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2016 FSAE Electric Vehicle Pedal Assembly Design

Evan Beery
eib3@zips.uakron.edu

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Honors Senior Design Project

Pedal Assembly

Beery, Evan

ADVISOR: DR. SHAO WANG

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Abstract

The purpose of this project was to design and produce the pedal box assembly for the electric formula SAE racecar team's 2016 racecar. To complete this project, a working 3D model and corresponding blueprints were created. Materials were selected, machined, and assembled. FEA software was used to verify the design. The final step was manufacturing and assembling all the components together and placing them in the racecar. The precision machining was completed on campus at the University of Akron, and was considered a vital measurable of the project.

This assembly allows for the actuation of two aluminum pedals. One pedal applies force to the master cylinders used in the hydraulic braking system. A balance bar is used to allow for the calibration of the hydraulic breaking system. The amount of force applied relative between the front wheels and rear wheels will be calibrated during the testing of the racecar. The other pedal actuates linear potentiometers that are used to gage the acceleration of the racecar. The linear potentiometers will be integrated into the electrical system of the car. The assembly is robust and adaptable.

The result of this project is a completed pedal assembly. The assembly is in alignment with the Electric Vehicle team's goal of continual design and manufacturing improvement. The final assembly improves upon the previous year's design as well as alleviating several concerns from the previous year. It has successfully integrated with the hydraulic breaking systems as well as other subsystems; particularly the frame and electrical systems.

This report explores several different conceptual pedal design solutions. Different basic sketches were created to help visualize the varied ideas and gain input from other potential drivers of the car. The integrating subsystem engineers were consulted with throughout design and manufacturing to insure successful incorporation into the car. This report documents the design process, describes the manufacturing process, and records lessons learned throughout the project.

Acknowledgements

I would like to extend a special thanks to my family for their loving support and motivation in this project and throughout my academic journey. Also a big thank you to Mr. Steve Gerbitz for all the time he spent teaching me the skills and techniques to manufacture this project. Lastly, thank you to the electric vehicle team for the encouragement, brainstorming sessions, and allowing me to be a member of the team.

Introduction

There are few things more exciting for car enthusiasts than racing. Persons that do not have a background in vehicular design do not often take the time to think about the one of the most important interactions a driver has with a car; the pedal assembly. Race teams often design their pedals specifically for a particular driver. The 2016 electric racecar will be driven by many different drivers. This does not diminish the importance of a well-designed pedal assembly.

Background:

The University of Akron's electric formula SAE race team is working on only its third car. The team is still developing best practice designs and developing their own standards. There are many styles of pedal assembly's in production today. This report explores three basic concepts for the pedals.

The first is having the pedals actuating below the axis of rotation. This concept is seen regularly in consumer vehicles. This type of design can be easier to adjust. A disadvantage in implementing it into the electric racecar is the cost and manufacturability. Another concept that is explored is having the axis of rotation near to the center of the pedal. This allows for a spring to pull the pedal back to its resting position after being actuated. This concept is cost effective as springs are very cost effective compared to a pneumatic spring. A disadvantage is that axis of rotation is near to the location of force input from the driver. Many drivers do not prefer this. A third concept is to design the pedal to actuate above the axis of rotation. This concept can be less cost effective since it costs more money to produce a mechanism to return the accelerator pedal to the resting position.

There are undoubtedly many more ideas of how to design a pedal assembly. Since these pedals were to be manufactured it was also important that any design could be realistically produced. The pedal concepts were explored as they were deemed most feasible and effective to produce and implement into the 2016 electric vehicle racecar (1).

Principles of Operation:

The principles of operation are important to take into consideration. The goal is to create an optimal pedal assembly based on the electric vehicle team's needs. These needs include envelope, weight, durability, adjustability, manufacturability, and cost. The final assembly must be effectively integrated into the frame and interact with the hydraulic brake system and the electrical system of the racecar. The pedal assembly must be in accord with the 2015-16 Formula SAE® Rules (2). Appendix A provides a list of the rules and regulations governing the pedal assembly.

Product Definition:

The final pedal assembly must be manufactured and satisfactorily transfer the force from applied from the driver into the hydraulic break system. It also must effectively provide minimal difference consistently between two linear potentiometers as stated in Rule EV2.3.4 and EV2.3.6. The assembly also needs to conform to all safety rules as well as implementing a brake over-travel switch according to rule T7.3.1. This switch must be designed so that if the hydraulic break systems malfunctions, and the brake pedal over travels, the switch will be actuated resulting in the shutdown system being activated. The final product will allow for the hydraulic system to operate as well as the electrical of the car.

Conceptual Design

In the 2016 electric vehicle racecar, the team wanted to improve the overall weight of the racecar. As a result it was desired to have a pedal assembly with a smaller envelope. The electrical engineers also requested that the linear potentiometers have a greater repeatability. This means that when the accelerator pedal was pressed, that the difference between the two potentiometers must be minimal. This would require a robust design that limits any movement of the accelerator pedal other than in the direction of actuation. The design of the pedal assembly is governed by envelope, weight, durability, adjustability, manufacturability, and cost. These design factors are all woven together and tradeoffs had to be made.

Segmentation Techniques:

Figure #1 displays the pedal assembly's functional flow. After developing a firm understanding with and the basic goals of the project, brainstorming could be done to develop concepts for the different aspects of the assembly. Figure #2 displays an objective tree which is a result of such brainstorming. It establishes the central objective and the supporting components that significantly impact the design.

Figure #1 – Functional Diagram

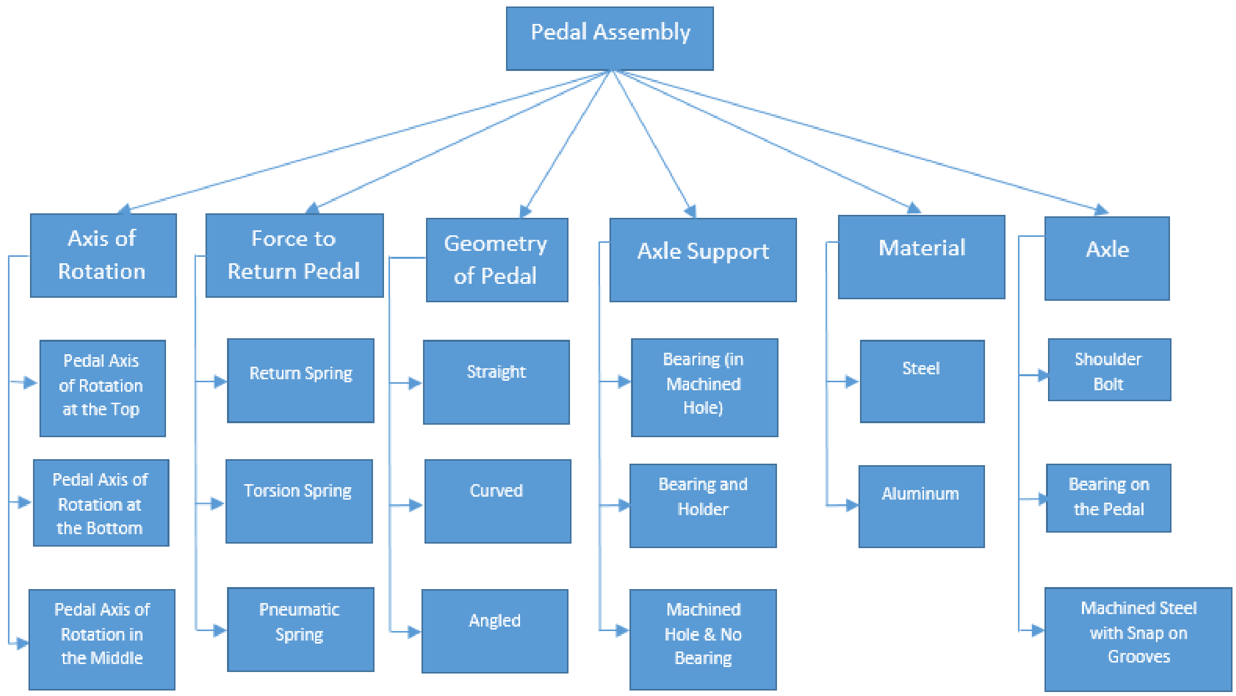


Figure #2 – Objective Tree

Morphological chart:

Several different concepts were developed for the accelerator pedal design. Ideas were taken from all members of the team and other vehicle designs (8). The brake pedal is constrained by the master cylinders and balance bar. The orientation of the brake pedal will therefore follow the orientation of the accelerator pedal. The master cylinders return the brake pedal to its resting position. A morphological chart for the accelerator pedal is shown in Figure #3.

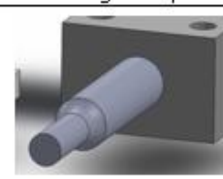
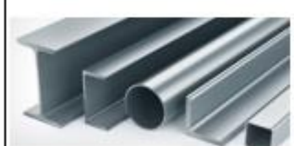
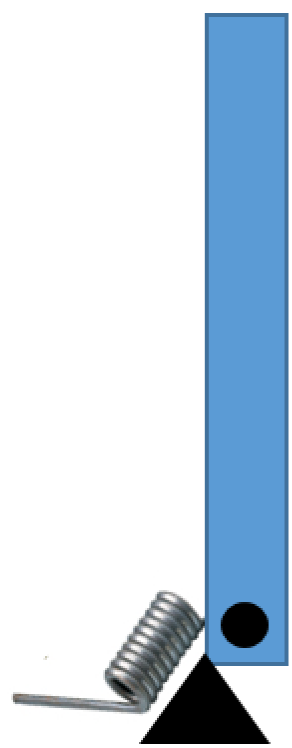
		Solution		
Function	**#**	**1**	**2**	**3**
Axis of rotation	1	 Pedal axis of rotation at the bottom	 Pedal axis at the top	 Pedal axis in the center
Force to return pedal	2	 Return Spring	 Torsion Spring	 Pneumatic Spring
Geometry of Pedal	3	 Straight	 Angled	 Curved
Axle	4	 Shoulder Bolt	 Machined Steel with snap on grooves	 Bearing on the pedal
Axle Support	5	 Bearing and holder	 Bearing	 Machined hole no bearing
Material	6	 Steel (Machined)	 Aluminum (Machined)	

Figure #3 – Morphological Chart for Accelerator Pedal Design

Concept Sketches:

From the morphological charts concept sketches can be generated. These sketches communicate graphically the general look and feel of the accelerator design with minimal actual engineering or developmental background. They allowed for input from other members of the team and knowledgeable persons.

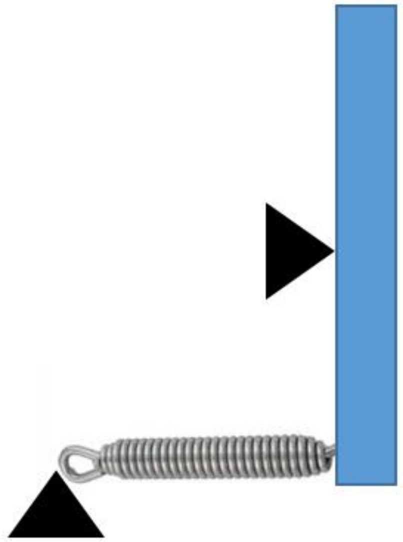
Concept Sketch #1



Concept sketch #1, option A, includes an axis of rotation at the bottom of the pedal with a torsion spring to return the pedal. The axle is made up of machined steel with snap on clips to retain it. The pedal is straight and made up of steel material and a bearings in holders support the axle.

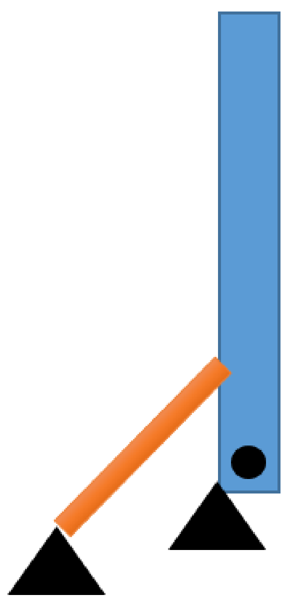
Concept sketch #1, option B, includes an axis of rotation at the bottom of the pedal with a torsion spring to return the pedal. The axle is made up of a shoulder bolt with a nylon lock nut to retain it. The pedal is straight and made up of aluminum material and has a machined hole to support the axle with no bearing.

Concept Sketch #2



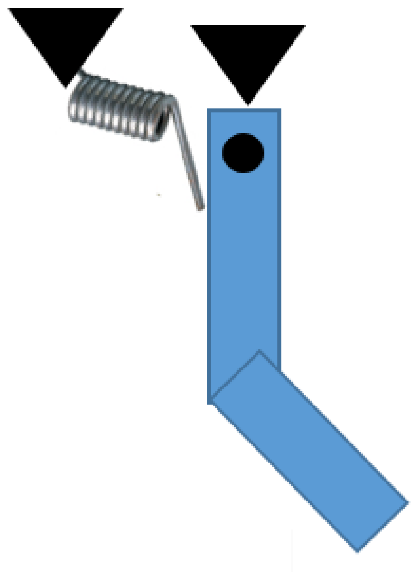
Concept Sketch #2 consists of an axis of rotation in the center of the pedal with a return spring returning the pedal. The pedal is straight and consists of aluminum material. The axle is made up of a bearing on the pedal.

Concept Sketch #3



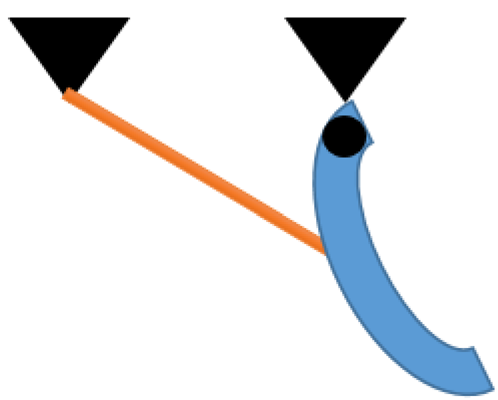
Concept Sketch #3 constitutes an axis of rotation at the bottom of the pedal with a pneumatic spring returning the pedal. The axis of rotation is a shoulder bolt inserted through a machined hole in the aluminum straight pedal with no bearing.

Concept Sketch #4



Concept Sketch #4 comprises an angled steel pedal with a torsion spring installed to return the pedal. The axle is machined steel with snap on clips to retain it supported by bearings in holders.

Concept Sketch #5



Concept Sketch #5 entails a steel curved pedal utilizing a pneumatic return spring to return the aluminum pedal. The axil is made up of a shoulder bolt through a machined hole with no bearing.

Weighted Decision Matrix:

To help to screen the concepts brainstormed, a weighted decision matrix was used. Figure #4 displays the origin of the weight assigned to each factor(7). The weights were assigned based on how important each respective aspect was to the overall design. Figure #4 displays the origin of the weights for the weights used in the weighted decision matrix assessment as shown in figure #5. Reference Figure #6 for the decision matrix showing unweighted assessment.

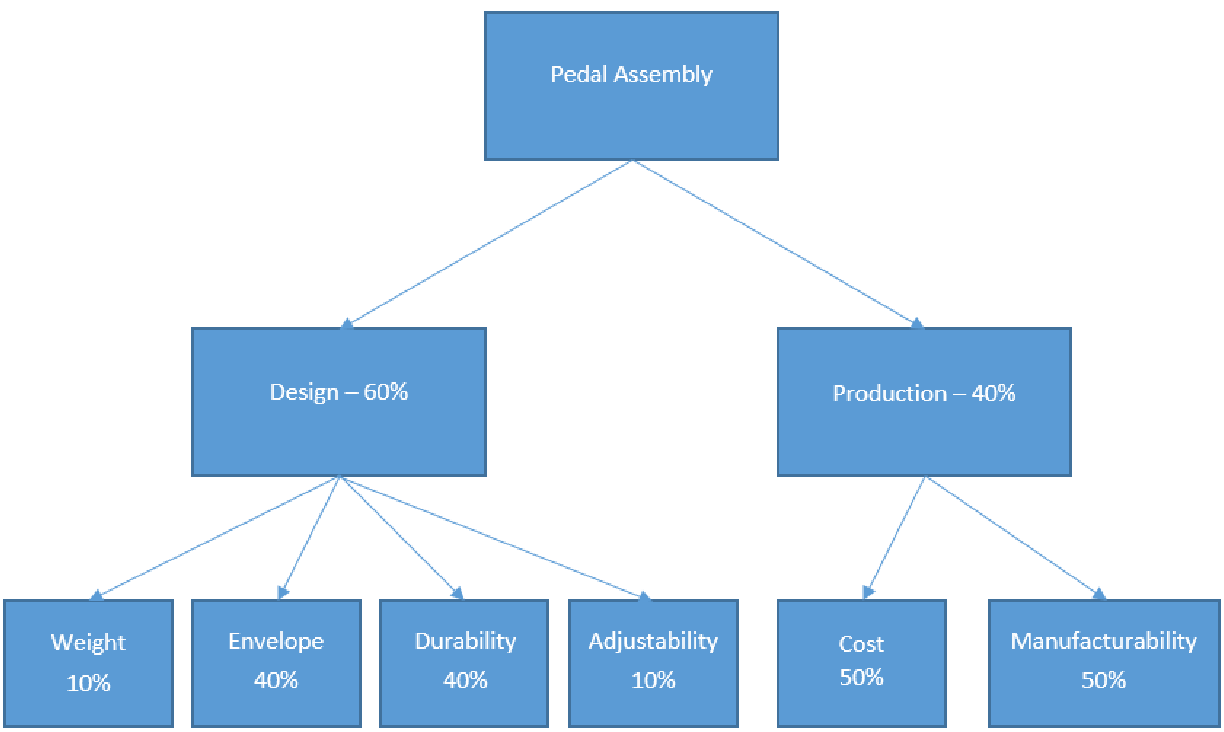


Figure #4 – Origin of the Decision Matrix Weights

Factors	Cost	Envelope	Durability	Weight	Adjustability	Manufacturability	Total
Weight Calculation	0.4*0.5	0.6*0.4	0.6*0.4	0.6*0.1	0.6*0.1	0.4*0.5	
Weights	20%	24%	24%	6%	6%	20%	
Concept #1 - Option A	0.8	1.2	0.72	0.24	0.18	0.4	3.54
Concept #1 - Option B	0.6	1.2	0.48	0.3	0.18	0.4	3.16
Concept #2	0.8	0.72	0.72	0.12	0.12	0.6	3.08
Concept #3	0.4	0.96	0.96	0.24	0.24	1	3.8
Concept #4	0.4	0.72	0.96	0.18	0.24	0.2	2.7
Concept #5	0.2	0.48	0.96	0.24	0.24	0.2	2.32

Figure #5 – Decision Matrix Displaying Weighted Assessment

Factors	Cost	Envelope	Durability	Weight	Adjustability	Manufacturability
Concept #1 - Option A	4	5	3	4	3	2
Concept #1 - Option B	3	5	2	5	3	2
Concept #2	4	3	3	2	2	3
Concept #3	2	4	4	4	4	5
Concept #4	2	3	4	3	4	1
Concept #5	1	2	4	4	4	1

Figure #6 – Decision Matrix Displaying Unweighted Assessment

The decision matrix is based on a range of scores from 1 to 5; a score of 5 being the most desirable while a score of 1 being the least desirable. From the weighted decision matrix in Figure #5 it can be determined that Concept #3 is the best option since it has the highest score of 3.8. Therefore, the pedal assembly design will consist of an axis of rotation at the bottom of the pedal with a pneumatic spring returning the pedal. The axis of rotation will be a shoulder bolt inserted through a machined hole in the aluminum straight pedal with no bearing.

Embodiment Design

With the basic concept of the pedal assembly established, it was then to possible to begin the development of the design in accordance with the technical and economic criteria established.

Envelope:

The design needed to be robust and adaptable to different drivers. The racecar must be able to accommodate heights from the 5th percentile female to the 95th percentile male. Section T3.10.4 of the FSAE rulebook sets the measurement standards to determine this. Figure #7 is taken from the rulebook. With the seat in the rearmost position and the pedals in the foremost position a radius of 915 mm minimum must be met.

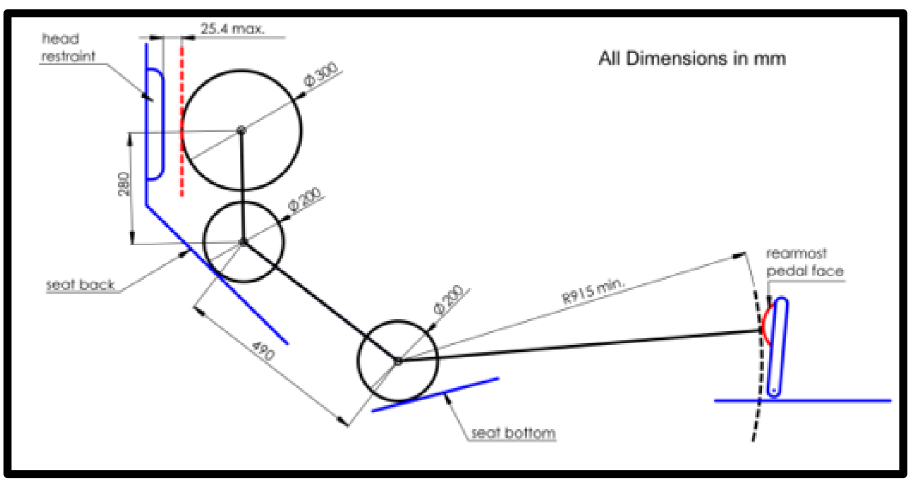


Figure #7

In conjunction with the frame lead on the team, a depth of 5 inches was agreed upon. This was the first design constraint. The maximum width of the assembly was given by the frame design as 12 inches. The height, also constrained by the frame, was 12.5 inches. The pedal assembly needed to fit in a 5 inch by 12 inch by 12.5 inch cube.

Durability

According to T7.1.9 in the SAE rulebook the brake pedal must be fabricated from steel, aluminum, machined steel, or machined aluminum. This greatly narrowed down material selection. Rule T7.1.8 states that the brake pedal also must be able to withstand a force of 2000 N without any failure to the pedal or the pedal assembly. At competition this will be tested by a judge sitting normally in the car and pressing the pedal with the maximum force that can be exerted.

Adjustability:

It is important that when testing the car that adjustments can be made to the available travel of both pedals. The electrical engineers requested that the accelerator pedal have both a positive and negative stop and that it be adjustable to have complete control over the range of motion of the linear potentiometers. The brake over travel switch had to be adjustable to allow for calibration during testing.

Weight:

There was no specific requirement given from the rules or the team as far as the overall weight of the pedal assembly. However, one of the goals for the 2016 racecar is to reduce the weight so it is a design constraint that had to be taken into consideration.

Cost:

The cost of the pedal assembly had to be kept at a minimum. Material that was already on hand was much preferred. The electric vehicle team has several sponsors that donate manufacturing processes and materials when needed. The master cylinders, balance bar and the linear potentiometers are reused from the racecar produced in 2015. This helped to reduce cost, but also constrained the design.

Manufacturability:

The components of the pedal box had to be designed as to alleviate complex manufacturing as it would be unable to be completed on campus and possibly become very costly. Processing had to be limited to machining able to be completed on a mill or lathe. Components could be sent out to a sponsor for laser cutting or water jetting as well. Appropriate fasteners had to also be taken into consideration. Article 11 of the rule book outlines appropriate fasteners. Rule T11.2.1 outlines that for all critical bolts, nuts, and other fasteners on the braking system must have positive locking mechanisms. Positive locking mechanisms included safety wiring, cotter pins, nylon lock nuts, and torque lock nuts. Rule T11.2.2 also specifies that there must be a minimum of two full threads projecting from any lock nut.

Material Selection

Material selection is limited by the rules to aluminum and steel. There will be a high amount of bending stress on the pedals in particular while in operation. Both pedals had to be able to handle large amounts of loads without excessive deformation while still maintaining reasonable machinability. Preliminarily, 6061 aluminum was chosen as main material to make up the components of the pedal assembly. 6061 displays desired properties such as a high strength to weight ratio and good machinability, as well as having stock already on hand and available.

Detail Design

For the detailed design, the modeling software SOLIDWORKS 2015 used to generate a live model of the pedal assembly (3). Also generated were corresponding component drawings. Figure #8 shows the final isometric view of the pedal assembly model. The model allows for the actuation of the pedals over their respective range of motions. Reference the following figures.

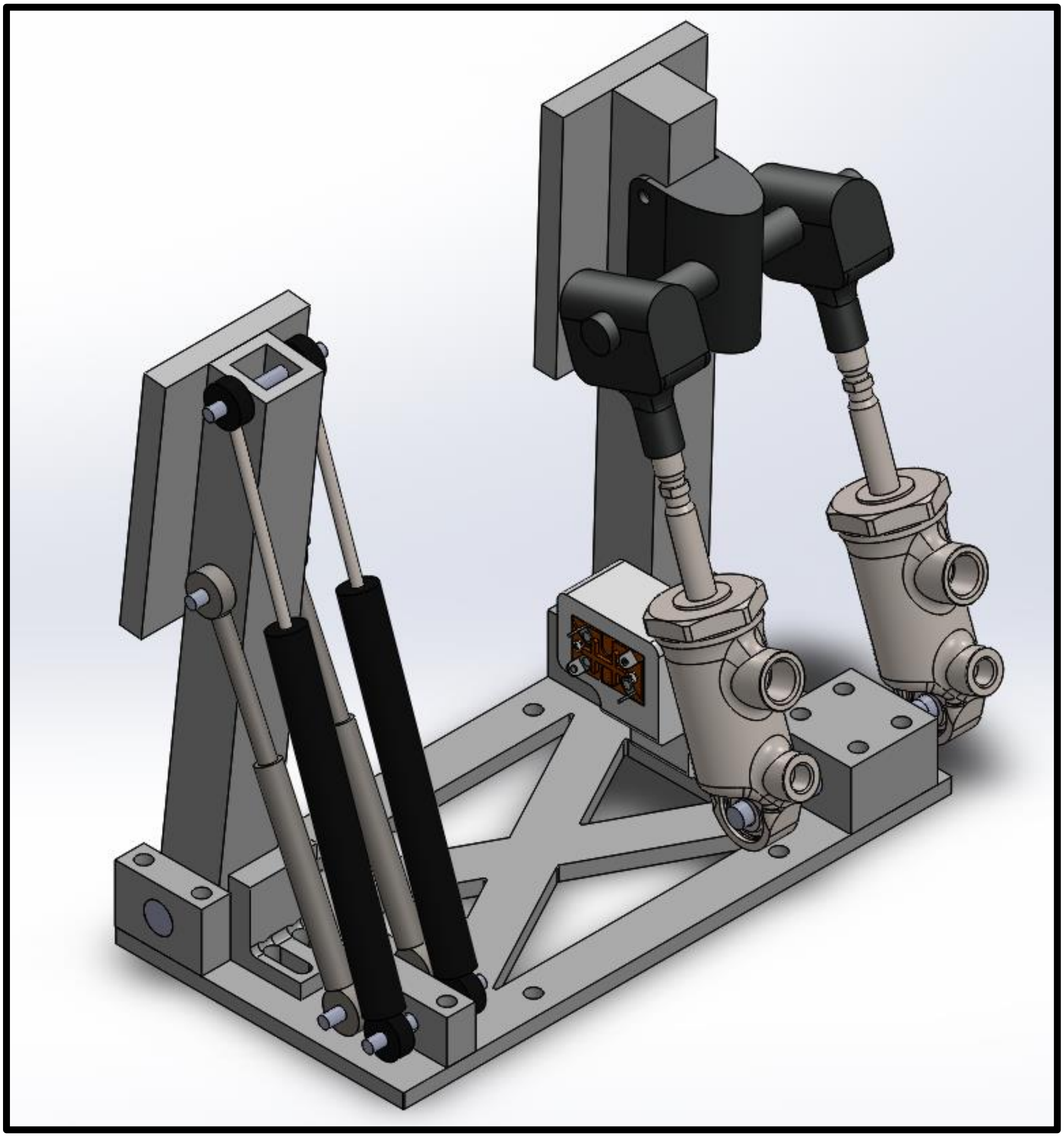
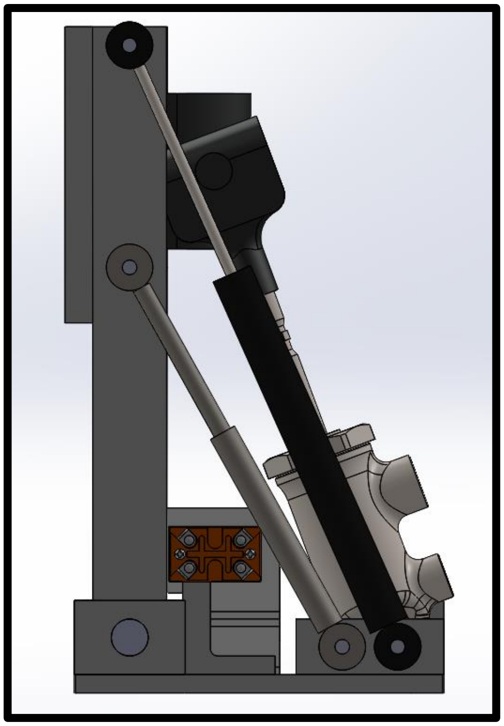


Figure #8 – Isometric View of Final Pedal Assembly



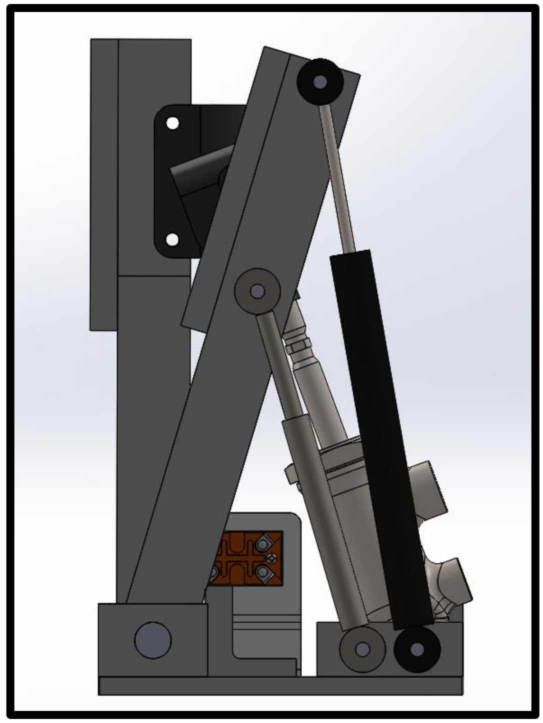


Figure #9 – Right Side View

Pedal in Resting Position

Figure #10 – Right Side View

Pedal in Actuated

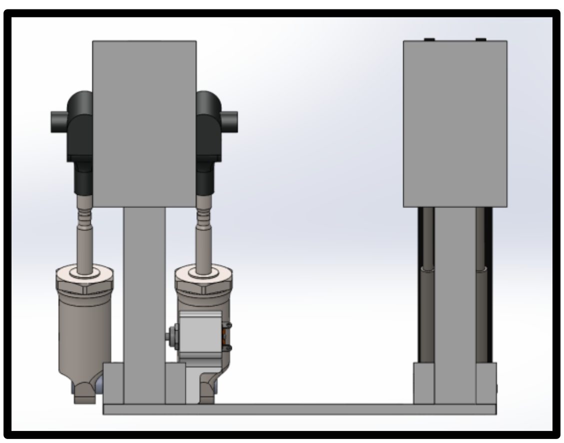


Figure #11 – Front View

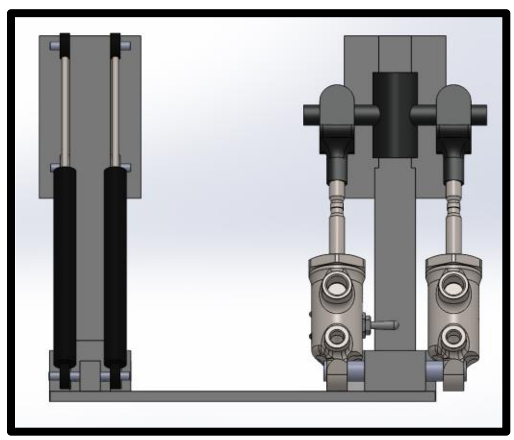


Figure #12 – Rear View

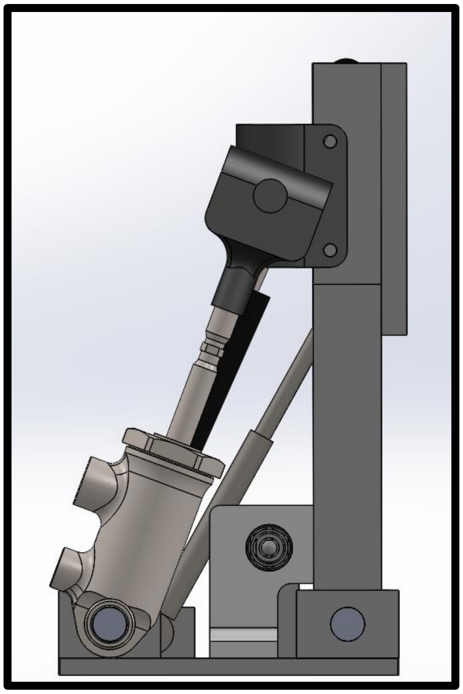


Figure #13 – Left Side View

Brake Pedal in Resting Position

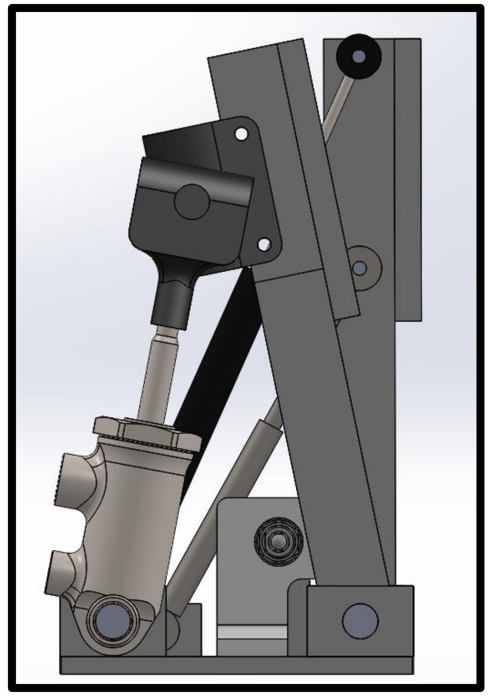


Figure #14 – Left Side View

Brake Pedal in Actuated

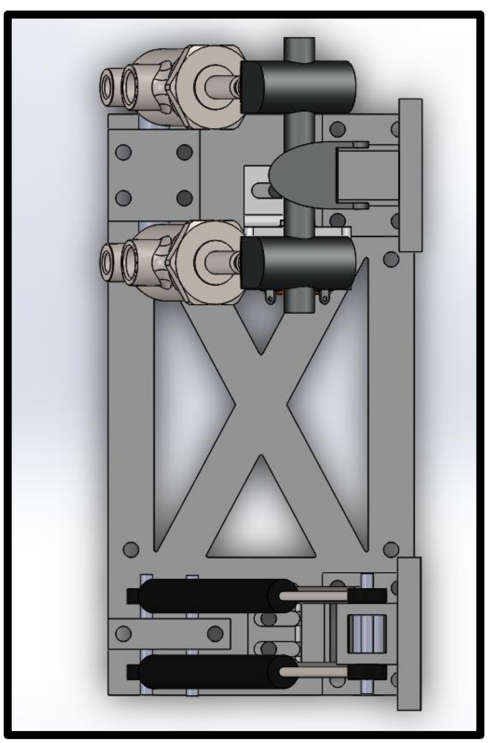


Figure #15 – Top View

Both Pedals in Resting Positions

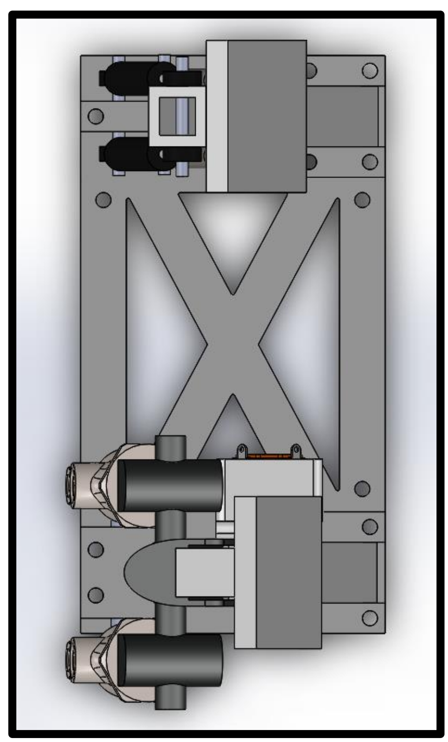


Figure #16 – Top View

Both Pedals in Actuated

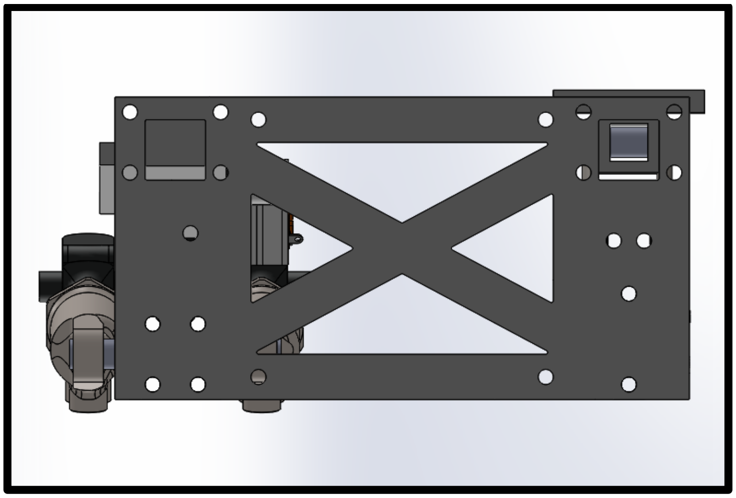


Figure #17 – Bottom View

Finite Element Analysis

Finite element analysis (FEA) was used to verify the design for strength, durability, and deflection (4). The software used was Autodesk Simulation Multiphysics 2013. Per the regulations, each component of the pedals must withstand a minimum of 2000 Newtons of force. For the FEA load, a factor of safety of 1.5 was used. Consequently each simulation used 3000 Newtons as the input force. The following figures display the FEA results. 6061 aluminum has a yield strength of 40,000 psi.

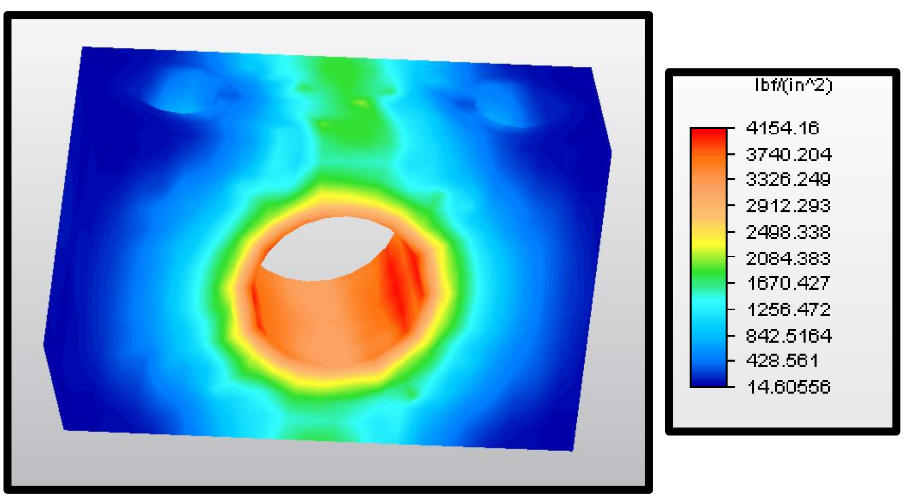


Figure #18 – Pedal Axle Mount FEA

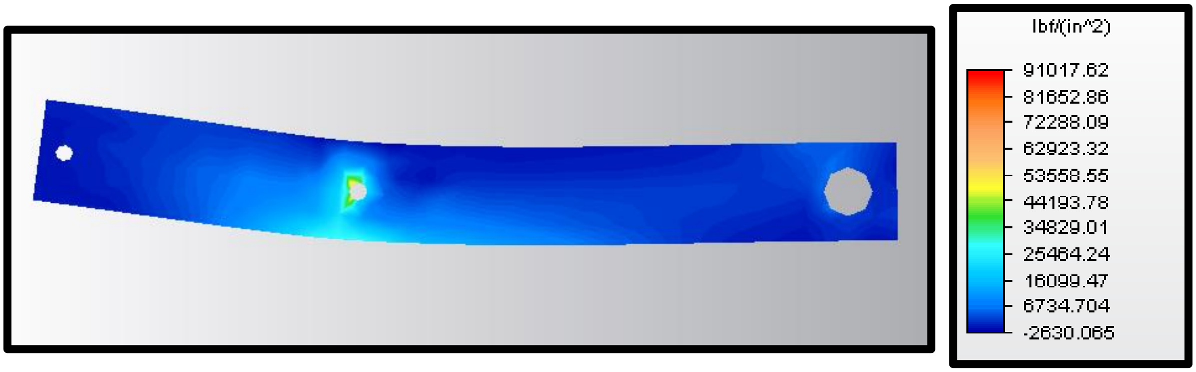


Figure #19 – Accelerator Pedal FEA

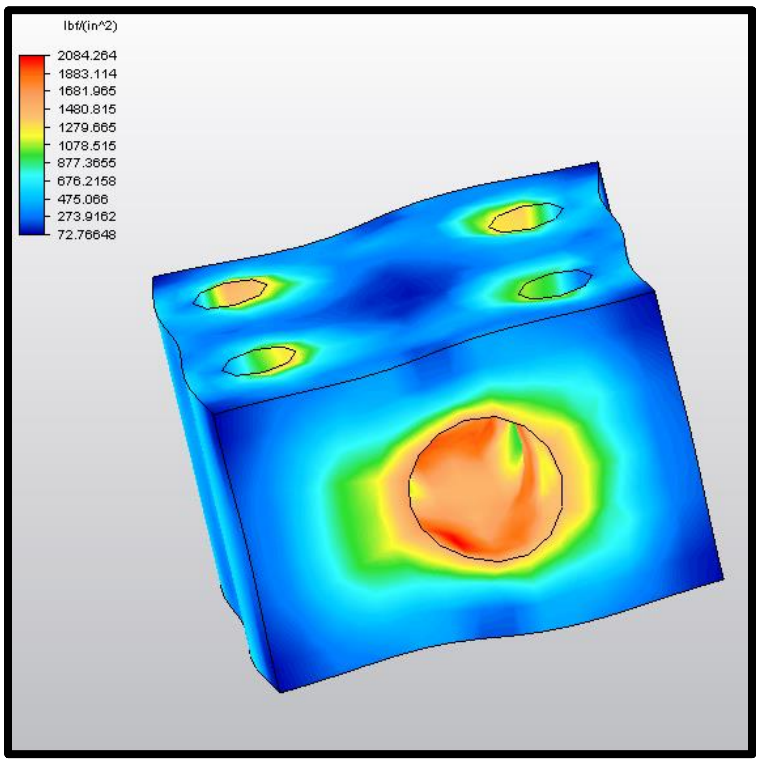


Figure #20 – Master Cylinder Axle Mount FEA

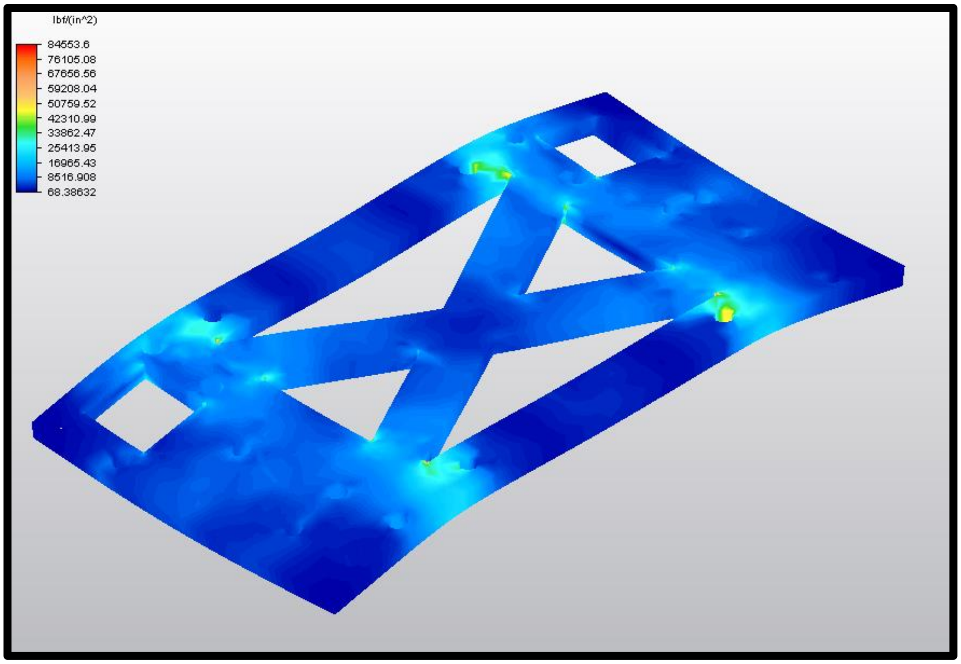


Figure #21 – Base Plate FEA

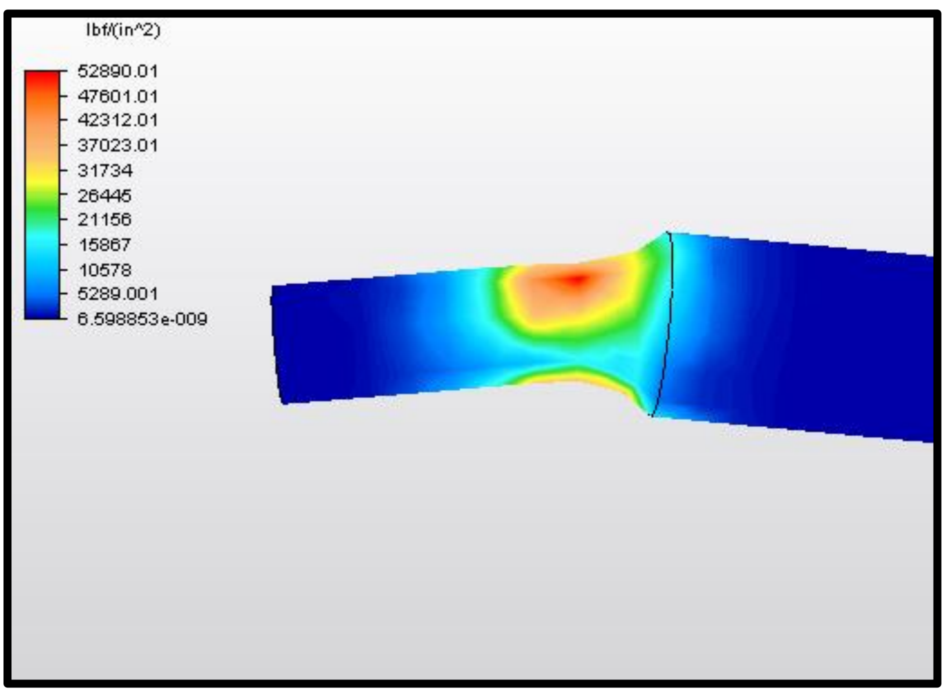


Figure #22 – Master Cylinder Axle FEA

Note that the master cylinder axle was made for AISI 1045 cold drawn steel which has a much higher yield strength of 65300 psi.

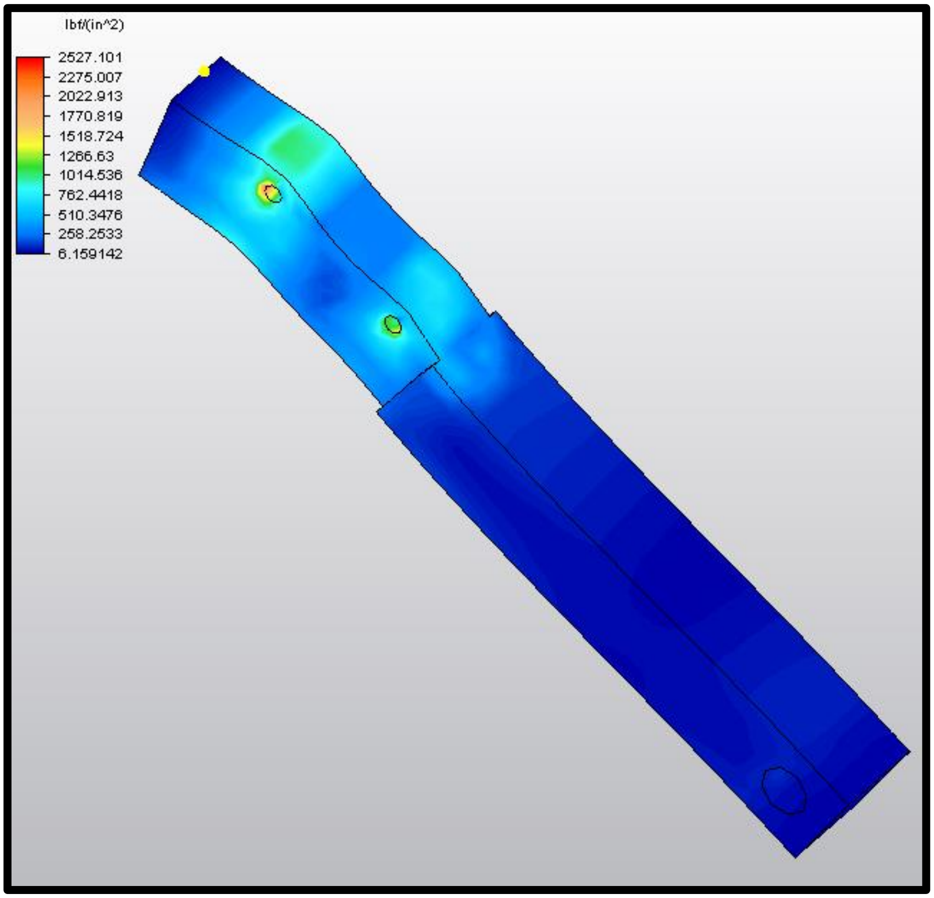


Figure #23 – Brake Pedal FEA

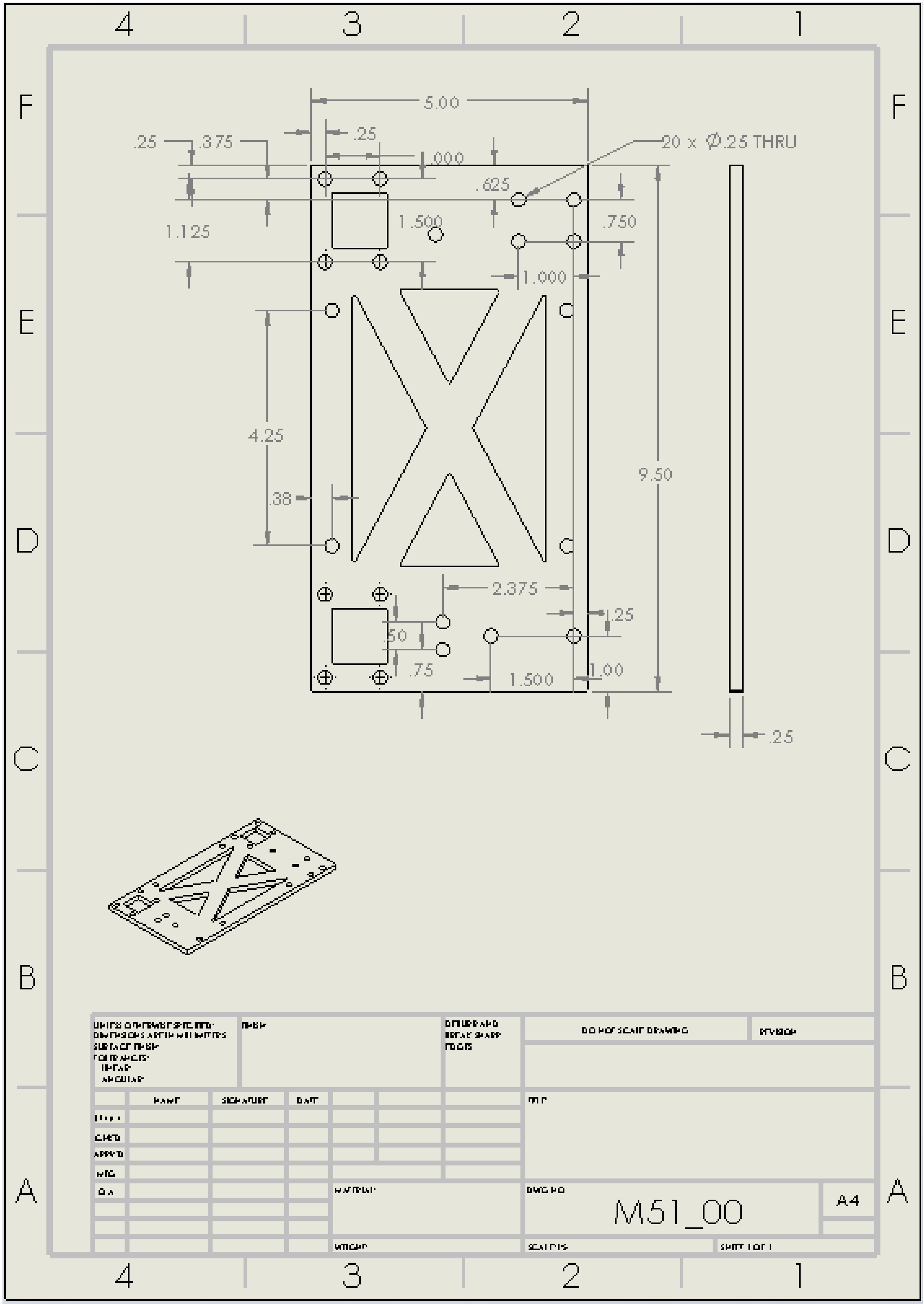


Figure #24 – Base Plate Drawing

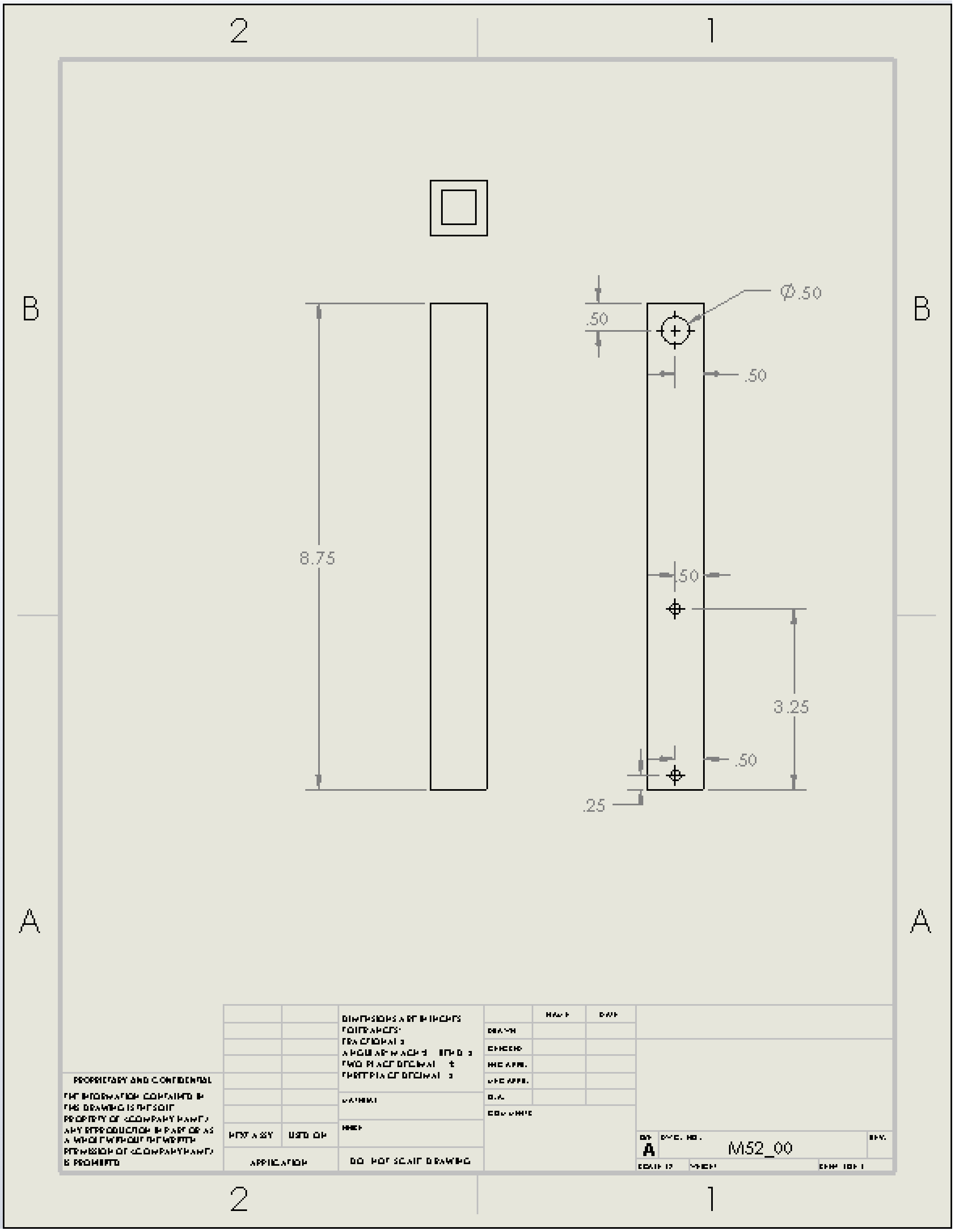


Figure #25 – Accelerator Pedal Drawing

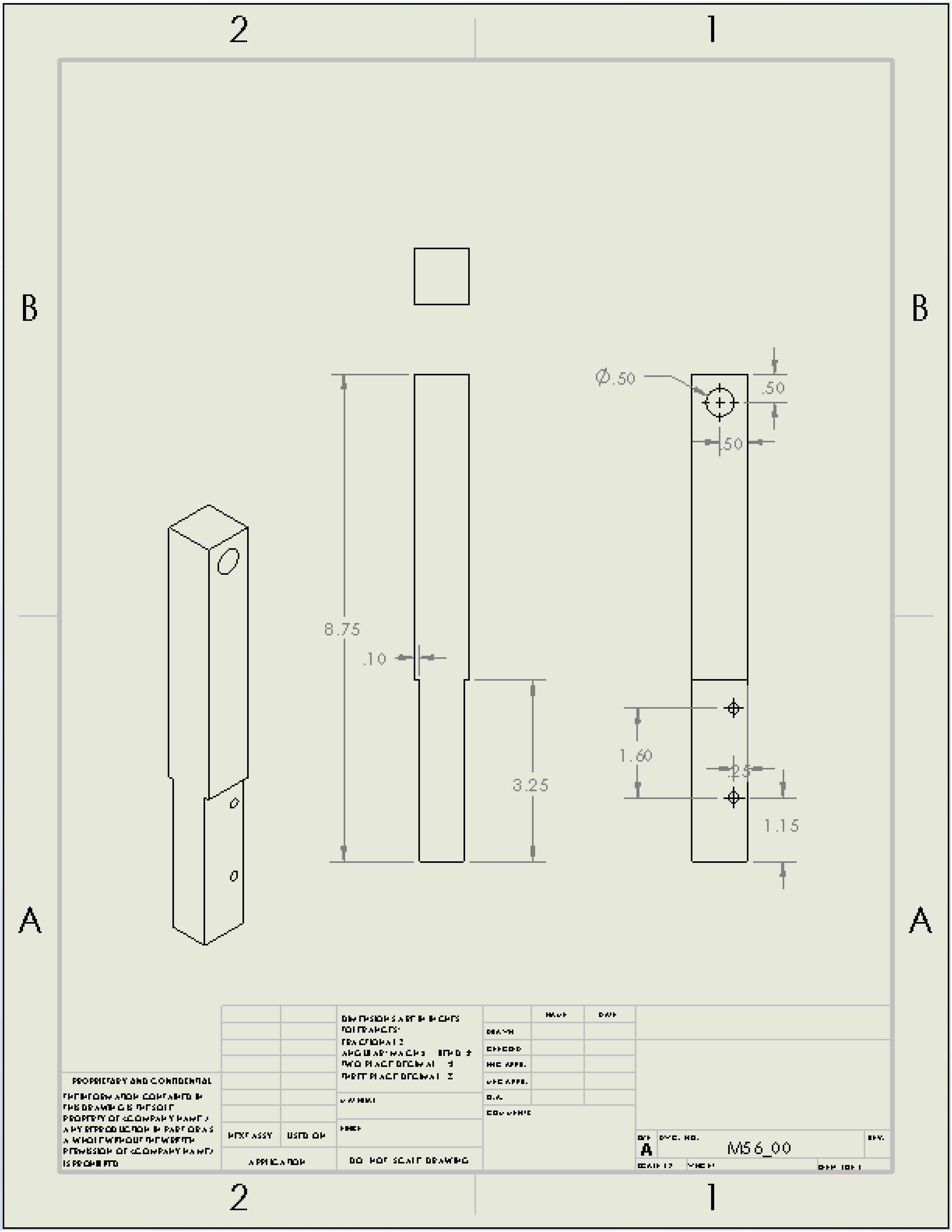


Figure #26 – Brake Pedal Drawing

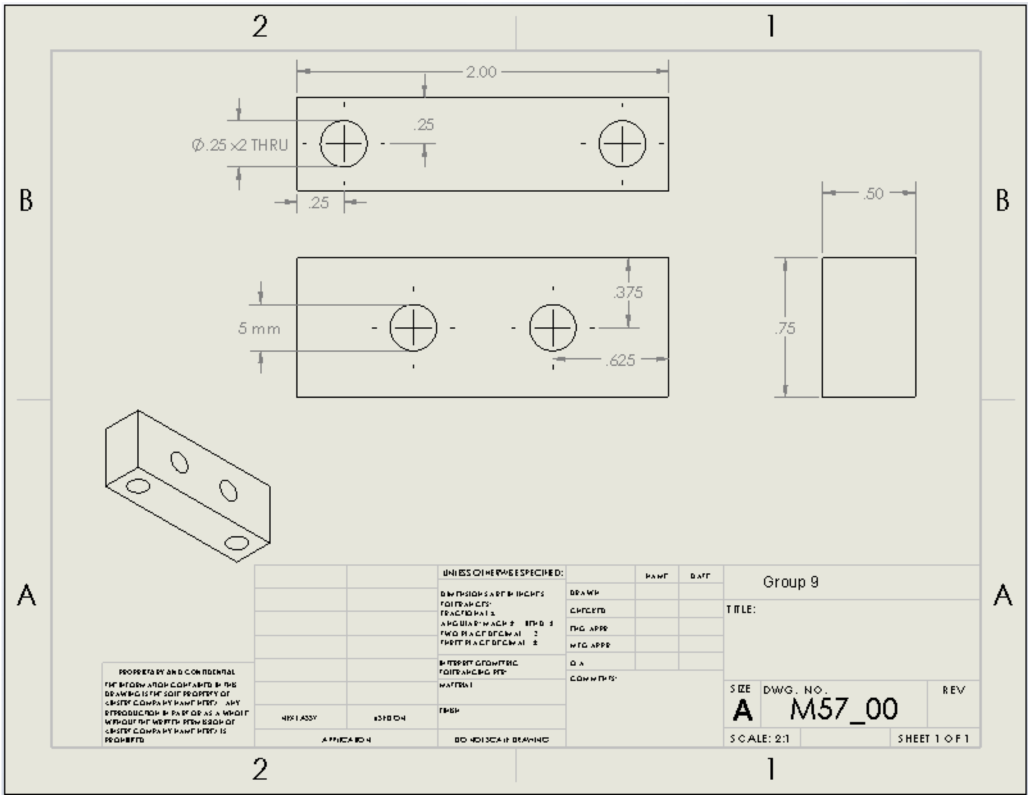


Figure #27 – Bracket for Gas Springs and Linear Potentiometers

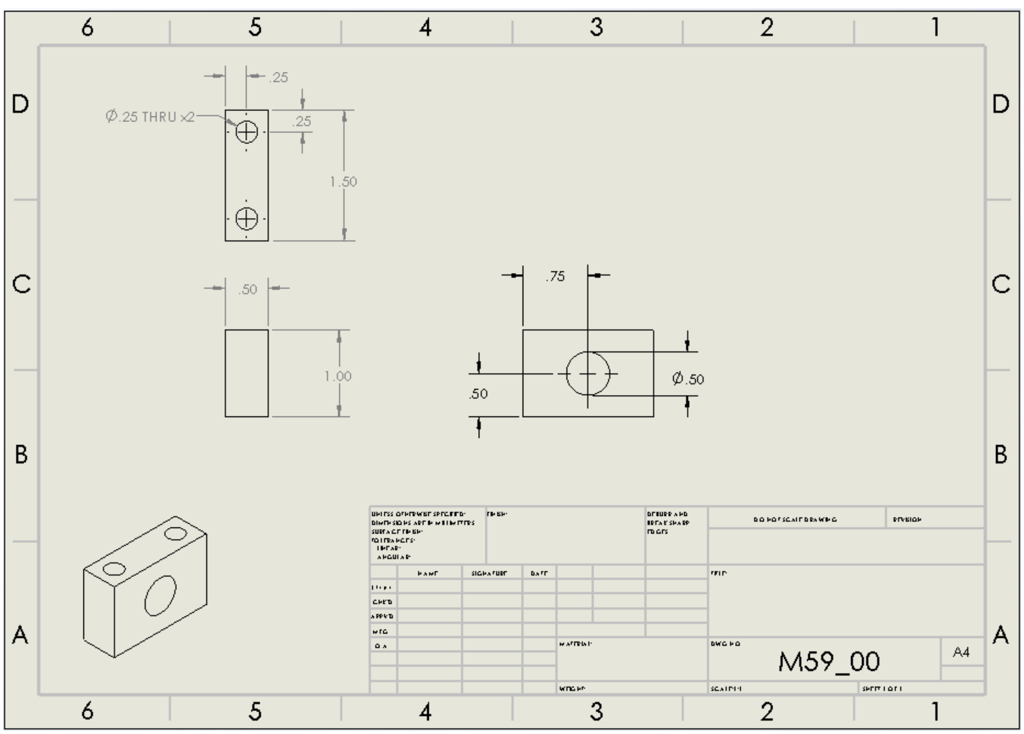


Figure #28 – Axle Mount

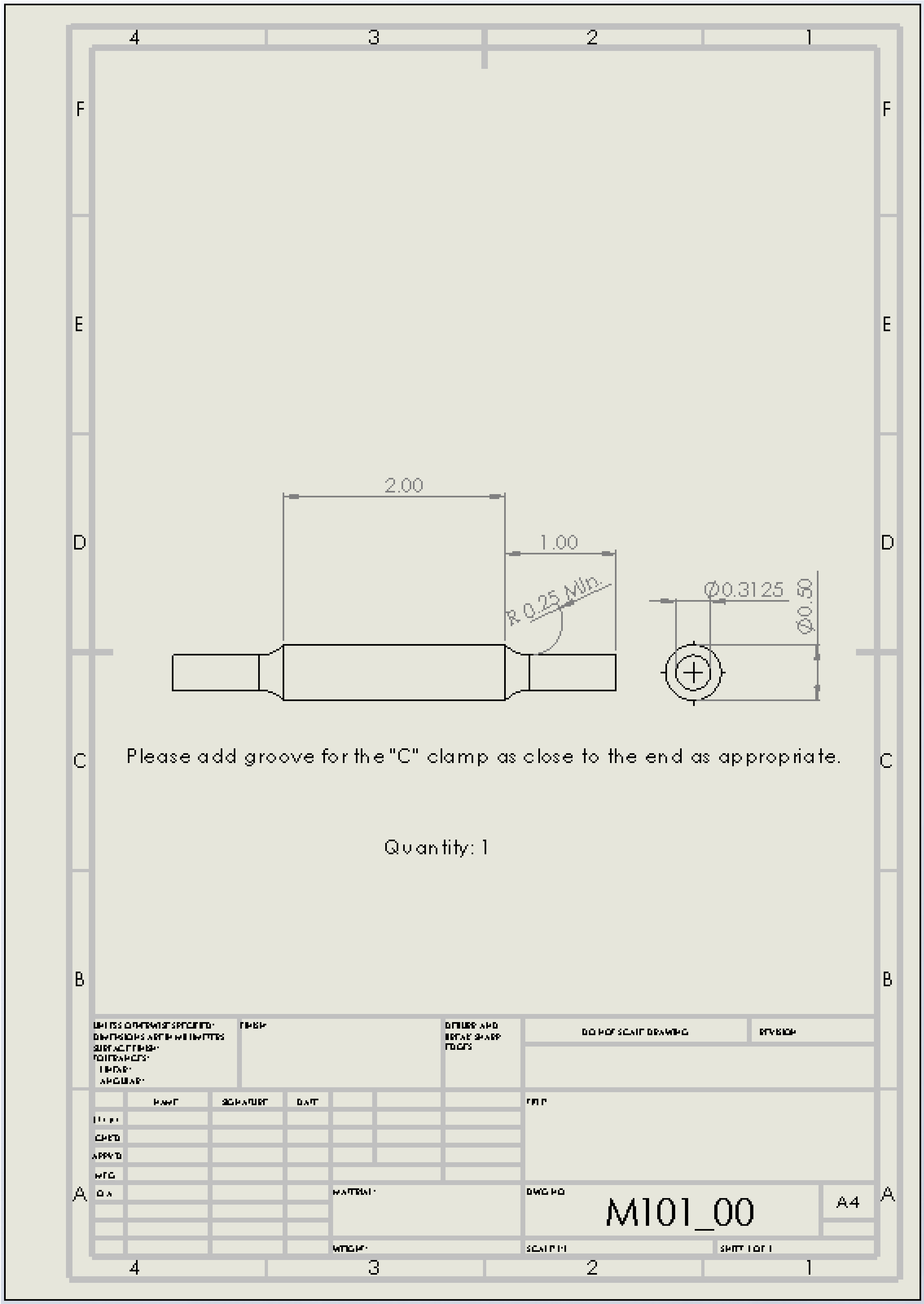


Figure #29 – Axle for Master Cylinders

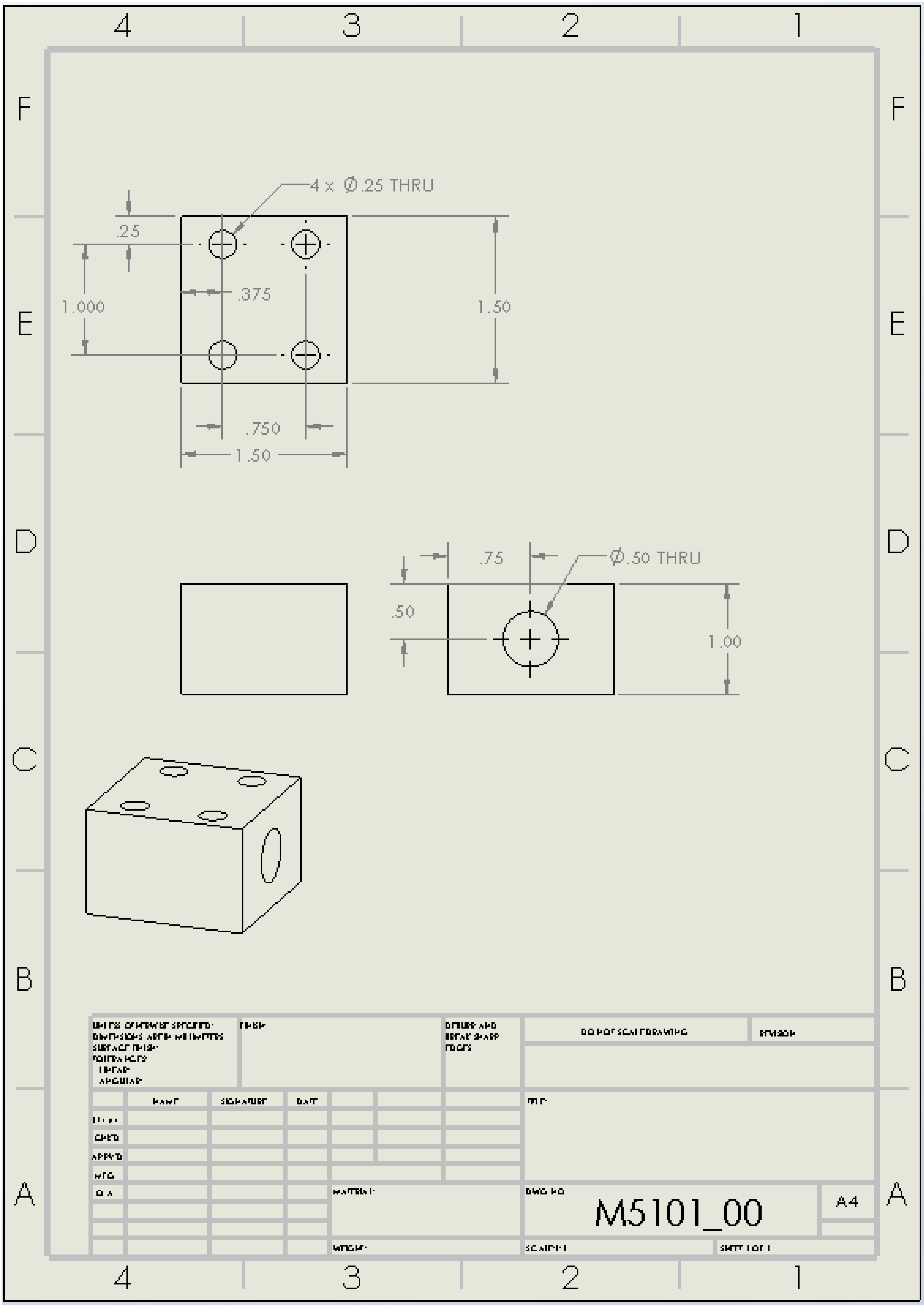
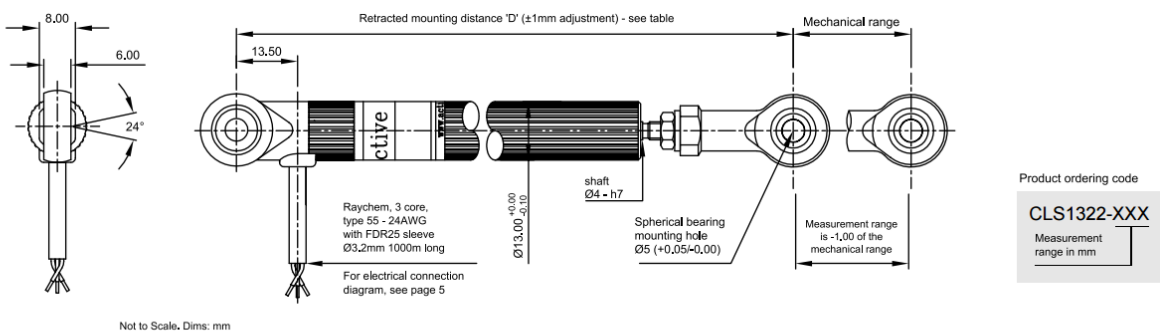


Figure #30 – Master Cylinder Axle Mount

Standard Components

The master cylinders and balance bar were purchased from Tilton racing (5). The master cylinders have bore diameters of 1 inch. The linear potentiometers were manufactured by Active Sensors. They are the CLS1322 model (6). Reference Figures #31, #32 & #33. The hydraulic braking system engineer requested two master cylinders to be incorporated into the design implementing a balance bar connecting them together. The balance bar allows to distribute the breaking force inputted between the two master cylinders.

CLS1322 - rod-end mounting



Electrical & mechanical information for CLS1320 range

Measurement range (±0.5mm)	25	50	75	100	125	150	175	200	225	250	300	350	mm
Retracted mounting distance (D)	123	148	173	198	223	248	273	298	323	348	398	448	mm
Retracted shaft length (R)	-	38.5	53.5	58.5	-	88.5	-	-	-	-	-	-	mm
Body length (C)	81	106	131	156	181	206	231	256	281	306	356	406	mm
Body length (G)	85	110	135	160	185	210	235	260	285	310	360	410	mm
Resistance (Typical)	1	2	3	4	5	6	7	8	9	10	12	14	kohms
Non-linearity	<±0.25		<±0.15										%
Applied voltage	<22	<45	<65	<90	<110	<130	<130	<130	<130	<130	<130	<130	Volts
Wiper load	>500	>500	>500	>500	>500	>600	>700	>800	>900	>1000	>1100	>1200	kohms
Mechanical range	Measurement range +1												mm
Shaft velocity	<10												m/sec
Insulation resistance (at 500V dc.)	>100												Mohms
Operating temp. range	-30° to +125°												°C
Sealing	CLS1321, 22, 24, 25, 26 - IP66. CLS1323 - IP50												
Shaft operating force	200 (typical)												grams
Shaft operating force (CLS1323)	150 - 350 (typical)												
Weight (approx.)	60	66	73	78	85	90	96	102	108	114	120	126	grams
Materials	Case - Aluminium 6063 - Sulphuric acid anodised Shaft - Stainless steel - 303 series Rod end bearing - Aluminium 6262 housing & Stainless steel ball												

Figure #31 – Linear Potentiometer Specifications

Figure #32 – Balance Bar

Figure #33 – Master Cylinder

The gas springs were purchased from Home Hardware Box. They have an extended length of 6 inches and a compressed length of 5 inches; from eyelet to eyelet. The each provide a return force of 60 newtons for a total return force of 120 newtons.

Optimization

To allow for accurate calibration during the testing of the race car the accelerator dead stop was designed with slots to allow for adjustments. Reference Figure #34. Similarly, the brake over-travel switch was designed with a slot to allow for adjustments during the testing phase of the car as shown in Figure #35.

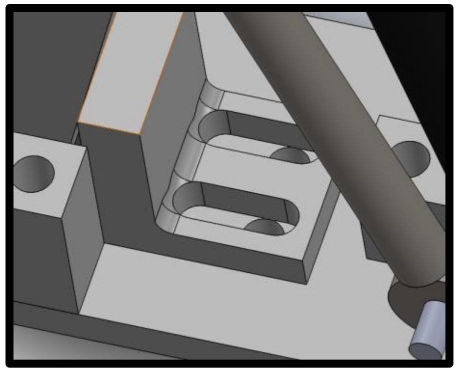


Figure #34 - Adjustable Accelerator Dead Stop

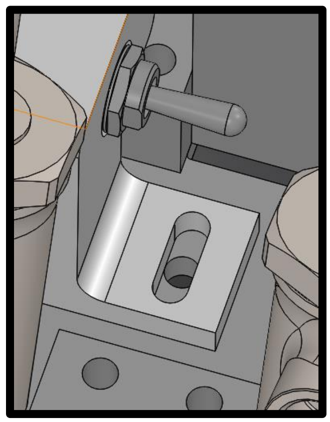


Figure #35 - Adjustable Brake Over-Travel Switch

To accommodate heights from the 5th percentile female to the 95th percentile male a set of 8 holes to be placed in the floor of the car. These eight holes allow the pedal assembly to be moved into three separate positions. The assembly can simply be unbolted, moved to the desired location, and reattached.

Manufacturing Methods

The main manufacturing method was machining. WARDJET is a sponsor of the team and donated waterjet cutting to produce the base plate. All the machined components were made of aluminum. The main machines used in processing where a Bridgeport mill, drill press, and band saw. Reference Figure #36.

Figure #36 – Machining with the Bridgeport Mill

Discussion

The assembly produced is an effective and efficient design fulfilling the needs of the 2016 formula electric race team's car. All manufacturing was done completely on campus with the exception of the waterjet cutting done by WARDJET to form the base plate. The main limiting factor of the design turned out to be the request to reuse the linear potentiometers from last year. This constrained the way the accelerator pedal had to be designed because of the necessity of robustness to achieve repeatability. The master cylinders and balance bar are top of the line components in worthy condition. Most likely they are what would have been selected and purchased in any case.

Improvements of the Design

The 2016 electric racecar's pedals are an improvement from past years pedal assemblies because of the envelope, the cost, adaptability, and robustness of the design. The assembly has only a 5 inch depth. This gave the frame engineers much more available design space to optimize the structure of the racecar. Because the components of the pedal assembly were manufactured with materials already on hand, material expense was zero dollars. This is important because the team is still establishing itself while developing a sponsor base. Consequently, conserving the available resources where possible is significant. Designing the assembly to adjust to the driver's height by translating the whole pedal provides several advantages. First, it is less complex and allows for a reduction in the weight of the assembly. Secondly, it improves the robustness of the pedals by removing connections, as in previous editions. Thirdly, it reduced the overall complexity which greatly increased the manufacturability as well as made it more feasible to achieve the desired envelope. In previous versions of the pedal assemblies there were concerns for plausibility of the two sensors. As seen in rule EV2.3.6, implausibility is defined as a deviation of more than 10 percent pedal travel between the two linear potentiometers. The new assembly, during testing, provided a maximum of 1 percent deviation between the two potentiometers. This was accomplished by using shoulder bolts combined with precision machining of the corresponding holes. Overall the new pedal assembly provided continuous improvement from the previous assemblies.

Conclusion

The pedal assembly produced effectively satisfies the project proposal. It allows for the operation of the hydraulic breaking system and the activation of the electrical acceleration system with a high level of repeatability. The costs of the project were minimal. The assembly is adjustable, accommodates an appropriate height range of persons, and correctly fits within the frame of the racecar.

This project proved both challenging and engaging. At the deadline for submission of this report, the 2016 electric SAE racecar has not been manufactured sufficient to provide live testing results in this report. This is unfortunate, as it was greatly anticipated to analyze the results and would have provided valued experience. Many skills were developed such as FEA, SolidWorks 3D modeling, vehicle braking theory, practical machining abilities, and machine operation skills. My favorite aspect of the project was learning custom machining techniques and learning to operate the machines.

I look forward to the installation, testing, and calibration of the pedal assembly in the 2016 electric SAE racecar. The team expects to compete at two separate Formula SAE competitions this summer.

References

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Appendix A – Rules and Regulations

T7.3 Brake Over-Travel Switch

T7.3.1 A brake pedal over-travel switch must be installed on the car as part of the shutdown system and wired in series with the shutdown buttons. This switch must be installed so that in the event of brake system failure such that the brake pedal over travels it will result in the shutdown system being activated and controlling the systems as defined in Part IC Article 4 (IC vehicles) or EV5.4 (electric vehicles).

T7.3.2 Repeated actuation of the switch must not restore power to these components, and it must be designed so that the driver cannot reset it.

T7.3.3 The switch must be implemented with analog components, and not through recourse to programmable logic controllers, engine control units, or similar functioning digital controllers.

T7.3.4 The Brake Over-Travel switch must be a mechanical single pole, single throw (commonly known as a two-position) switch (push-pull or flip type) as shown below.

T7.1.8 The brake pedal shall be designed to withstand a force of 2000 N without any failure of the brake system or pedal box. This may be tested by pressing the pedal with the maximum force that can be exerted by any official when seated normally.

T7.1.9 The brake pedal must be fabricated from steel or aluminum or machined from steel, aluminum or titanium.

EV2.3 Torque Encoder (throttle pedal position sensor)

EV2.3.1 Drive-by-wire control of wheel torque is permitted.

EV2.3.2 The torque encoder must be actuated by a foot pedal.

EV2.3.3 The foot pedal must return to its original position when not actuated. The foot pedal must have a positive stop preventing the mounted sensors from being damaged or overstressed. Two springs must be used to return the throttle pedal to the off position and each spring must work with the other disconnected.

NOTE: The springs in the torque encoders are not acceptable return springs.

EV2.3.4 At least two separate sensors have to be used as torque encoder. Separate is defined as not sharing supply or signal lines.

EV2.3.5 If an implausibility occurs between the values of these two sensors the power to the motor(s) must be immediately shut down completely. It is not necessary to completely deactivate the tractive system, the motor controller(s) shutting down the power to the motor(s) is sufficient.

EV2.3.6 Implausibility is defined as a deviation of more than 10% pedal travel between the sensors.

EV2.3.7 If three sensors are used, then in the case of a sensor failure, any two sensors that agree within 10% pedal travel may be used to define the torque target.

EV2.3.8 Each sensor must have a separate detachable connector that enables a check of these functions by unplugging it during Electrical Tech Inspection.

EV2.3.9 The torque encoder signals must be sent directly to a controller using an analogue signal or via a digital data transmission bus such as CAN or FlexRay. Any failure of the sensors or sensor wiring must be detectable by the controller and must be treated like an implausibility, see EV2.3.5. This implausibility must either be directly detected by the motor controller or transmitted to the motor controller such that power from the motor controller to the motor(s) is immediately and completely shut down.