of an electric motor or a mechanical cam system. This system is modular and can attach to other modules to make it remote-operated. Much like the previous example, this solution would require tearing out the mechanical system in order to install this hydraulic system.

3 Concept Design and Specification

3.1 User Needs and Metrics

3.1.1 Record of the user needs interview

The following summarizes a user needs interview between our group members and Kenneth Vaughn (chief engineer at Intramotev) conducted on June 28th 2023.

Importance scale 1-5 (5 being most important 1 being least)

Table 1: User needs interview.

Question	Cust. Statement	Int. Need	Importance
What size requirements are you looking for in the design?	It would be nice if it was form-fitting to the size of what we saw on the ground. There is a height limit we must adhere to because of the rail cars. Be careful in height. There is some freedom in length and width, however.	Device should fit within a 5’x2’x1’ (LWH) area.	3
Is there an optimal speed requirement you would like to meet for switching the rail?	30 sec to a minute (top speed 25mph) going about 10 mph	It must receive a signal, switch, and check for safety within 1 minute.	4
How important is it for the final design to be weatherproof/ durable?	We learned with the customer visit, there are very crazy operating temperatures with their customers. Rainproof, water proof. Operating between 30F-130F. Switches have not really been maintained.	It must be rain or waterproof and be able to operate between 30-130F.	5
How important do you believe it is to keep the main original components such as the original lever for the switch?	The federal railway association has some regulations on the type of switches and modifications that could be made to the switch. Is there an MSRP that covers tracks?	The design must use a majority of the original mechanism to retail code safety.	5
How important is having a control system for the switch where it can tell what position it is in?	It would be important to determine the switch position mechanically. The flag on the top helps as well to identify the switch position. Can't always rely on red and green arrows because some wear off.	There must be more than one way to check the switch position than just through	5

	Railroad workers may be able to identify the switch position given the position of the handle	visual inspection.	
If the design included an electrical locking system, how important would it be to still have the manual foot press locking system?	We may not have that answer, but we will still want to have the manual operation. Can the device move without being powered? Concern. There needs to be another system to use it manually. Can it be disabled?	The device should lock under normal operations, but still be able to move as a failsafe.	5
What type of range are you expecting from the device?	50ft or more potentially from the rail switch. They may have to be able to see what the tug volt can do. (thinking it could be the command center sends the command to the switch), Would the position need to flow back to the network we decide on?	Receiving range must be at least 50-150ft.	4
What is the importance of the device switching the track remotely?	That is what we are looking to do. The main goal	The switch **MUST** be able to be switched without the use of the lever or physical force.	5
What is the importance of the device switching the track accurately? (can be repeated multiple times with success.)	We need the reliability to be there, it should be able to operate 24/7 365. I don't know if it needs a battery system or if it's hooked up electrically.	Must operate in all conditions, either be attached to the grid or have a large power source.	5
Jakiela Question Is this an add-on?	Wants to be able to attach the motor to the original hand crank mechanism. Doesn't think we want to touch the railroad spikes, And we want to be able to work with a couple of different styles.	Design must not completely tear up the original system, with minimal changes to the rail system.	5

3.1.2 List of identified metrics

TABLE 2: IDENTIFIED METRICS.

Need	Description	Importance (1-5)
1	Device must fit within a 5’x2’x1’ area (excluding the area of the rail switch).	**3**
2	Device must do everything required to switch positions between .5 to 1 minute.	**4**
3	Device must be weatherproof between 30-130F.	**5**
4	Device must use a majority of the original system.	**5**
5	Device must have more than one control system that tracks switch position (mechanical or electric).	**5**
6	Device needs an electric locking system that can still be mechanically used if needed (part failure).	**5**
7	Device should be able to read signals within 50-150FT	**4**
8	**Device must remotely switch track positions.**	**5**
9	Device must be reliable and switch positions with accuracy.	**5**
10	Device must keep some form of mechanical lever system.	**5**

3.1.3 Table/list of quantified needs equations

Table 3: Quantified needs.

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	**1**	Area	Ft^3	1	10
2	**2**	Time	sec	30	60
3	**3**	Weatherproof (30F-130F)	percentage	100	0
4	**4,10,6**	Original system used	percentage	100	50
5	**5,6**	Switch position monitoring (control systems)	integer	3	1
6	**6,10,4**	Locking system (mech. Or electrical)	integer	2	1
7	**7,8**	Accurately read signals	Ft	150	50
8	**8**	Remote switch operation	percentage	100	0
9	**9,5,6**	Reliable and accurate switches	percentage	100	0
10	**10,4,6**	Mechanical lever system	integer	1	0

3.2 CONCEPT DRAWINGS

DESIGN CONCEPTS:

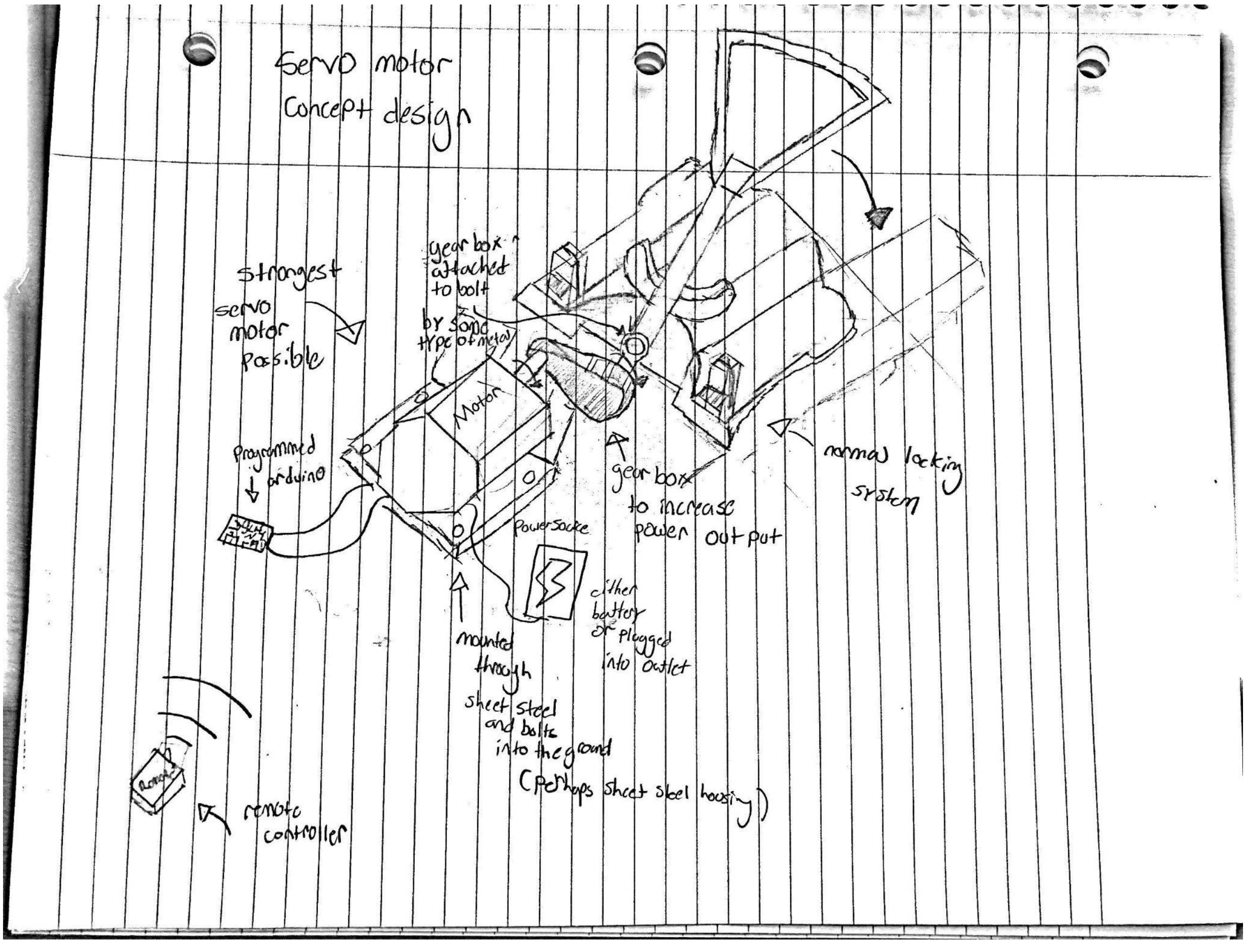


FIGURE 3: SERVOMOTOR DESIGN CONCEPT.

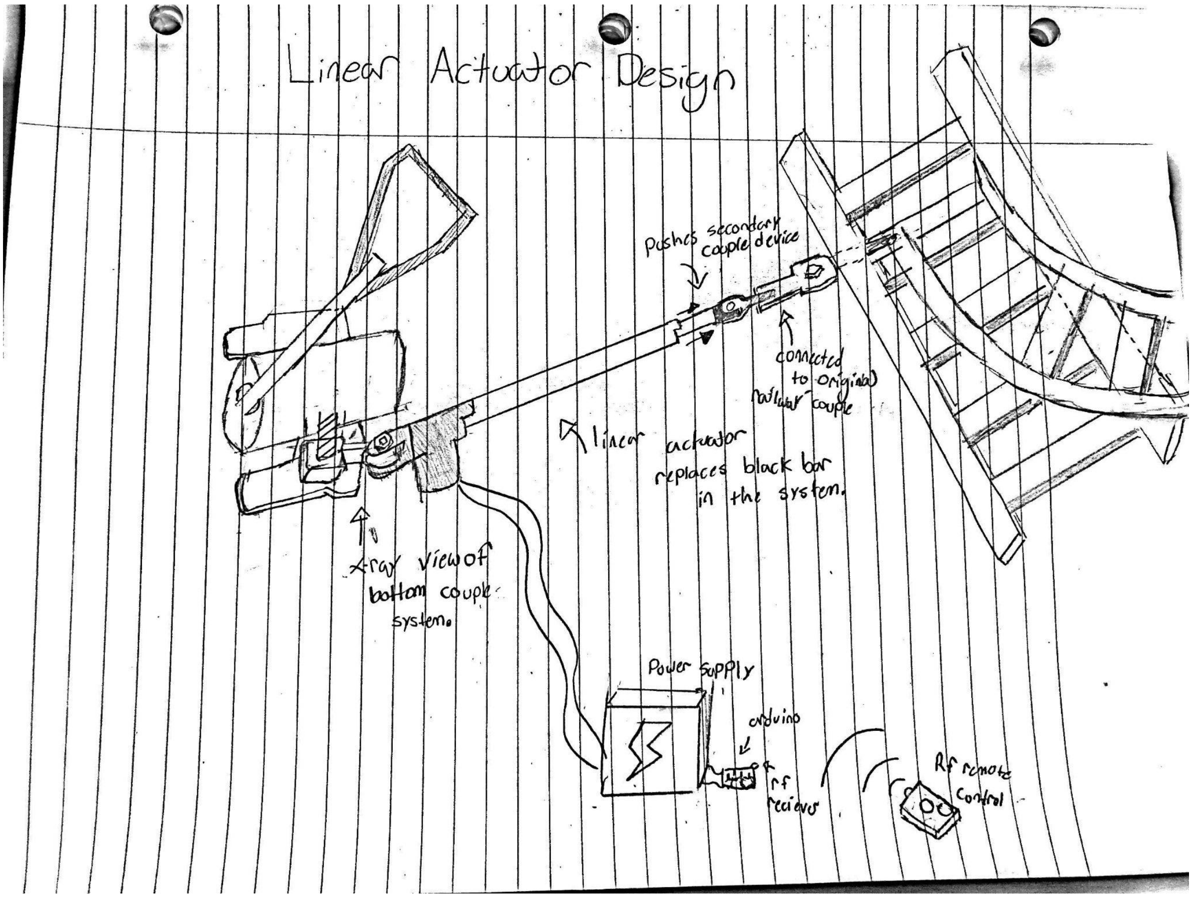


FIGURE 4: LINEAR ACTUATOR DESIGN CONCEPT.

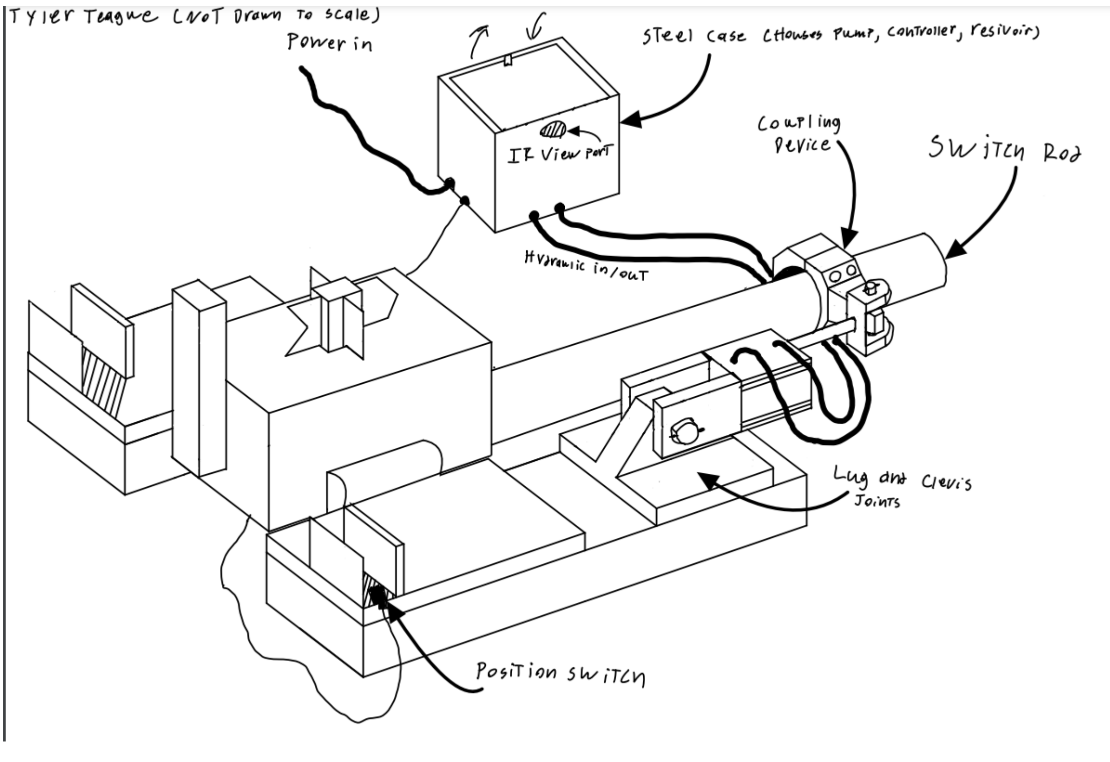


FIGURE 5: HYDRAULIC CYLINDER DESIGN CONCEPT.

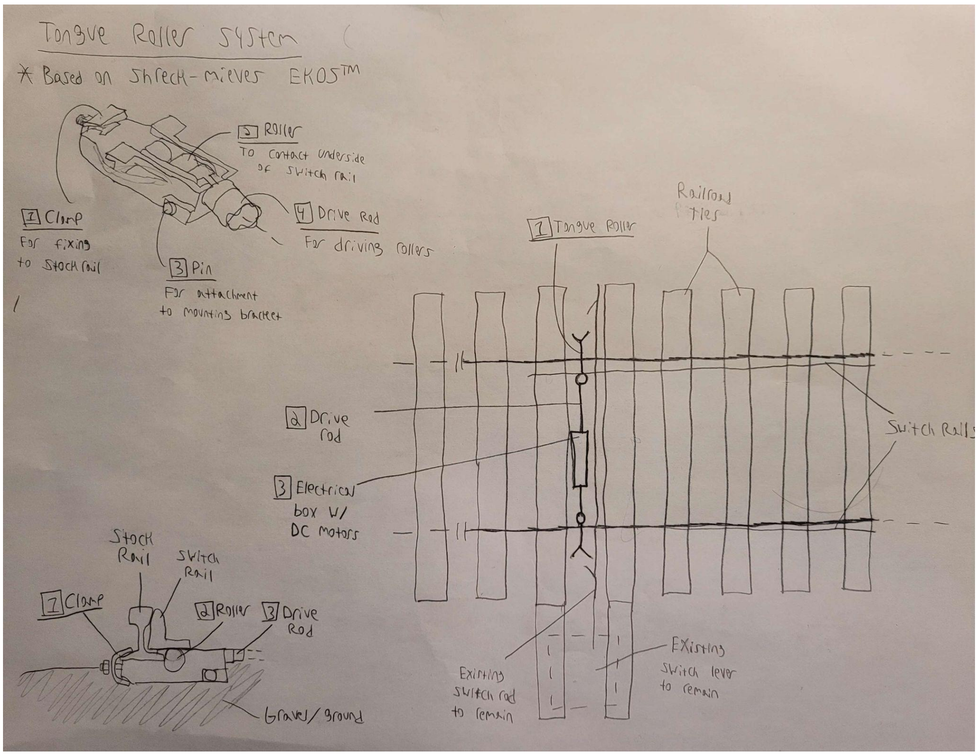


FIGURE 6: TONGUE ROLLER SYSTEM DESIGN CONCEPT.

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring (not screening)

Design 1: Servo Motor		Metric												
		Area	Time	Weatherproof	Original system used	Switch position monitoring	Locking system	Signal range	Remote operation	Reliabily and accuracy	Mechanical lever	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	Total area	1										0.333	0.065	0.021645
2	Time to switch		1									0.5	0.087	0.0435
3	Weatherproofing			1								0.7	0.109	0.0763
4	Original system used				0.8		0.05				0.15	1	0.109	0.109
5	Posistion control systems					0.75	0.25					1	0.109	0.109
6	Electric locking system				0.1		0.75				0.15	1	0.109	0.109
7	Signal range							0.9	0.1			0.55	0.087	0.04785
8	Remote control								1			1	0.109	0.109
9	Accuracy and reliability					0.15	0.05			0.8		0.92	0.109	0.10028
10	Mechanical lever				0.2		0.05				0.75	1	0.109	0.109
Units		ft^3	sec	percent	percent	integer	integer	ft	percent	percent	integer	Total Happiness		0.834575
Best Value		1	30	100	100	3	2	150	100	100	1			
Worst Value		10	60	0	50	1	1	50	0	0	0			
Actual Value		4	45	70	100	3	2	100	100	90	1			
Normalized Metric Happiness		0.333	0.5	0.7	1	1	1	0.5	1	0.9	1			

FIGURE 7: SERVO MOTOR

Design 2: Linear actuator		Metric												
		Area	Time	Weatherproof	Original system used	Switch position monitoring	Locking system	Signal range	Remote operation	Reliably and accuracy	Mechanical lever	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	Total area	1										0.333	0.065	0.021645
2	Time to switch		1									1	0.087	0.087
3	Weatherproofing			1								0.7	0.109	0.0763
4	Original system used				0.8		0.05				0.15	0.92	0.109	0.10028
5	Posistion control systems					0.75	0.25					1	0.109	0.109
6	Electric locking system				0.1		0.75				0.15	0.99	0.109	0.10791
7	Signal range							0.9	0.1			0.55	0.087	0.04785
8	Remote control								1			1	0.109	0.109
9	Accuracy and reliability					0.15	0.05			0.8		0.92	0.109	0.10028
10	Mechanical lever				0.2		0.05				0.75	0.98	0.109	0.10682
Units		ft^3	sec	percent	percent	integer	integer	ft	percent	percent	integer	Total Happiness		0.866085
Best Value		1	30	100	100	3	2	150	100	100	1			
Worst Value		10	60	0	50	1	1	50	0	0	0			
Actual Value		4	30	70	95	3	2	100	100	90	1			
Normalized Metric Happiness		0.333	1	0.7	0.9	1	1	0.5	1	0.9	1			

FIGURE 8: LINEAR ACTUATOR

Design 3: Hydraulic cylinder		Metric												
		Area	Time	Weatherproof	Original system used	Switch position monitoring	Locking system	Signal range	Remote operation	Reliably and accuracy	Mechanical lever	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	Total area	1										0.334	0.065	0.02171
2	Time to switch		1									0.5	0.087	0.0435
3	Weatherproofing			1								0.9	0.109	0.0981
4	Original system used				0.8		0.05				0.15	1	0.109	0.109
5	Posistion control systems					0.75	0.25					0.625	0.109	0.068125
6	Electric locking system				0.1		0.75				0.15	1	0.109	0.109
7	Signal range							0.9	0.1			0.55	0.087	0.04785
8	Remote control								1			1	0.109	0.109
9	Accuracy and reliability					0.15	0.05			0.8		0.765	0.109	0.083385
10	Mechanical lever				0.2		0.05				0.75	1	0.109	0.109
Units		ft^3	sec	percent	percent	integer	integer	ft	percent	percent	integer	Total Happiness		0.79867
Best Value		1	30	100	100	3	2	150	100	100	1			
Worst Value		10	60	0	50	1	1	50	0	0	0			
Actual Value		4	45	90	100	2	2	100	100	80	1			
Normalized Metric Happiness		0.334	0.5	0.9	1	0.5	1	0.5	1	0.8	1			

FIGURE 9: HYDRAULIC CYLINDER

Design 4: Tongue Roller System		Metric												
		Area	Time	Weatherproof	Original system used	Switch position monitoring	Locking system	Signal range	Remote operation	Reliabily and accuracy	Mechanical lever	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	Total area	1										0.334	0.065	0.02171
2	Time to switch		1									0.95	0.087	0.08265
3	Weatherproofing			1								1	0.109	0.109
4	Original system used				0.8		0.05				0.15	0.95	0.109	0.10355
5	Posistion control systems					0.75	0.25					0.75	0.109	0.08175
6	Electric locking system				0.1		0.75				0.15	0.25	0.109	0.02725
7	Signal range							0.9	0.1			0.55	0.087	0.04785
8	Remote control								1			1	0.109	0.109
9	Accuracy and reliability					0.15	0.05			0.8		0.75	0.109	0.08175
10	Mechanical lever				0.2		0.05				0.75	0.95	0.109	0.10355
Units		ft^3	sec	percent	percent	integer	integer	ft	percent	percent	integer	Total Happiness		0.76806
Best Value		1	30	100	100	3	2	150	100	100	1			
Worst Value		10	60	0	50	1	1	50	0	0	0			
Actual Value		4	30	5	100	3	1	100	100	75	1			
Normalized Metric Happiness		0.334	0.95	1	1	1	0	0.5	1	0.75	1			

FIGURE 10: TONGUE ROLLER SYSTEM

3.3.2 Preliminary analysis of each concept's physical feasibility

Servomotor design: Happiness score (83%)

Using a servomotor with a type of gear system ended up meeting a lot of the requirements placed on our design. Motors are relatively easy to work with and easy to incorporate into a control system. The main issue we may face with the servomotor design is finding a servomotor large enough to turn the lever through its complete half-rotation. It would have to be very powerful even when using a gearbox to increase torque. When we utilize a gearbox we take the risk of slowing down the system and could potentially get out of the time frame of 30 seconds to 1 minute. Even though that's a pretty large timeframe. Many servomotors that large are very expensive and we don't have the proper funding to spend on an industrial-sized servo. Perhaps a regular motor may suffice with the proper control system. Given the current condition of the system, it’s possible that the estimated forces are lower than the actual forces needed to switch positions. I believe while this system seems the simplest on paper we may have challenges bringing this idea to a prototype financially. However, I do pride the design for being more of an “attachment” than an overhaul.

Linear Actuator design: Happiness score (86%)

Replacing the main bar with a linear actuator allows us to keep almost all of the old system working while still being able to automate it. A linear actuator is able to meet our push/pull requirements, tell when it is extended/retracted, and lock in place. We might have an issue with finding one that will extend as much as we need it to. Since the main component will be ordered from a supplier it will be easy to replace should it break. We will most likely need to design and manufacture a few parts to connect the actuator to the rail switch.

Hydraulic Cylinder design: Happiness score (80%)

This design uses a double-acting hydraulic cylinder to actuate the switch rod between switch points. Since this is a linear motion of between 4.5-5" with a maximum force between 1750-2000 lbs, a hydraulic cylinder would be the prime candidate for this task. Even small cylinders are able to push and pull over 2000 lbs, well over what we need. Almost all of the parts needed can be bought from places like Mcmaster-Carr, and there are plenty of cylinder and mounting options. I would choose lug and clevis joints, as they allow a wide range of movement in pitch when operating. The pins that connect the lug and clevis joins would also have cotter pins, which allows for easy deconstruction of the assembly. I would mount the cylinder to the rail ties, as they can withstand large amounts of force both in shear and compression. There are many different designs of hydraulic fluid reservoirs and compressors on the market, and many are already weatherproof and use solenoids to actuate the different inputs, which would be easy to automate when connected to something like a Raspberry Pi or other controllers. Potential issues are that hydraulic cylinders are very hard to come by in half-inch increments, and 5" of extension may be too great for our rail switch, and 4" too little. Using trigonometry, we may be able to find specific angles Θ and ϕ for yaw and pitch, respectively. This may cause problems if these angles are too large. We would also need to make a new part, a coupling device that would connect the cylinder rod to the switch rod. This would be two half-cylinders with an inner diameter equal to that of the outer diameter of the switch rod. Two threaded bolts on either end will connect the two parts together with enough clamping pressure force to actuate the switch rod without slipping. A simple lug will be on 1 or both parts to attach to the clevis mount on the piston rod.

Tongue Roller System Design: Happiness score (77%)

This design bypasses the existing rail switch system completely by supporting the switch rail on a roller system. These rollers are turned using a drive shaft which is powered by a DC motor. This system requires two roller systems, meaning two separate motors are required for the full operation of the system. Each roller is lodged under the stock rail and fixed to it using a bolt and clamp. The tongue roller is additionally fixed to the surrounding railroad ties using brackets. They are to be positioned parallel to the switch rod and located either between the same railroad ties, or an adjacent set of railroad ties. The box that houses the DC motors should be weatherproof. An electrical line needs to be run to this box from some other location on-site. The downside to this system is that installation would require digging under the stock rail. A larger issue is that the components would require precise machining which cannot be easily worked around. While this design is an alteration of an existing design, the company that produced the original roller has been defunct since 2013 or so. This means the construction of this system would be very complex compared to other potential designs.

3.3.3 Final summary statement

We chose the hydraulic design as the winner because of a few main considerations. The first is that hydraulic cylinders are able to output a large amount of force without requiring a large amount of electricity or other energy sources to operate. We were able to find that the maximum switch rod force was 1750 lbs, and even with increasing it to 2000 lbs due to things like wear and excessive friction hydraulic cylinders would continue to perform impressively. There are many hydraulic cylinders on the market, and we were able to find a cylinder that meets our specifications. The same company also makes lug and clevis mounts for both the piston rod and cylinder body, which makes installation very easy. Cotter pins are on the lug and clevis pins, which makes us able to completely remove the piston from the rail switch if needed. There are many hydraulic fluid pumps on the market, and we are able to find ones that use solenoids to actuate between the 2 pump outputs. This allows us to not be constrained with where we put the pump and other controllers. Ultimately, this gives us the ability to fully motorize this rail switch without modifying the mechanical system already in use. The linear actuator design seems to be very comparable to the hydraulic design, as we are both using linear motion to move the switch rop. The linear actuators have one distinct feature: replacing the switch rod with the linear actuator itself. Not only would this mean partially disassembling the rail switch, but there are also concerns about the switch not being to be mechanically moved in case of failure of the linear actuator. Although the tongue roller design would seem to be the best performer from these designs, the company that designed this type of system is now defunct, which means building the entire system from scratch. This would prove very cost and time intensive, and would not be possible given our current resources. The servo motor design was almost chosen to be our design concept, but we were unable to find servo motors with enough torque to move the system. We would need to either find or make a gear system to increase the torque output, increasing cost and difficulty. Another consideration is that of space around the rail switch, there is only one orientation that the motor can mount to the system, and there might not be enough room for the servo motor and gear system. We chose the hydraulic cylinder because of the ability to buy the majority of parts needed, the performance of hydraulic cylinders, and the space effectiveness that this design gives us. The single user need that we will be considering as the overall performance measure is need #8, ***Device must remotely switch track positions.***

3.4 Proposed performance measures for the design

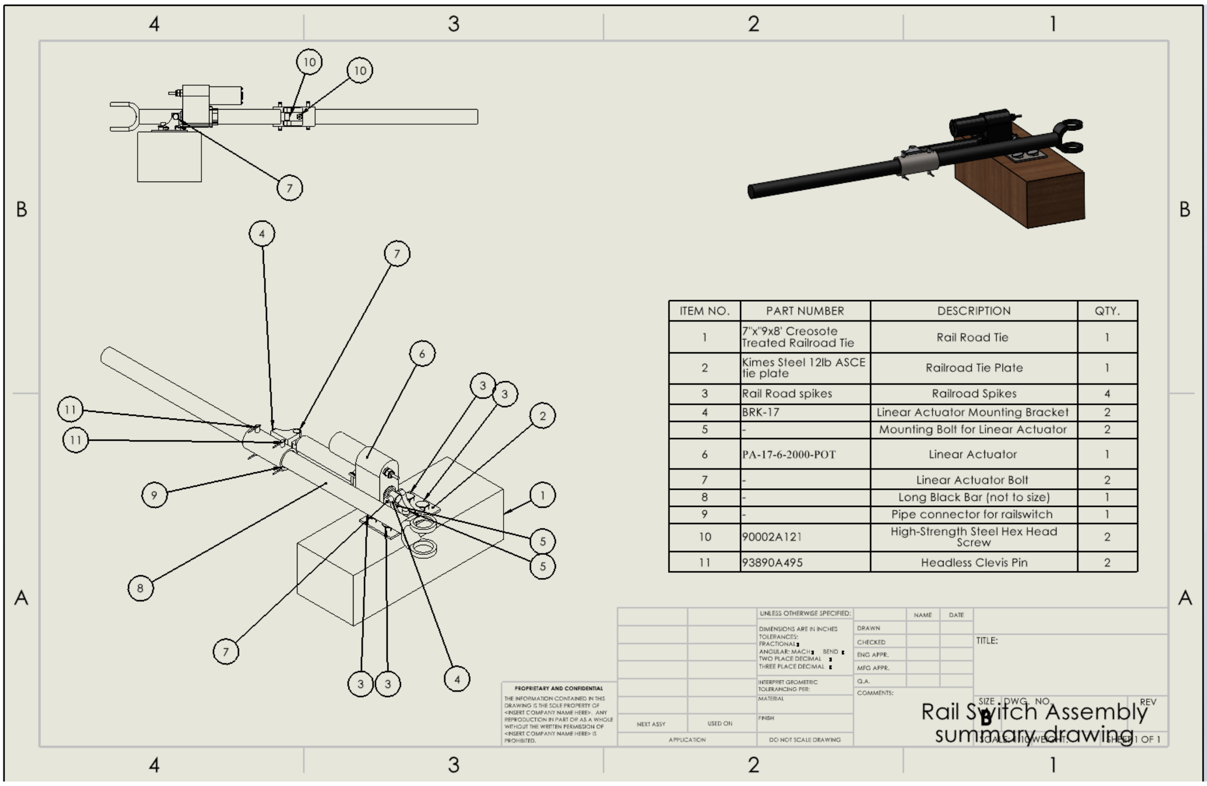
Device must remotely switch track positions.

3.5 Revision of specifications after concept selection

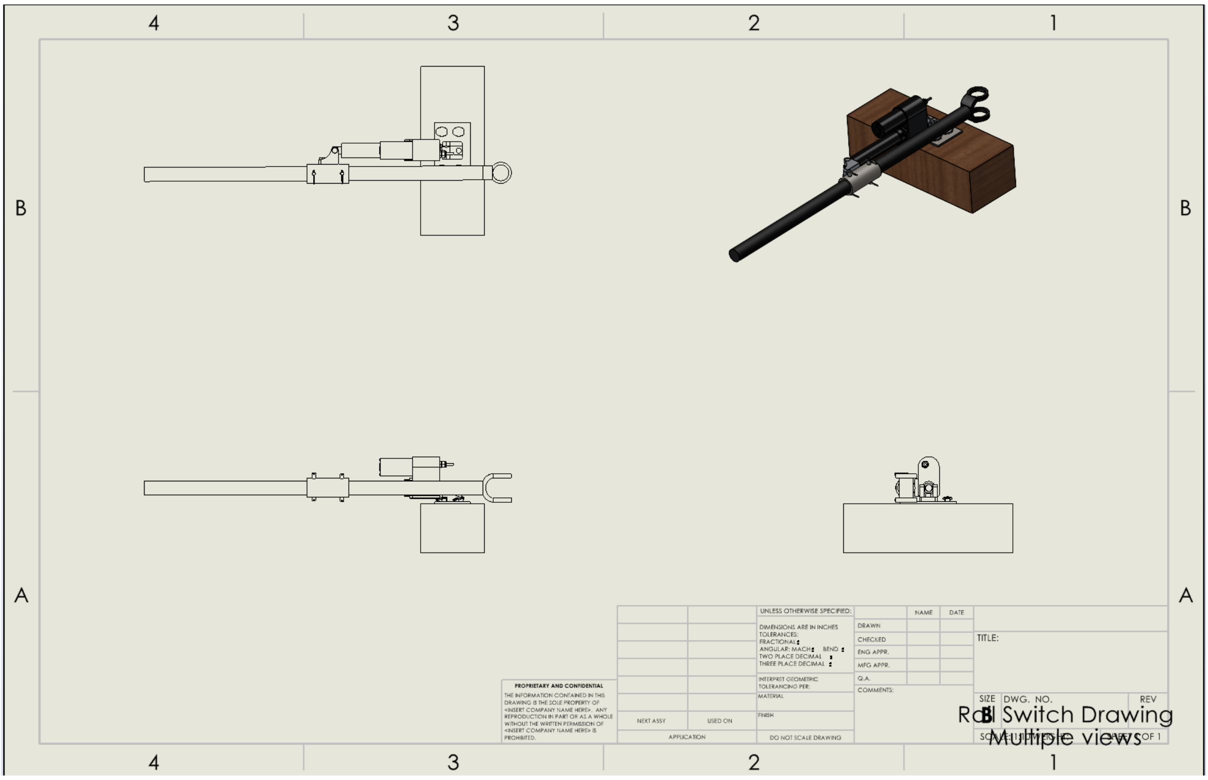
We decided to go with the hydraulic cylinder overall design, but use of a linear actuator in place of the actual hydraulic cylinder. After searching online, we were unable to find a coupler that we were satisfied with, so we decided to make our own. We also adjusted how the components were mounted based on the different coupler.

4 Embodiment and fabrication plan

4.1 Embodiment/Assembly drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	7"x9x8' Creosote Treated Railroad Tie	Rail Road Tie	1
2	Kimes Steel 12lb ASCE tie plate	Railroad Tie Plate	1
3	Rail Road spikes	Railroad Spikes	4
4	BRK-17	Linear Actuator Mounting Bracket	2
5	-	Mounting Bolt for Linear Actuator	2
6	PA-17-6-2000-POT	Linear Actuator	1
7	-	Linear Actuator Bolt	2
8	-	Long Black Bar (not to size)	1
9	-	Pipe connector for railswitch	1
10	90002A121	High-Strength Steel Hex Head Screw	2
11	93890A495	Headless Clevis Pin	2



Figures 11 and 12: BOM and three view drawings of the embodiment drawing.

4.2 Parts List

Table 4: BOM for project embodiment.

No.	Description	Unit Cost	Quantity	Total
1	Progressive Automations PA-17-6-2000-POT linear actuator with potentiometer.	$343	1	**$343**
2	Progressive Automations BRK-17 heavy-duty mounting bracket for PA-17.	$23.99	2	**$47.98**
3	Progressive Automations PS-10-12-67 12 VDC IP67 power supply.	$104	1	**$104**
4	Progressive Automations PA-3 1 channel control box.	$89	1	**$89**
5	Stockcar Steel 1026 steel DOM thick-walled tubing.	$72.06	1	**$72.06**
6	McMaster-Carr 93890A495 .5” clevis pin with cotter pins.	$8.78	2	**$17.56**
7	Kimes Steel 12 lb ASCE rail tie plate.	$5.85	1	**$5.85**
8	Blacksmiths Depot ⅝” rail spikes.	$2	6	**$12**
9	Polycase ML-57F weatherproof NEMA enclosure.	$31.59	1	**$31.59**
10	Railroad Tie	24.78	1	**$24.78**
11	High strength steel Hex Head bolts	13.47	1	**$13.47**
	15% Contingency			**$114.19**
	Total with Contingency			**$875.48**

4.3 Draft detail drawings for each manufactured part

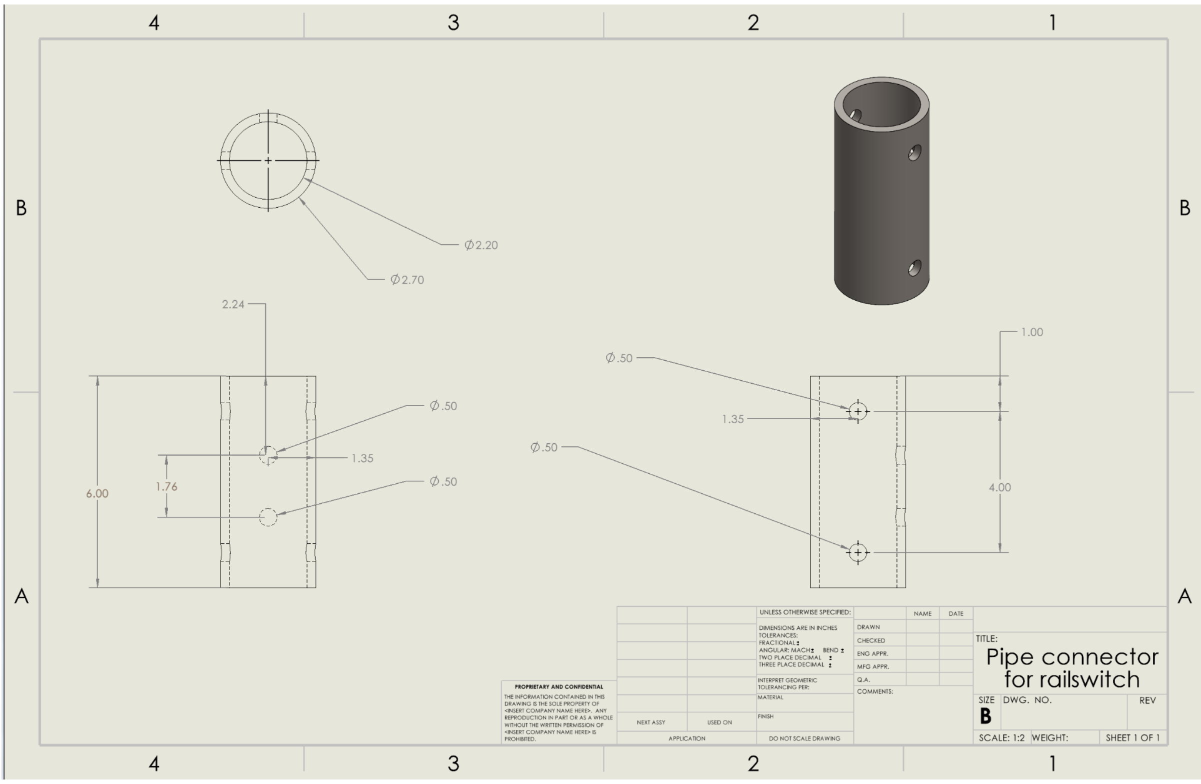


Figure 13: Draft drawing of switch rod coupling device.

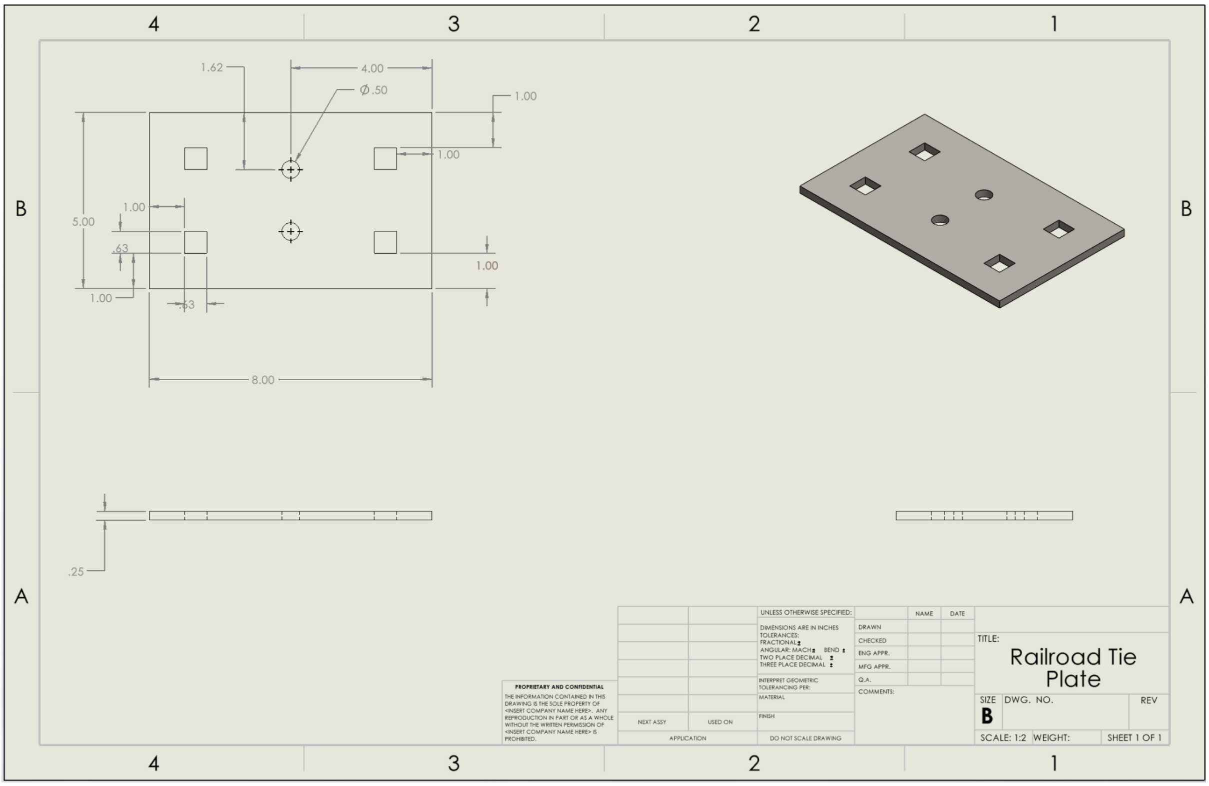


Figure 14: Draft drawing of rail tie plate mount.

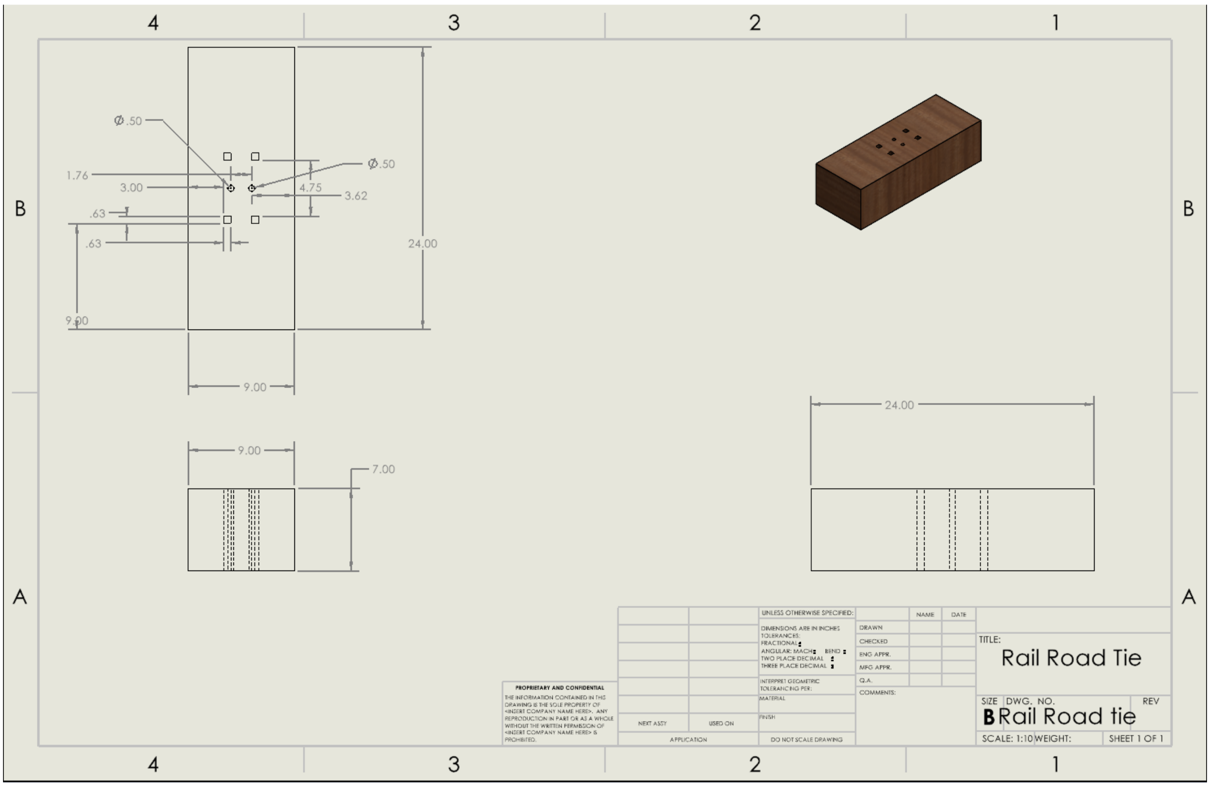


FIGURE 15: EXAMPLE RAIL TIE SECTION.

4.4 DESCRIPTION OF THE DESIGN RATIONALE

PA-17 Linear actuator: We went with a linear actuator because it was simpler than a hydraulic system and less expensive. This particular actuator was chosen because it has an IP-65 weather rating, has the necessary extension length of at least 4.5", and is capable of providing the force required to move the switch.
BRK-17 Mounts: These mounts are designed for the PA-17, and can support up to 8000 lbs. Two of these are required and are mounted to our rail tie mount and switch rod coupler.
12 VDC IP67 power supply: Supplies the 12 VDC 20 A needed. IP-67 rated.
PA-31 Single channel control box: This control box comes from Progressive Automations for use with their linear actuators.
Steel 1026 steel DOM thick-walled tubing: Used to make our coupling mechanism.
McMaster-Carr clevis pin with cotter pins: For use in the coupling mechanism.
Kimes Steel 12 lb ASCE rail tie plate: Used to attach one of the mounts to the rail tie.
Blacksmiths Depot ⅝" rail spikes: Holding the rail tie plate.
Polycase ML-57F weatherproof NEMA enclosure: IP-67 rated to protect the control box.
High-strength steel hex head bolts: These bolts are needed to mount the BRK-17 to the mounting plate.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT

ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: Remote Rail Switch NAMES: Kameron Ripple INSTRUCTOR: Geismann
Tyler Teague Jakiela
Nolan Celestine
Dylan Light

The following engineering analysis tasks will be performed:

1. Shear stress analysis between rail tie plate and rail spikes.
2. Shear stress analysis of bolts between lug and clevis mount and shaft coupler.
3. Maximum shear force between shaft coupler and switch rod, and required bolt clamping force for a static system.
4. Maximum bolt torque based on required bolt clamping force.
5. Shear stress analysis of shaft coupler flange based on maximum bolt torque load.
6. Moment on the system from the applied linear force, and sizing calculations for coupler bolts and flanged based required for static equilibrium.

The work will be divided among the group members in the following way:

Item 1 – Nolan N.C.

Item 2 – Dylan D.L.

Item 3 – Tyler T.T.

Item 4 – Kameron K.R.

Item 5 – Tyler T.T.

Item 6 – Kameron K.R.

Instructor signature: Mark Jakiela; Print instructor name: Jakiela

(Group members should initial near their name above.)

FIGURE 16: SIGNED ANALYSIS CONTRACT.

5.2 Engineering analysis results

5.2.1 Motivation

To ensure our embodiment of the prototype is even feasible, 6 analyses must be done to ensure that the prototype works without unnecessary part wear or failure. A shear stress analysis was done on the rail tie mounting plate to ensure that it does not fail under stress. We did a bolt shear analysis of the BRK-17 mount to see the minimum grade of bolts needed, as shorter bolts are needed for the rail tie mounting plate. The maximum shear force between the switch rod coupler and switch rod was determined, and then this force was used as a frictional force to find the clamping force required to make the coupler and switch rod static. This force was then used to find the bolt torque needed and to see the minimum specification of the bolts needed. Using these bolt clamping forces as a point load, a shear analysis on the coupler's flanges determined the minimum area and material needed to not undergo deformation. Finally, an in-field stress test was used to determine if the part would fail from the moment the system produces.

5.2.2 Summary statement of analysis done

To determine the shear force, we use the equation $\boldsymbol{\tau}$**=F/A**, where F is the force and A is the cross-sectional area. We use this equation in analyses 1, 2, 3, and 5 to find a shear force in psi (pounds per square inch). If the shear force is less than the yield stress (τ_y) of a specified material, then the material will not yield or deform under these forces. In analysis 3 we used the summation of forces **ΣF=0** to find our reaction force $\mathbf{F_R}$ on the switch rod. With this force, we can use the frictional force equation **F=**$\boldsymbol{\mu}$**N,** where F can be equated to the reaction force $\mathbf{F_R}$ and $\boldsymbol{\mu}$ is the friction coefficient. We can solve for **N** which is our clamping force required to keep the coupler from slipping. For the next analysis, we can use the equation **F=T/DK,** where F is the clamping force, T is bolt torque, D is bolt diameter, and K is the bolt friction coefficient. We can rearrange the equation to solve for T to find the minimum bolt torque needed to keep the coupler from slipping. Once the required torque is point, we can find the point loads on each bolt. We then take these point loads into a singular load to find the shear force acting on the flanges of the coupler. Each shear force was compared with the yield stress to see if the part would fail, and the bolt torque value was compared with the recommended maximum torque values to see if the bolts would fail.

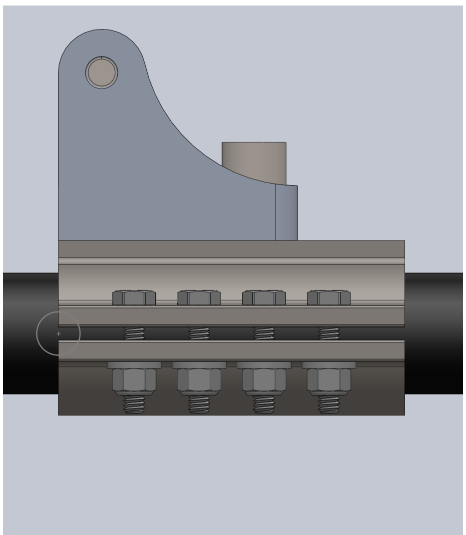


Figure 17: Side profile of entire shaft coupler assembly.

Assumptions:
Linear actuator acts in pure shear (θ=0) with a force F=2000lbf.
The railway factor of safety (FOS) is FOS=2.
The friction coefficient for dry cast iron to steel is μ=0.4.
Since the actuator cannot push more than 2000 lbf, FOS_{used}=1.
We can use a simple summation of the forces of the top shaft coupler piece to find the maximum shear as follows:

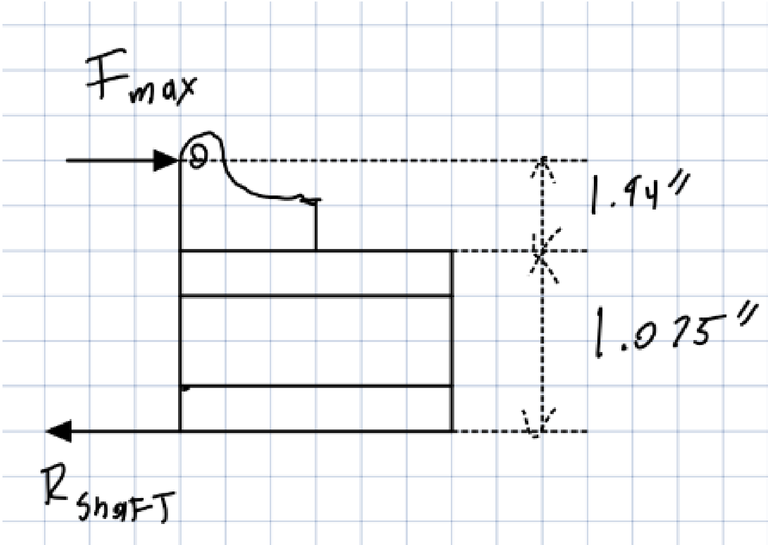


FIGURE 18: FBD OF COUPLING, SIDE VIEW.

ΣF=0;

$$F_{max} * 2 - R_{shaft} = 0 \Rightarrow R_{shaft} = 2000lbf(1) \Rightarrow R_{shaft} = 2000 \text{ lbf}$$

Using this reaction force as the max shear value, we can solve for the clamping force required as:

$$F = \mu * N \Rightarrow N = \frac{F}{\mu}$$

Where F is the frictional force, μ is the friction coefficient, and N is the clamping force.

$$N = \frac{2000\ lbf}{0.4} \Rightarrow N = 5000 \text{ lbf}$$

This is the clamping force required to keep the coupler from slipping when being acted on in pure shear.

$$F = T/DK \Rightarrow T = FKD, \qquad F = F_{max}/n$$

Where F is the clamping force, T is bolt torque, K is the friction coefficient, and n is the number of bolts.

F = 5000 lbf/8 = 625 lbf

T = 625 lbf(0.23)(0.25in) = 35.94 lbf-in = 2.99 lbf-ft

The ¼” SAE grade 8 steel bolts can be torqued up to 10 lbf-ft, to correct for any discrepancies in friction and bolt lubrication, we will be torquing these bolts to 5 lbf-ft. This will make sure that the shaft coupler will not slip while in use. The maximum recommended torque is 27 lb-ft.

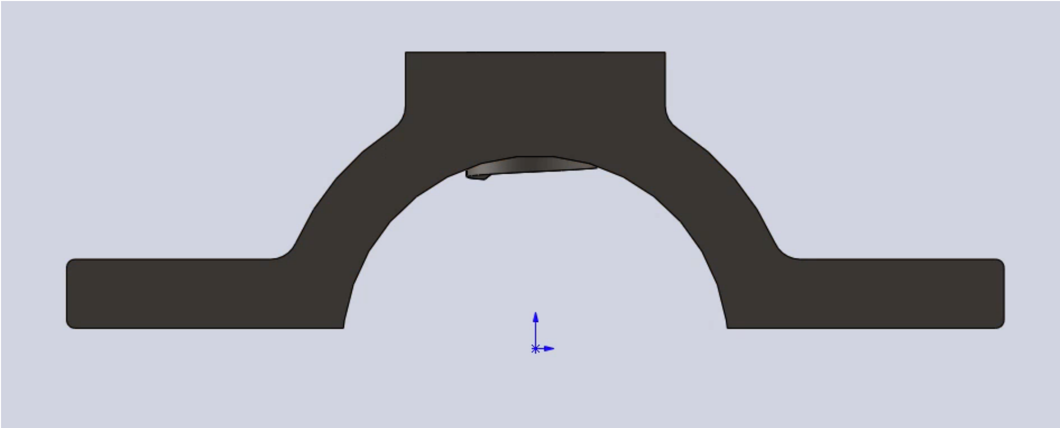


Figure 19: Front view of the coupler.

Assumptions:

1018 cold-rolled steel, τ_{yield} = 53700 psi.

FOS=1.

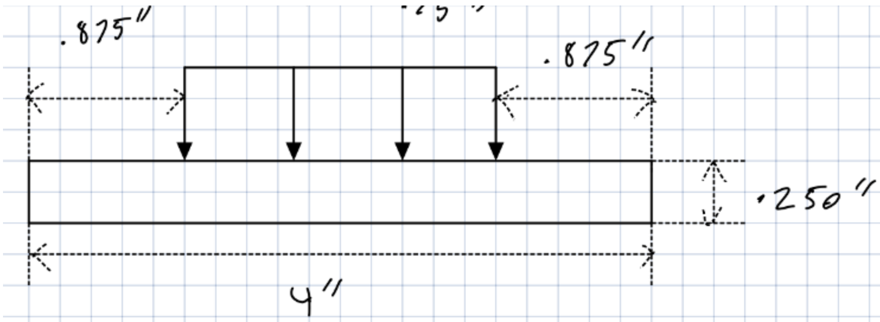


Figure 20: Coupler side profile FBD.

$$F_{dist} = \frac{F}{d} \Rightarrow F_{dist} = \frac{625\ lbf}{0.75"} \Rightarrow F_{dist} = 833.34\ lbf/in$$

$$F_{cent} = F_{dist} * 2.25" \Rightarrow F_{cent} = 833.34\ lbf/in * 2.255\ in \Rightarrow F_{cent} = 1875\ lbf$$

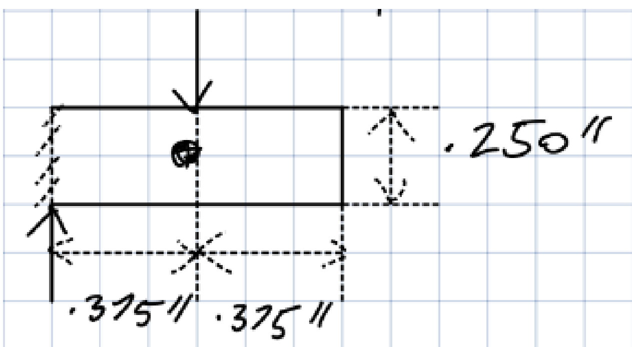


Figure 21: Cutout FBD of flange.

$$\tau = F/A \Rightarrow \tau = 1875\ lbf/(0.375"*0.250") \Rightarrow \tau = 1875\ lbf/.095"^2 \Rightarrow \tau = 20000\ psi$$

$$\tau < \tau_{yield}$$

The flanges will not yield under the specified shear force. The specified dimensions are able to be used without the part yielding.

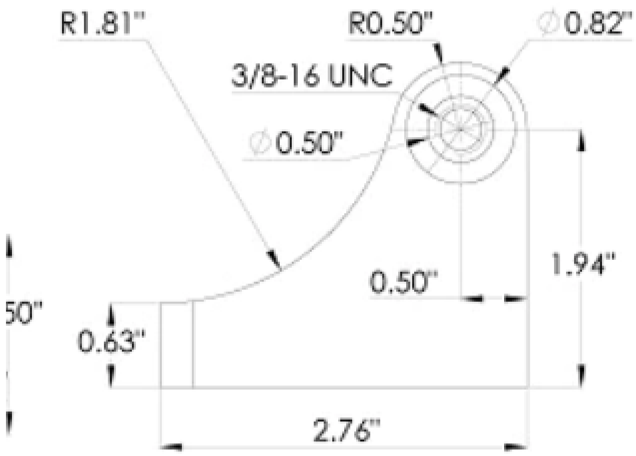


FIGURE 22: BRK-17 DRAWING, SIDE.

ΣF = 0;

2000 lbf * 2 - R_{bolt} * 2 = 0 ⇒ R_{bolt} = 2000 lbf
$\tau = R_{bolt} * 4/\pi(0.50")^2$ ⇒ τ = 8000lbf/0.785"^{2} ⇒ τ = 10185.92 psi

For SAE grade-8 steel (J-429):
τ_{yield} = 130000 psi > τ

SAE J-429 ½" bolts will be able to be used without yielding. Due to their extreme yield strength, lesser-grade steel may be used. Since bolts like these are <$10 for a pack of 5, we will still use them.

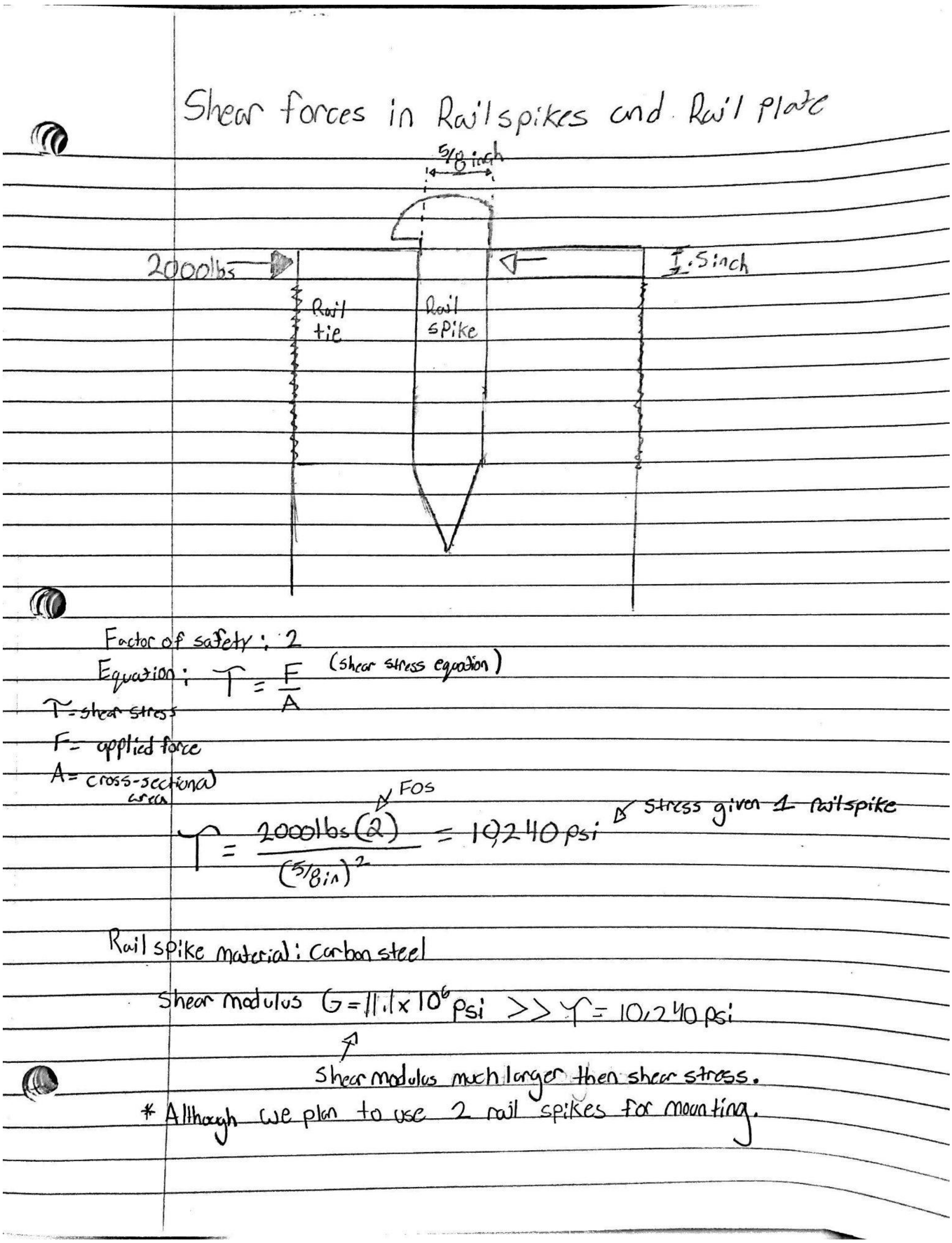


Figure 23: Rail tie plate shear calculations.

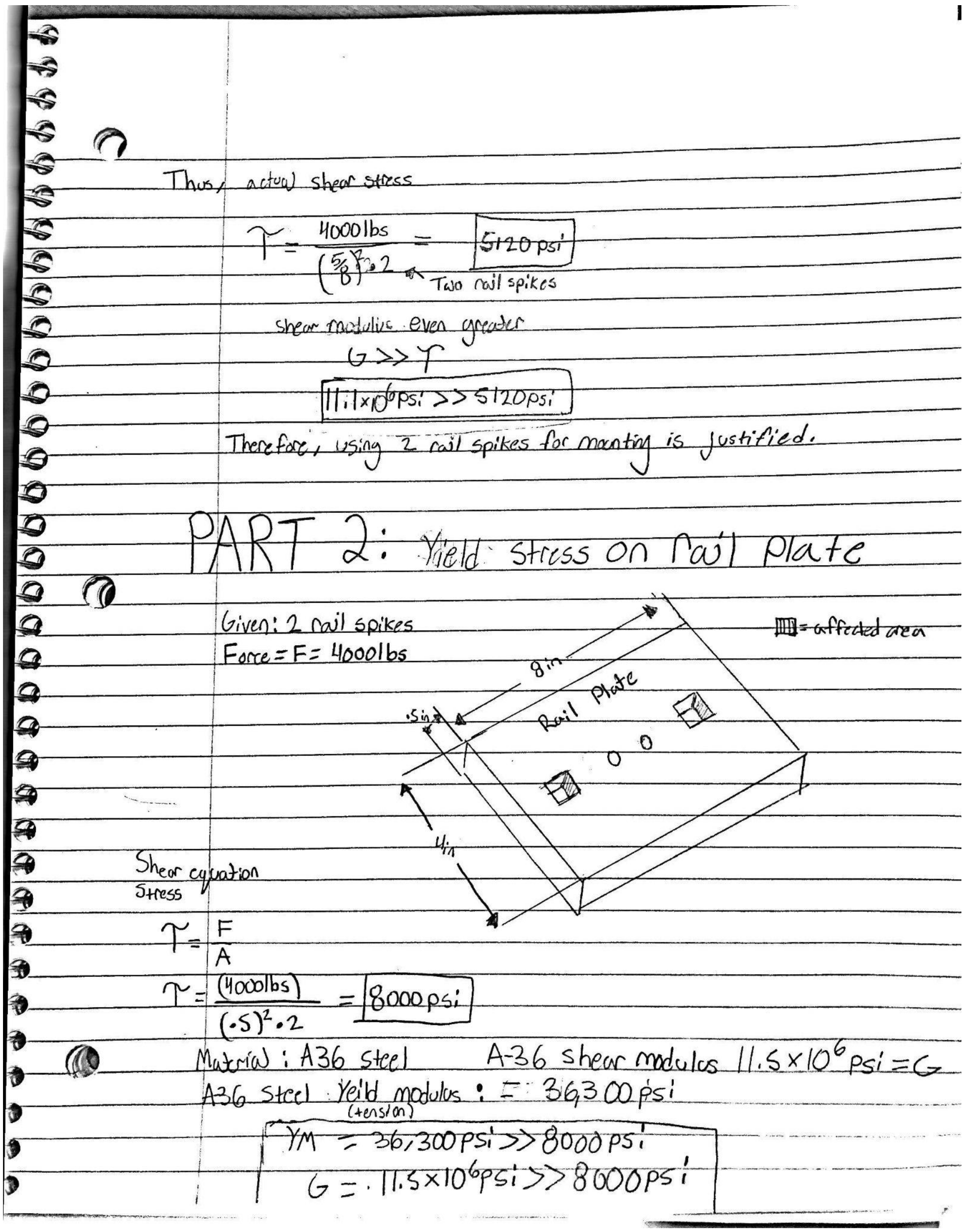


FIGURE 24: RAIL TIE PLATE SHEAR CALCULATIONS CONTINUED.

5.2.3 Methodology

For all analyses done prior to the in-field stress test, hand calculations were used to compute the necessary values. Each analysis was double-checked by a second team member to ensure accuracy.

5.2.4 Results

Using a 2000 lb force acting on the shaft coupler, we found the required clamping force induced by the bolts would be 5000 lb in total. Based on this, we found that each of the 8 bolts would need to be torqued to at least 2.99 lb-ft.

The force of each bolt produced a distributed load which we reduced to a point load of 1875 lb at the center of the flange. This force would produce a shearing force of approximately 20,000 psi which is much lower than the yield stress of our material. Thus no changes were required.

Looking at the shear forces on the pin of our BRK-17 mount, a 2000 lb force was applied directly to the pin which resulted in a stress of 10185.92 psi. This stress was significantly lower than the yield stress of our grade 8 steel bolts, so no changes were needed.

Regarding the rail spikes and tie plate, the shearing stress acting on the spike was found to be 5120 psi which falls under the yield stress that these spikes were able to withstand. The shearing stress acting on the plate was 8000 psi, which also lies under the yield strength of the plate's material.

5.2.5 Significance

Given the forces determined in our analysis, we found that no components would yield as a result of shear stress. In this respect, no design changes were required. However, the consideration of a moment on our system led us to make some considerable design changes. To prevent the coupler flanges from yielding, their thickness was increased past that of the switch rod radius. The resulting part would take the form of two 1.5" plates each with a 0.7" half circle on the bottom. The moment would also have an effect on the frictional force required to keep the coupler from slipping. To compensate, the coupler bolts were upsized from ¼" to ⅜". Both of these design changes were made to more than counteract the forces our system was experiencing, and final values were ultimately chosen for ease of machining and material sourcing.

6 Risk Assessment

Risk Management Register

0	Open Red Risks
0	Open Yellow Risks
0	Open Green Risks
0	Risks w/ no Response Strategy
0	Closed risks

Project Name: Remote Rail Switch
Project Manager: Nolan Celestine
Start Date: 7/15/2023
Location: Washington University St.louis
Add'l Info:
Updated On:
Overall Project Risk Indicator: 9

Risk Level

Probability					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
Impact	1	2	3	4	5

Legend:
Impact: 1 - Negligible, 2 - Marginal, 3 - Significant, 4 - Critical, 5 - Catastrophic
Probability: 1 - Rare, 2 - Unlikely, 3 - Possible, 4 - Likely, 5 - Certain

Item	Project/ Phase	Risk Status	Risk	Potential Impact (Cause and Effect)	Risk Response Strategy	Triggers (Indicators that the risk will occur)	Estimated Schedule Impact (Days)	Maximum Exposure ($000)	Estimated Exposure (Contingency) ($000) $97	Risk Category	Risk Sub Category	Action Owner	Start Exposure	End Exposure	Baseline Risk Scoring: Impact: Tech Perf	Schedule	Cost	Safety	Probability	Risk Ranking
0			Schedule	Potentially not all members present. Parts not arriving in time	Cordination to find free days and times for all members	Work, other projects, Intramotev schedule, part delays	7	$50	$10	Schedule	Labor Availability	Tyler	07/15/23	08/14/23		2			3	6
1			Wiring/controls	Difficult electrical wiring, malfunctioning wires.	Get help from the Intramotev team to help with wiring the system.	Improper gauges, carlessness, accident	7	$50	$17	Construction	Applicable Prior Experience	Nolan	07/20/23	08/07/23	2	2	2	4	1	4
2			Building incompatability	Incompatable parts that wont function as expected	Research bought parts thoroughly before purchasing	System not strong enough to support forces, wrong item purchased, too small amperage control system	14	$70	$7	Financial/Regulatory	Cost, Budget, Forecast in Alignment	Everyone	07/15/23	08/07/23		1	3		3	9
3			Size issues/digging	Design wont fit in the given space	Orient design to fit in between rail ties and underneath switch bar	Switch bar in the way, inconsistent distance between railroad ties	4	$20	$7	Construction	Layout and Constructability	Kameron	07/15/23	08/07/23		5			4	20
4			Battery error	Battery malfuctions, wont power the system	Test to make sure the battery and drive the linear actuator and keep battery protected from the elements	Sun, overheating, leaking, not working	1	$60	$6	Operational Impact	Reliability, Capacity and Performance (Heat Rate)	Everyone	07/25/23	08/07/23		1			5	5
5			Unexpected mounting angles	Rail road ties not parrellel resulting in creative mounting and unknown stresses	Drive the linear actuator as in line with the switch bar as possible	Inconsistent switches	4	$40	$4	Construction	Layout and Constructability	Everyone	08/01/23	08/07/23	3	1			3	9
6			Part failure	Linear actuator, original system failure	Setting up the system in retraction and stopping the linear actuator before it puts unwanted stress on the system	Crushing sounds, bending, snaping	14	$300	$32	Operational Impact	Reliability, Capacity and Performance (Heat Rate)	Everyone	08/01/23	08/07/23	5			5	1	5
7			Actuator power	Acutator not providing enough power	Research linear actuator and forces requred to move track, must be over 1 factor of saftey	linear actuator not pushing the coupler	7	$400	$10	Construction	Layout and Constructability	Nolan	08/01/23	08/07/23	5	3			1	5
8			Weather	Rain ruining the system	Work on the system on sunny days or overcast, buy waterproof enclosures	Rain	4	$117	$3	Schedule	Weather, Site Conditions, Essential Services	Everyone	08/01/23	08/07/23		4			3	12
9			Failure due to shear	Shear is too much for the lags screws and the steel plate	Include a factor of safety	Too weak of screws, too thin mounting plate	4	$50	$1	Construction	Layout and Constructability	Tyler	07/30/23	08/07/23	1	2	1		1	2
10			Modifiying existing system	Original system rusted or bent	Removing locking system and switch bar	Broken switch, bent switch	2	$20	$1	Construction	Layout and Constructability	Everyone	08/01/23	08/07/23		1			5	5

Figure 25: Risk assessment.

6.1 Risk Identification

The risks identified for our project were:

- Scheduling
- Wiring/ Controls
- Building Incompatibility
- Sizing issues/ digging
- Battery error
- Unexpected Mounting Angles
- Part Failure
- Actuator Power
- Weather
- Failure due to shear
- Modifying the existing system

6.2 Risk Analysis

One of the largest risks we faced during this project was dealing with the size constraint. This risk was so important because it would completely change what items we are able to use on the design and strongly effects building capability. There were multiple rail switches we could have used and each one had inconsistent spacing and angles between the railroad ties. There were approximately 10 inches of space between the railroad ties of the switch that we chose. Which did fit our linear actuator when driven in line with the switch bar. However, building the design was much more complicated and drawn out due to the limited space. If the linear actuator did not fit between the railroad ties it would have cost us time and money to find a new placement method or a different actuator.

Another risk we faced was wiring the control system and the battery. This was mainly a risk due to our inexperience with wiring electrical systems. Which posed a risk to safety for us while connecting our system to the battery. Our system runs off of a 12V DC battery at 20 amps. Improper use while wiring could be essentially fatal, therefore we had the engineers at Intramotev wire the design for us and show us a proper connection to the battery. Then we repeated their process to ensure we were safe while connecting the system. Additionally, improper wiring could destroy our control system and cause us to have to purchase a new one.

There was also the risk of part incompatibility. While everything seems to work together on paper there is always risk in actually building the design. Given there is an issue with the building or a problem we overlooked it would likely take around multiple days to come up with a new method and test if it works. We ran into this problem while choosing our control system. The original control system was not made for 20 amps to run through it. Therefore, we had to purchase a new control system and use larger gauge wires.

Weather also played a big factor in building this project. Since our design was outside it is subject to the elements and makes building it more difficult. We did not want to ruin our electrical connections or battery due to rain or have our battery overheat due to excessive heat. Therefore, we had to be very careful when deciding to build and test the system. This risk forced us to purchase weather protection for both our battery and control system. A large IP-rated case for the battery was very expensive and hard to come by therefore our enclosure for our battery was only water resistant. However, while choosing mostly sunny days to build our design helped us mostly avoid this risk. If our system was going to be used permanently additional solutions would have to be developed to deal with having the battery outdoors and maintaining it.

A smaller risk we took on was the chance our design could have failed due to the shear of both the mounting plate and lag screws. However, this risk was largely avoidable due to our analysis of the system and having a factor of safety of 2 for the max force on those individual parts. Even with our factor of safety, our yield strength and shear modulus for both our mounting plate and screws far surpassed it. Ultimately, due to our analysis, it was a small risk to consider.

Another risk was the unexpected mounting angles. While taking the dimensions of the rail ties of the switch we realized that the two ties do not sit exactly parallel with one another and perpendicular to the track. This slightly restricted our placement of the linear actuator. And due to the railroad ties not being parallel with the switch bar, we assumed there would be slight forces pushing vertically or diagonally on the bar (which affects the total force we can use to drive the switch bar into position). Luckily, due to the clever placement of the mount, our linear actuator was able to move slightly with the switch bar.

There was also a risk of the actuator not performing the way we expected or entirely not working. This was a relatively small risk due to our testing of the part before we used it in the design. But if we found the actuator was not functioning we would either have to research and purchase another or get a replacement from the same company. This would have taken time and possibly additional money for shipping.

Along with the actuator failing a number of parts we were working with were capable of failure. The rail switches we worked with appeared to be relativity old, bent, and rusted, therefore failure was even possible with the original system. While failure of our own parts would simply result in the purchase of an additional part, failure of the original switch would have set us back considerably. We would either have to analyze the problem and attempt to fix it or use another switch that has completely different spacing and angles for building.

A low risk we faced during our project was scheduling. We had to work with the times Intramotev was available as well as scheduling within our group. Given other classes, work, and personal life we are not available at any time to work on our project. Therefore, we had to work around this small obstacle and each find time to contribute to the project.

Another potential scheduling problem involved purchasing items and making sure we can receive them in time to build our prototype.

Our final risk involved having to modify the old switch system. Due to the poor condition of the original switch, we assumed we would have to take off the locking system and bent parts to get it to function normally. Ultimately, we did have to momentarily remove the locks and the lever arm due to its severe bending.

6.3 Risk Prioritization

L**argest Risk:** Sizing issues/ digging

This risk would cost us the most time and money and affect nearly every part of our design. We would either have to get new parts or figure out different methods to install and work with the old ones.

Medium Risks: Weather, Unexpected angles, Building Incompatibility

These risks were not detrimental and tended to only affect one aspect of our design such as buying more parts or placement of the design.

Low Risks: Schedule, Failure due to shear, Actuator power, Part failure, Battery error, Wiring controls, Modifying the original system.

These risks were not very harmful to our project and some could entirely be avoided with proper analysis and safe practices.

7 Codes and Standards

7.1 Identification:

Codes and standards followed: Federal Railway Administration Department of Transportation Chapter 2 Subtitle B.

7.2 Justification:

Title 49 Subtitle B Chapter II Part 213 Subpart B: This subsection is important because our design sits in the roadbed, and these regulations could limit where we are able to place it. While these standards mostly focus on vegetation obstructions, obstruction of our attachment system would be equally as unacceptable.

Title 49 Subtitle B Chapter II Part 213 Subpart D: Subpart D deals with ballasts, crossties, track assembly fittings, and the physical conditions of rails. Additionally, the ballasts need to provide adequate drainage for the track. Since we will be using the same ballast, we just need to make sure if we have to move some in order to fit our design, that there still needs to be adequate drainage. We also don't know if digging space for more room under the switch bar will cause flooding. When it comes to cross-ties, the codes are very important since we will be attaching our product directly to them. We would likely do this through rail spikes and custom-made tie plates which can support our linear actuator mount. This subpart includes the main codes for rail switches. The most significant include each switch stand and connecting rod shall be securely fastened and operable without excessive lost motion. While we aren't directly interacting with the switch we would likely have the same constraints with our attachments as the original switch. Finally, each throw lever shall be maintained so that it cannot be operated with the lock or keeper in place, and each switch position indicator shall be clearly visible at all times. When talking to Intermotev this wasn't a big deal for them because the original locking mechanism would still be present. Additionally, it would be near impossible to move the linear actuator when it is not powered.

7.3 Design Constraints

7.3.1 Functional

Title 49 Subtitle B Chapter II Part 213 Subpart D:

We need to secure the system with the same constraints as a normal switch stand. This was originally going to be done with rail spikes. However, we decided to use multiple lag screws to mount the system due to easier installment. Nevertheless, the screws are capable of withstanding far beyond the shear forces applied. (Proper mounting could also fall under safety constraints)

7.3.2 Safety

Title 49 Subtitle B Chapter II Part 213 Subpart D:

When removing soil from in between the rail tie we need to make sure excessive gravel or surface is not being removed or the system could potentially flood. This could completely destroy the system making the switch a dangerous safety hazard. Effects could be anywhere from dangerous current running through the puddle or train derailment due to the inoperable switch.

Additionally, we need to include some type of locking system for the design so it can't be tampered with or switched accidentally. (This would also fall under legal constraints.)

7.3.3 Ergonomic

Title 49 Subtitle B Chapter II Part 213 Subpart B:

Our design cannot be too large or obtrusive to where it would be covering important parts of the original system. Additionally, the original switch must be easily accessible for workers. As well as being able to function the switch manually.

7.4 Significance

Title 49 Subtitle B Chapter II Part 213 Subpart B: We designed our design to be as unobtrusive as possible to the original system. Firstly, we are doing no modifications to the original switch therefore after a small pin release it is completely manually operable again. Additionally, given the obstruction constraint along with the space constraint, we decided to place our linear actuator below the railroad ties. Therefore, there are little to no visible obstructions to the system.

Title 49 Subtitle B Chapter II Part 213 Subpart D: To prevent flooding the system cannot be excessively far below level ground. Turning the system sideways should allow us more than enough vertical space and the surrounding gravel should disperse the water and prevent flooding.

We plan to secure our system utilizing four lag screws which have more than enough shear resistance given the forces that are required to switch the rails shown in our analysis.

Because we are not touching the original system it can still be locked manually.

8 Working prototype

8.1 prototype Photos

Figure 26: Remote Rail Switch full assembly.

The photo above shows the entire Remote Rail Switch system. Starting in the upper left, a 12.8 VDC battery in a weatherized enclosure connects to our RF control system enclosed in an IP68 junction box. The RF controller connects to our linear actuator (center). The actuator is attached to 2 BRK-17 mounts, either attached to our rail tie mounting plate (left) or our switch rod coupler (right). A better view of the rail tie mounting plate is shown below.

FIGURE 27: RAIL TIE MOUNTING PLATE CONNECTED TO THE LINEAR ACTUATOR.

This photo provides a view of the system between the railroad ties, pointing towards the rail track, and shows how the actuator is connected to the rail tie and the coupling. It also shows how the coupling is attached to the switch rod, which is the shaft that switches rail positions.

8.2 WORKING PROTOTYPE VIDEO

Here is a short video showing a general overview of the system and its overall performance:

https://youtu.be/gFmko2DbL_E

8.3 Prototype components

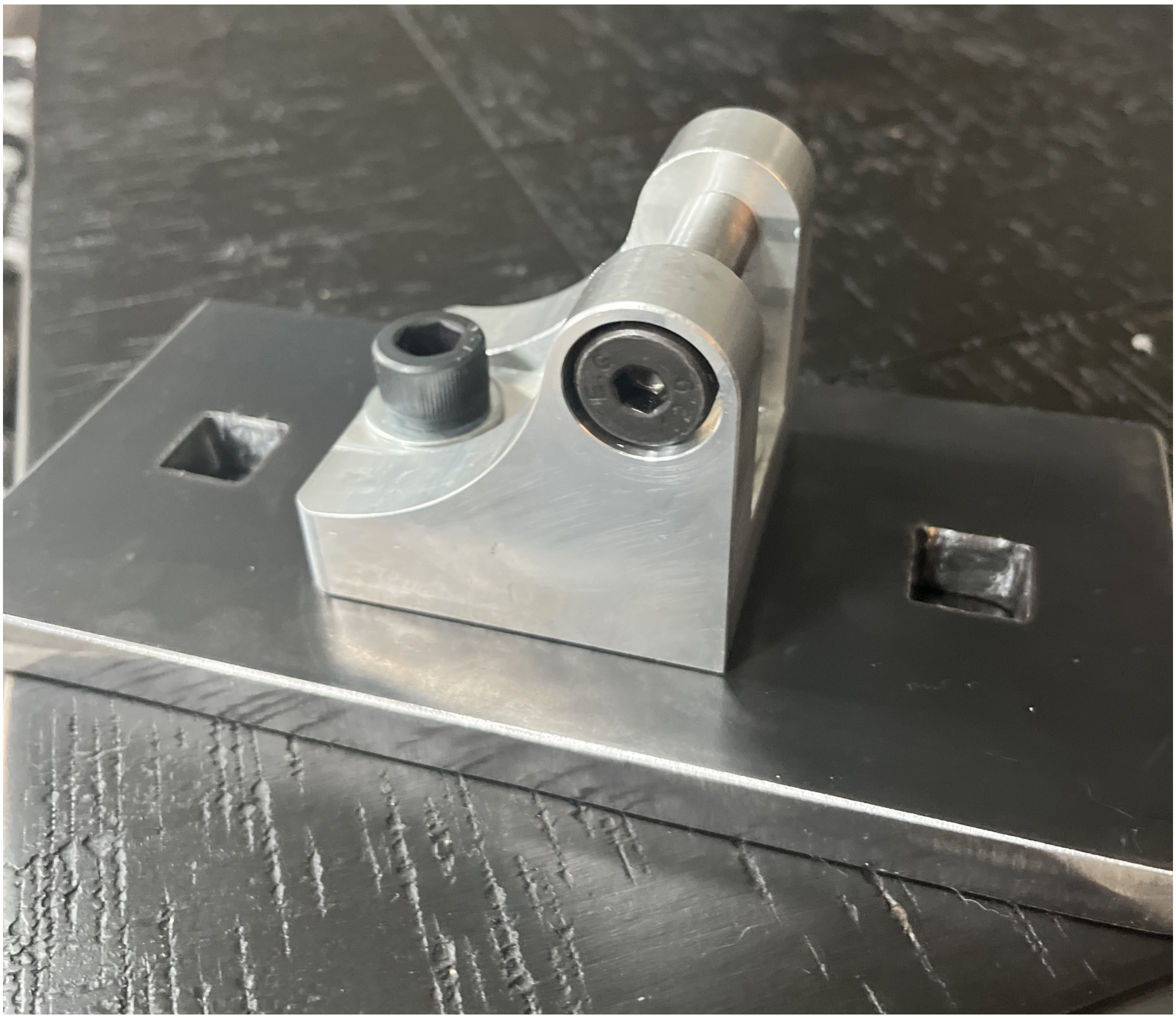


Figure 28: Rail tie mounting plate with BRK-17 attached.

The photo above shows the rail tie plate mount with a BRK-17 clevis mount attached. The plate is made from ½” A36 plate steel. A plasma CNC was used to make all cuts. NOTE: Buy more material than needed (1’ x 1’). We recommend using a vertical milling machine for this part, as a plasma CNC will harden this material. 2 SAE ½” - 13 threads are tapped to accept the BRK-17’s bolts.

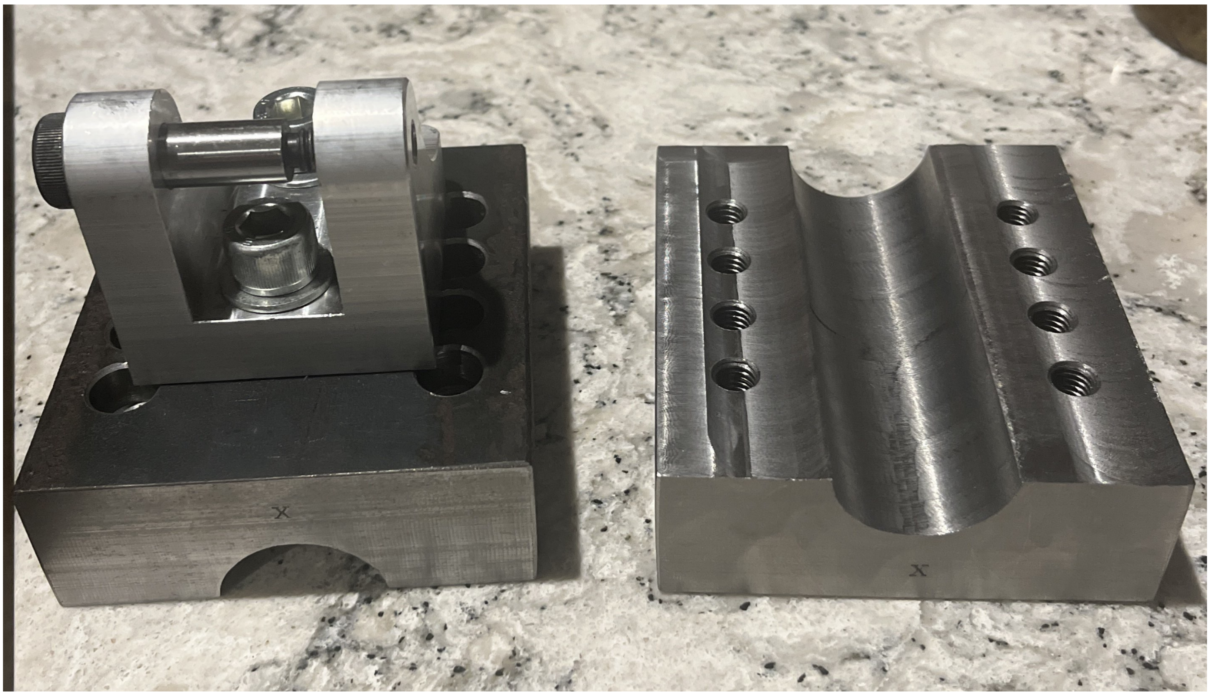


FIGURE 29: SWITCH ROD COUPLER WITH BRK-17 ATTACHED.

This shows our switch rod coupler. It is composed of two 1.5” X 4” segments of 1018 hot-rolled steel, each 4.5” in length. Both segments were put in a vice, and then a 1.4” hole was made down the center of each. Both segments have 8 holes for ⅜”-16 bolts, one segment is counterbored for the socket head, while the other is tapped for ⅜”-16 threads. Two more SAE ½”-13 holes are drilled and tapped for the BRK-17. 0.050” are milled off from the inside face of each segment to ensure the ability to clamp down on the switch rod. NOTE: Tap threads for the segment that has the BRK-17 mounting holes. This will make assembly much easier, as we had to torque the bolts upside down to assemble the project.

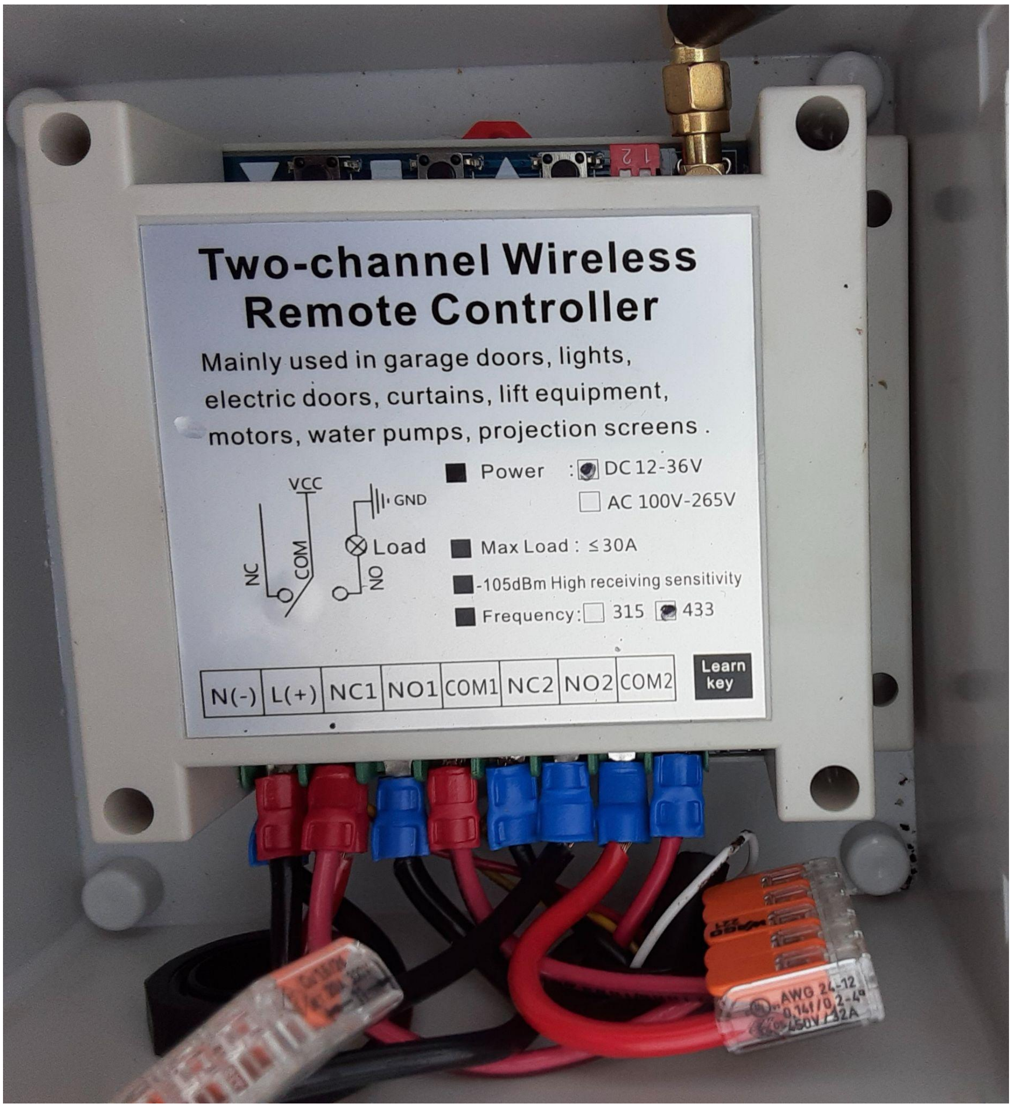


Figure 30: RF control box.

This shows our fusionsea 2-channel RF remote control box fully wired. We used the wiring schematic given with the controller to control the linear actuator. N(-) and L(+) are the terminals connected to the 12 VDC battery, while COM1 and COM2 connect to the negative and positive wires of the linear actuator, respectively. You will need to either solder wires or use Wagos to connect 3 wires into 1 terminal. We also recommend buying the next size up of junction box, as there is barely enough room for everything.

FIGURE 31: BATTERY AND RF CONTROLLER.

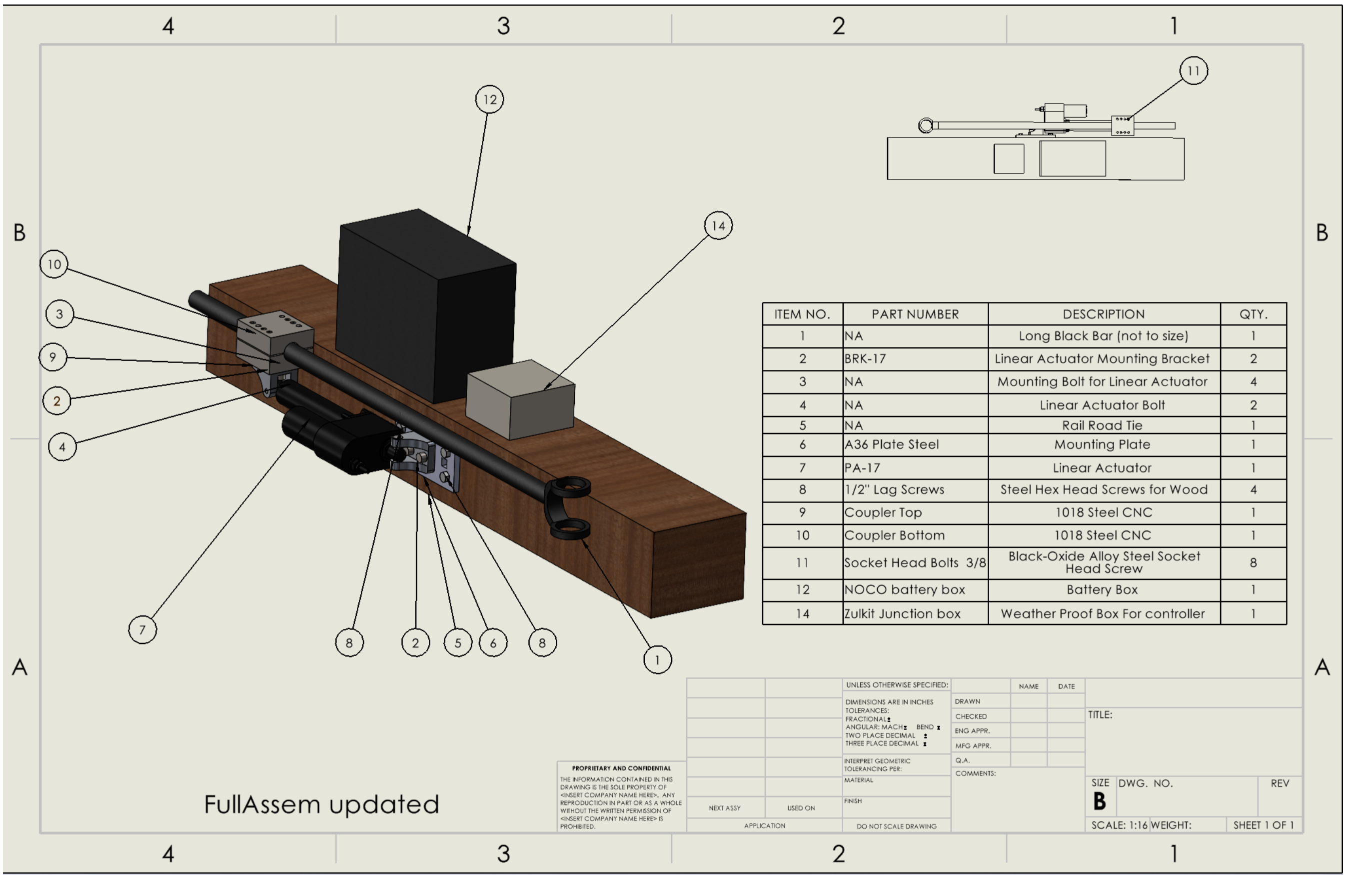
This shows four 3.2 VDC 102 Ah batteries connected in series to make a 12.8 VDC 102 Ah battery that our linear actuator is rated to use. It is housed inside a weatherized case which is then connected to our RF controller inside our IP68 junction box. Two ⅞” holes were cut into the junction box so the black waterproof fittings could be installed.

9 Design documentation

9.1 Final Drawings and Documentation

9.1.1 Engineering Drawings

See Appendix C for the individual CAD models. All dimensions are in inches.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	NA	Long Black Bar (not to size)	1
2	BRK-17	Linear Actuator Mounting Bracket	2
3	NA	Mounting Bolt for Linear Actuator	4
4	NA	Linear Actuator Bolt	2
5	NA	Rail Road Tie	1
6	A36 Plate Steel	Mounting Plate	1
7	PA-17	Linear Actuator	1
8	1/2" Lag Screws	Steel Hex Head Screws for Wood	4
9	Coupler Top	1018 Steel CNC	1
10	Coupler Bottom	1018 Steel CNC	1
11	Socket Head Bolts 3/8	Black-Oxide Alloy Steel Socket Head Screw	8
12	NOCO battery box	Battery Box	1
14	Zulkit Junction box	Weather Proof Box For controller	1

Figure 32: Final assembly drawing with BOM.

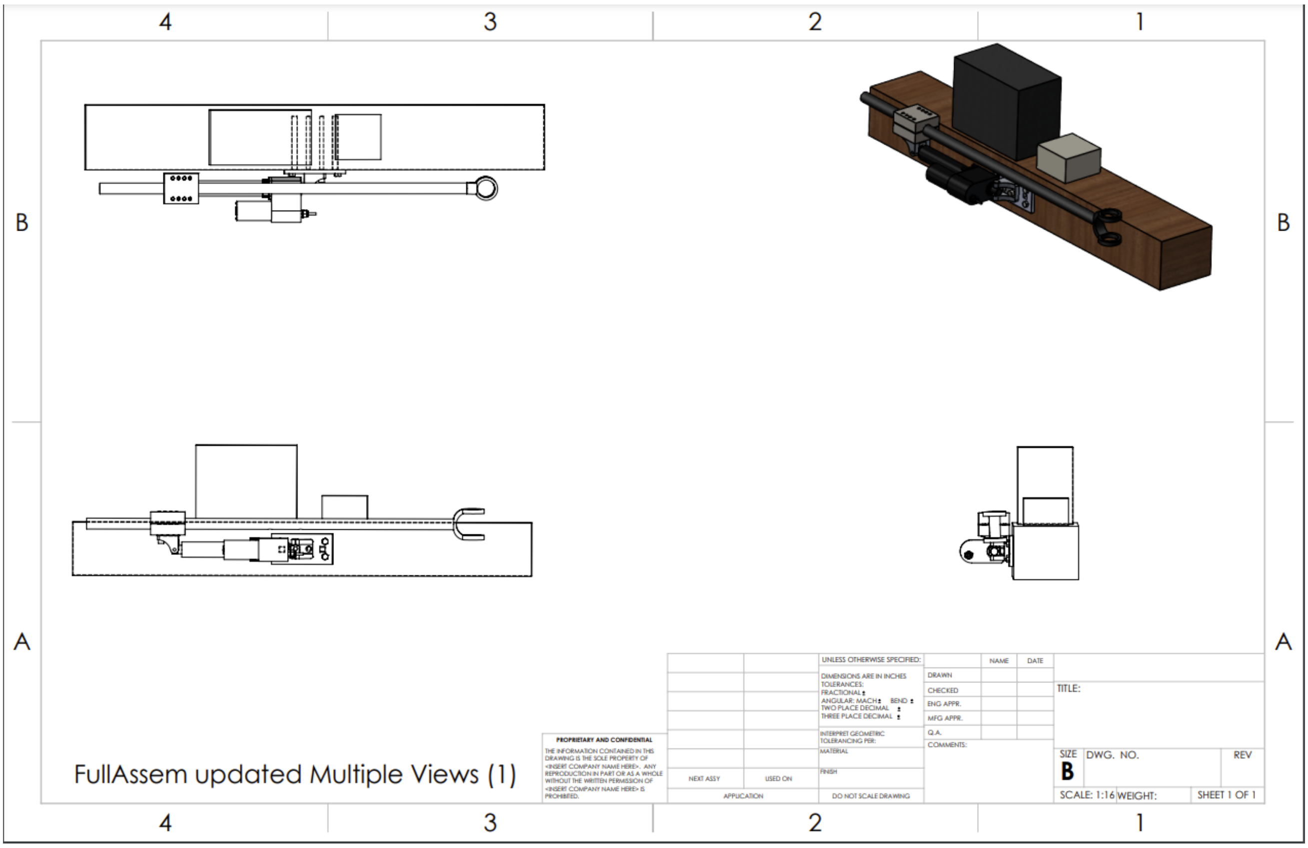


FIGURE 33: 3-VIEW DRAWING OF FINAL ASSEMBLY.

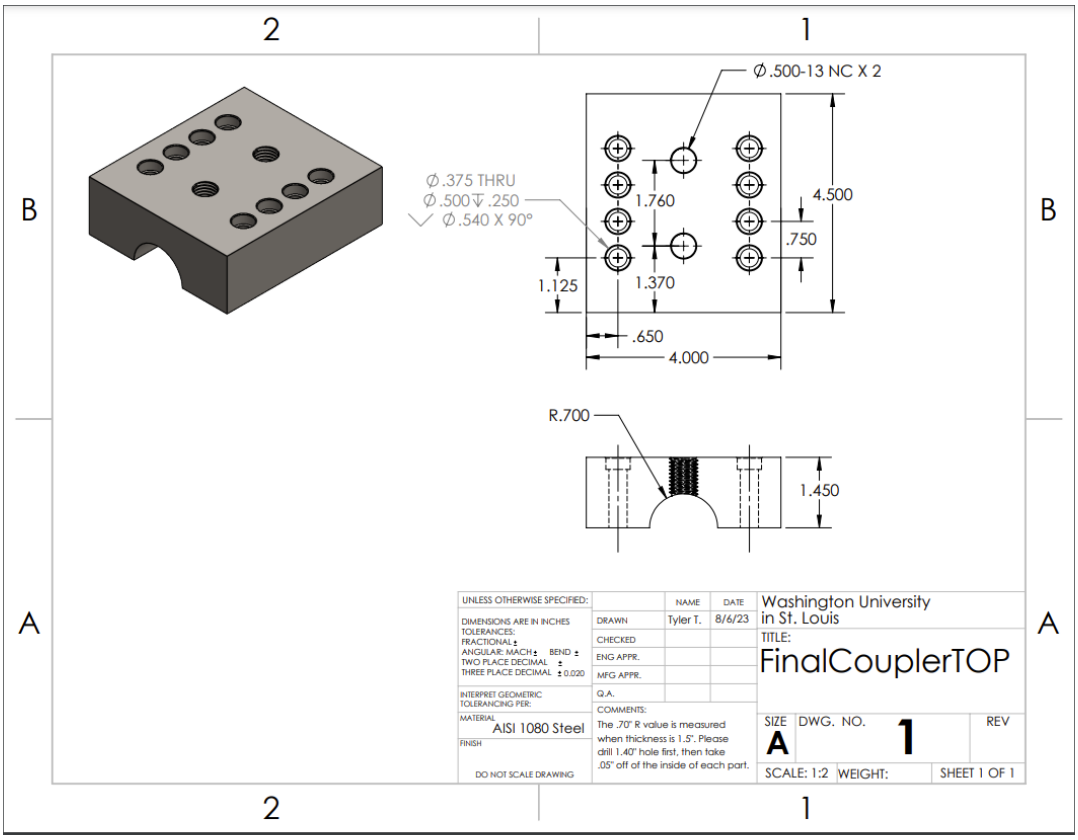


Figure 34: Drawing of the top segment of the switch rod coupler.

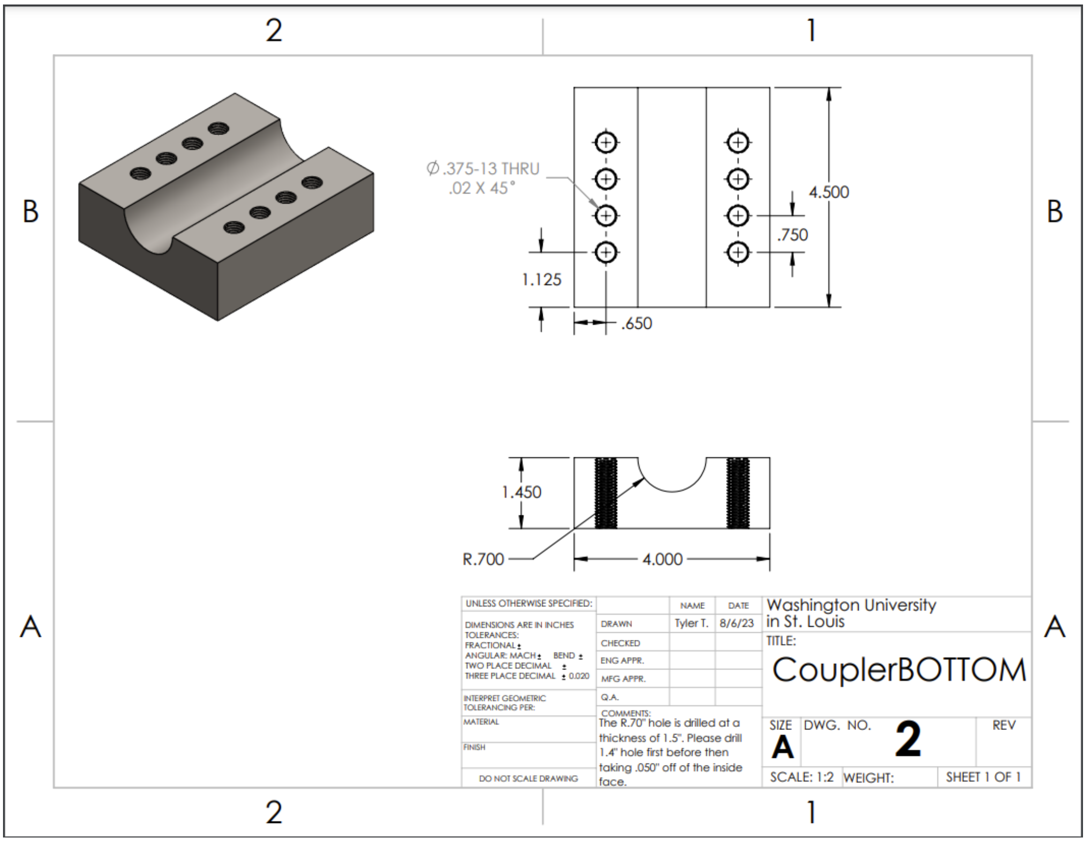


Figure 35: Drawing of the bottom segment of the switch rod coupler.

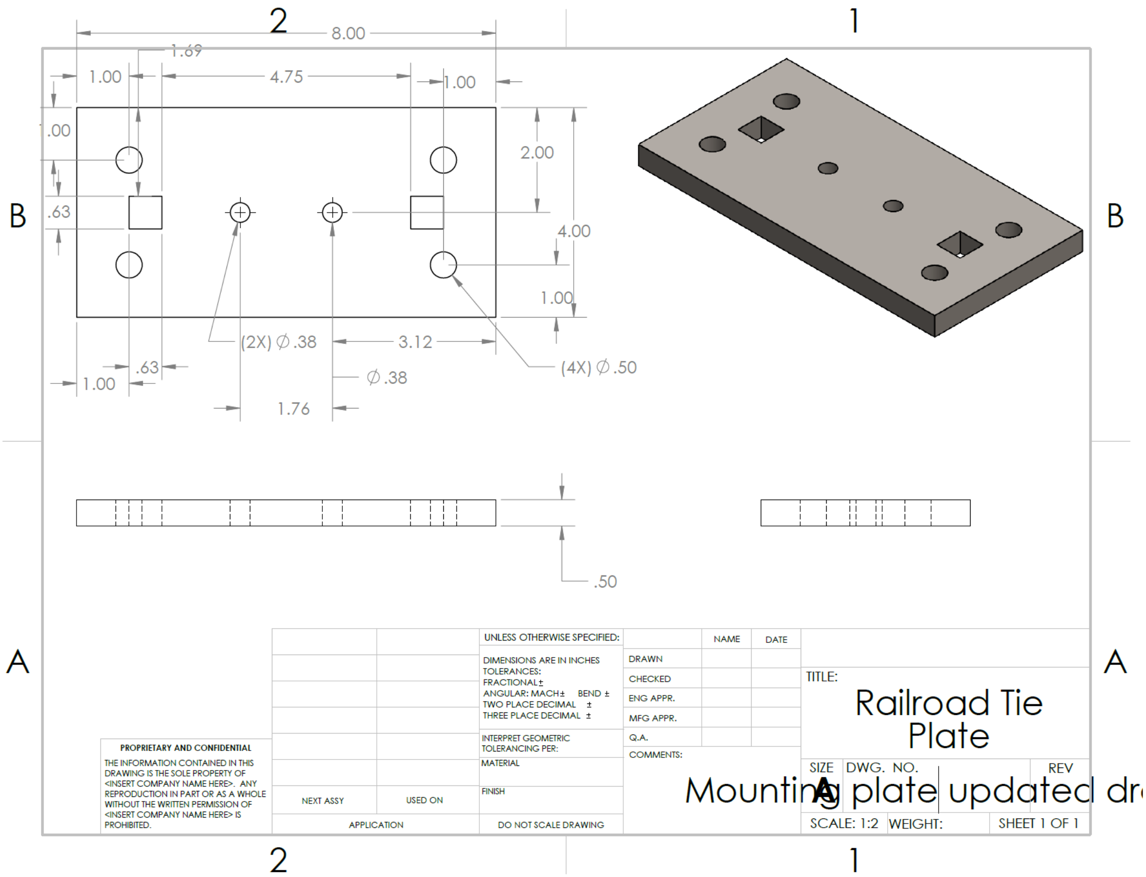


Figure 36: Drawing of the rail tie mounting plate.

9.1.2 Sourcing instructions

1. **PA-17 Linear actuator:** This part is the heart of our design; This linear actuator can push and pull up to 2000 lbs. This actuator is IP65 rated and has a stroke length of 6" and a potentiometer for feedback (not needed). PA-17-6-2000-POT
2. **BRK-17 Mounts:** These mounts are designed for the PA-17, and can support up to 8000 lbs. 2 of these are required and are mounted to our rail tie mount and switch rod coupler. BRK-17
3. **fusionsea wireless controller:** This controller is made for many applications, mainly garage doors and linear actuators. The included RF remotes have an up, down, and pause function with a range of up to 650 ft. B09G63T9KP
4. **12 VDC battery:** Since the sponsor of this project, Intramotev, works with converting rail cars into autonomous EVs, we were able to borrow batteries for our project. The PA-17 runs on 12 VDC and uses 20 A under max load. We were able to use 4 of their 3 VDC batteries in series to get the voltage draw we require. There are many options for 12 VDC batteries in the market, we would recommend a lead-acid battery for their reliability. An example can be found here.
5. **A36 Steel plate:** The 1st of 2 manufactured parts needed is a plate that has tapped holes for the BRK-17's ½"-13 bolts. 4 ½" holes are drilled to accept the lag screws that drill into the rail tie. Many places have A36, and we recommend getting a square foot of ½" thickness. Shapiro Metal supply is where we purchased all of our raw metal materials from.

6 **1018 Steel bar:** The 2nd manufactured part is our switch rod coupler. 2 pieces of 1.5” by 4” 1018 steel bar was needed, each 4.5 inches long. If you don’t have access to a CNC machine or milling machine, there are alternatives to this part. NOTE: This alternative may not work, and a clevis mount or tapped holes for the BRK-17 is needed for these parts to work.

7 **½” Socket head bolts:** The socket head bolts that come with the BRK-17 are too long to use with our rail tie mounting plate, so new bolts are needed. These are gotten from any hardware store and are SAE ½”-13 threads. Our engineering analysis shows that nearly any bolt grade will work with our design. Given the availability and cost-effective nature of bolts, we recommend grade 8 or higher bolts. The ones needed are 1-¼” in length and can be purchased at any hardware store.

8 **⅜” Socket head bolts:** To get the clamping force needed to keep the switch rod coupler from slipping while in action, bolts in tension are the best and most cost-effective solution. 8 ⅜”-16 bolts are needed for the switch rod coupler. Due to the large couple force acting on this part, grade 8 steel bolts are required. 2-½” length bolts are what we used, but a length of up to 3” can be used.

9 **Zulkit Junction box:** Our wireless controller isn’t weatherproof, since our project is outdoors in a rail yard all parts must be IP65 rated or above. This junction box is IP68 rated and has enough room for the controller and wires. It comes with 2 cable glands which allow us to port 2 groups of cables through the junction box while still keeping its IP68 weatherproofing. It can be found on Amazon here.

10 **NOCO Battery box:** Like the part mentioned previously, our battery system must also have an enclosure. This box is designed to protect batteries in harsh environments. It has 4 cable ports and holes for proper ventilation. It can be found on Amazon here.

11 **½” Lag screws:** These lag screws are used to mount the rail tie mounting plate directly to a rail tie. These lag screws are available at every hardware store and are very inexpensive. We were able to scrounge some from our machine shop, but you can find them at every hardware store.

12 **12 AWG wire:** The PA-17 requires 20 amps of current under maximum load. 12 AWG wire is rated to a max current of 20 amps. We were able to borrow a spool of wire for our project. 12 AWG wire can be found anywhere copper wire is sold. Here is a spool from Amazon.

7.2 Final Presentation

https://youtu.be/gFmko2DbL_E

8 Teardown

All parts used were kept by Intramotev for future use.

9 Appendix A - Parts List

Table 5: Project Embodiment BOM

No.	Description	Unit Cost	Quantity	Total
1	Progressive Automations PA-17-6-2000-POT linear actuator with potentiometer.	$343	1	**$343**
2	Progressive Automations BRK-17 heavy-duty mounting bracket for PA-17.	$23.99	2	**$47.98**
3	Progressive Automations PS-10-12-67 12 VDC IP67 power supply.	$104	1	**$104**
4	Progressive Automations PA-3 1 channel control box.	$89	1	**$89**
5	Stockcar Steel 1026 steel DOM thick-walled tubing.	$72.06	1	**$72.06**
6	McMaster-Carr 93890A495 .5” clevis pin with cotter pins.	$8.78	2	**$17.56**
7	Kimes Steel 12 lb ASCE rail tie plate.	$5.85	1	**$5.85**
8	Blacksmiths Depot ⅝” rail spikes.	$2	6	**$12**
9	Polycase ML-57F weatherproof NEMA enclosure.	$31.59	1	**$31.59**
10	Railroad Tie	$24.78	1	**$24.78**
11	High strength steel Hex Head bolts	$13.47	1	**$13.47**
	15% Contingency			**$114.19**
	Total with Contingency			**$875.48**

10 Appendix B - Bill of Materials

Table 6: Final BOM

Part	Cost ($)	Quantity
PA-17 Linear actuator	**347.00**	**1**
BRK-17 clevis mounts	**23.99**	**2**
fusionsea controller	**45.99**	**1**
12 VDC Battery	**Scrounged**	**1**
½” A36 Plate steel	**81.00**	**1**
1.5” 1018 Steel bar	**20.00**	**2**
½” Socket head bolts	**2.89**	**2**
⅜” Socket head bolts	**1.39**	**10**
Zulkit junction box	**18.99**	**1**
NOCO battery box	**18.99**	**1**
½” Lag screws	**Scrounged**	**4**
12 AWG wire	**Scrounged**	**1**
Total	**$615.63**	

11 Appendix C – Complete List of Engineering Drawings

All CAD models and drawing can be found using the link below:

https://drive.google.com/drive/folders/15P98V5SQa0aQNIxww2-xi8rukjRxn7kW?usp=drive_link

12 Annotated Bibliography

[1] *A36 Steel Technical Data Sheet*. American Metals Co. (n.d.). https://www.metalshims.com/t-A36-Steel-Technical-Datasheet.aspx

This citation shows the data sheet for the material properties of A36 Steel which we used for our analysis.

[2] Edge, E. (n.d.). *Shear modulus of rigidity table of engineering materials*. Engineers Edge - Engineering, Design, and Manufacturing Solutions. https://www.engineersedge.com/materials/shear_modulus_of_rigidity_13122.htm

This citation shows the shear modulus for different metals and was used to obtain the shear modulus for carbon steel in our analysis.

[3] *Electric Switch Systems*. Wabtec Corporation. (n.d.). https://www.wabteccorp.com/rail-infrastructure/signal-wayside-components/electric-switch-systems

This citation shows the built-in electrical switch system we used for information in our background research.

[4] The Federal Register." *Federal Register :: Request Access*, www.ecfr.gov/current/title-49/subtitle-B/chapter-II/part-213?toc=1 . Accessed 17 July 2023.

This citation shows Chapter 2 of Track Safety Standards for the Federal Railroad Administration Department of Transportation. This is where we took our applied codes and standards from.

[5] *TS-4500 Hydraulic Switch Machine*. Apex Rail Automation. (n.d.). https://apexrailautomation.com/ts-4500-hydraulic-switch/

This citation shows the hydraulic switch sold by Apex Rail Automation which we used for our background research.