Designing a Mechanical Emergency Brake System for a Fully Autonomous Vehicle

Department of Mechanical and Aerospace Engineering

University of California, San Diego

Instructor:

Professor Dr. Jerry Tustaniwskyj

TA:

Gaoweiang (Darren) Dong

Group 24:

Sebastian Lee

Angel Ramirez

Nicholas Vo

Alex Wang

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Abstract

The Emergency Brake System (EBS) project, driven by TritonAI's participation in the competition hosted by Autonomous Karting Series (AKS) , aims to develop an offline, remote, and replicable emergency braking system for autonomous go-karts, conforming to the 2023 competition guidelines. The objective was to ensure safety by rapidly halting the kart within 10 meters of emergency shut off of power to the kart, or locking the wheels in response to power outages, whether intentional or due to equipment failure. The system hinges on an electromechanical design involving a spring mechanism and an electromagnet. In normal operation, the electromagnet maintains spring tension, keeping the brake calipers disengaged via a lever arm and brake cable. Power loss deactivates the electromagnet, releasing the spring tension and activating the brakes. The brake system is designed to be lightweight, cost-efficient, and energy-efficient to minimize interference with kart performance and promote compatibility. The system underwent preliminary tests, with the system able to output 99N-m of braking torque. This braking system will enhance the safety of autonomous karts, allowing for safer testing and competition.

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Chapter 1: Project Description

Background of Project

Autonomous vehicles, equipped with sensors, algorithms, and computational prowess, are designed to navigate the complexities of road transport without human intervention. This technology has been shaped by an intricate blend of robotics, artificial intelligence, and machine learning, leading to vehicles that can perceive their environment, make decisions, and execute actions independently [1]. These include but are not limited to braking autonomously, changing lanes and accelerating. This sophisticated technology promises to reshape transportation by enhancing efficiency, reducing accidents, and freeing up time for commuters [1].

However, the progression toward autonomous driving is not without its challenges, particularly when considering high-speed applications such as autonomous kart racing. The heightened speed and maneuvering associated with kart racing intensifies the need for precise sensor data interpretation and rapid decision-making, demanding flawless performance from both software and hardware. In this context, safety becomes paramount, and the need for robust, fail-safe systems such as emergency brakes become evident. The design and implementation of such systems, in compliance with established AKS safety guidelines, is a crucial aspect of autonomous vehicle technology.

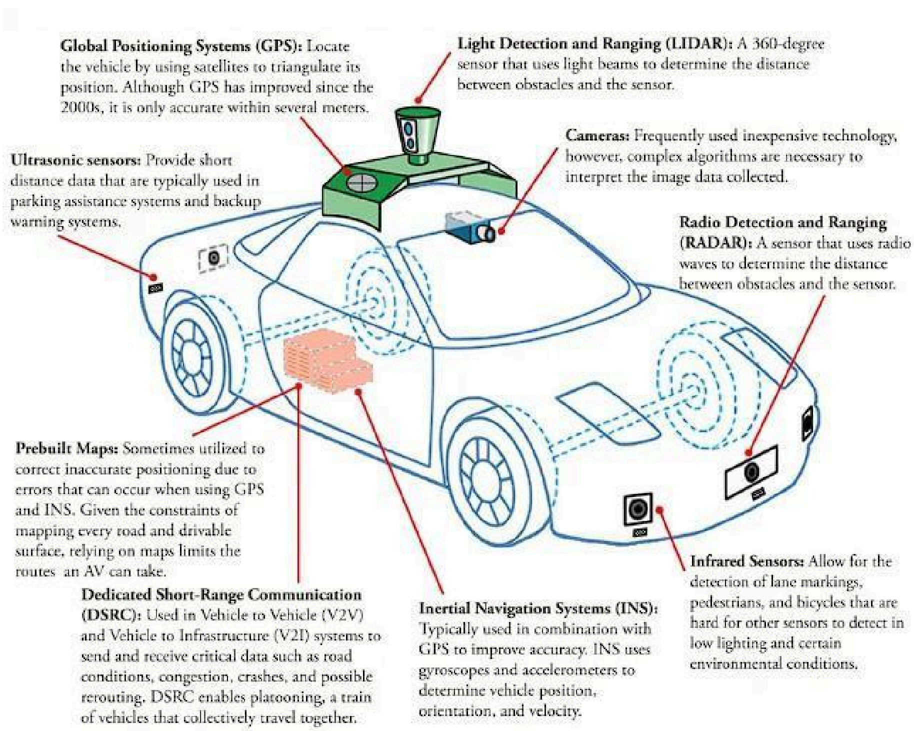


Fig 1: Breakdown of autonomous vehicle and major components [1]

Introduction to Braking Systems

Braking systems constitute a critical aspect of vehicle design, being the primary mechanism responsible for controlling speed and ensuring safe stops. Broadly, braking systems are categorized into mechanical, hydraulic, or electronic, each with unique characteristics and applications. Mechanical systems often involve cables and levers, while hydraulic systems use fluid pressure to transmit force from the brake pedal to the brake pads [2]. In recent years, electronic systems have gained prominence due to their integration capabilities with other vehicle systems and their adaptability to varying driving conditions.

The design of braking systems requires a holistic understanding of the vehicle's dynamics, including its weight, speed capabilities, and the specific use case it's designed for. A well-designed braking system provides consistent performance, requires minimal maintenance, and ensures the safety of the vehicle occupants and others on the road. In the context of autonomous vehicles, the design becomes even more complex as the system must perform reliably under the command of the vehicle's control algorithms, adding an additional layer of criticality to its performance.

Autonomous Racing and Safety Technologies

Autonomous racing provides a challenging and dynamic environment that propels the development of innovative safety technologies for autonomous vehicles. High-profile competitions like the EvGrandPrix and the Autonomous Karting Series serve as catalysts for accelerating advancements in this area. They not only push the boundaries of autonomous driving technology but also play a significant role in fostering education in autonomous systems [3].

These competitions expose autonomous vehicles to a range of complex situations, highlighting the importance of designing autonomous vehicles that can swiftly respond to unexpected incidents. Whether that be an unresponsive car, or getting dangerously close to another competitor, the safety of all participants must be ensured. However, the existing karts used in these series often come with a limited framework that may not fully support the integration of advanced safety technologies. The chassis consists of a go-kart chassis, and due to its size and shape, a sophisticated safety system is difficult. This brings attention to the significance of modular components, which can allow for greater flexibility and customization, thereby enhancing the kart's overall safety and performance while making use of the karts design and space.

Introduction to Electromagnetic and Friction-Based Braking Systems

The concept of braking in autonomous vehicles marries the traditional mechanisms of friction-based braking with cutting-edge technology like electromagnets. Conventional braking systems, such as brake calipers, are a proven technology that effectively slows down or stops vehicles by converting kinetic energy into heat via friction [4]. However, they are typically activated using systems connected to the vehicle itself – systems that may require complete vehicle functionality. In response to these challenges, the project incorporated an electromagnet in conjunction with a traditional brake caliper, crafting a unique braking system. Electromagnets, with their ability to generate a magnetic field when powered and lose it when power is cut off, serve as an ideal actuator for a fail-safe emergency braking system.

Impact and Importance of Emergency Brake Systems in Autonomous Vehicles

An emergency braking system is a fundamental component in this safety framework, designed to protect the vehicle and its surroundings from unforeseen incidents, including potential system malfunctions or power losses [5]. The crux of the system's significance lies in its automatic activation in case of power loss, rendering it a vital fail-safe mechanism. This automatic engagement is a requirement in the design of autonomous vehicles, ensuring that they can come to a safe and controlled stop, regardless of the circumstances. Moreover, the system's impact extends beyond immediate safety: it also contributes to public trust in autonomous technology by providing tangible evidence of built-in safety precautions.

Review of Existing Design Solutions

Emergency brake systems have evolved, continually integrating more advanced technological components to enhance their functionality, reliability, and responsiveness. However, within the context of autonomous kart racing, the requirements for these systems deviate from the standard, necessitating offline operation, remote activation, fail-safe mechanisms, and specific stopping power. Two noteworthy products currently in the market, Bosch's iBooster and WABCO's MAXX brakes, embody these advancements in braking technology. Yet, their application to autonomous karting may present unique challenges, warranting a closer examination.

Bosch iBooster

The Bosch iBooster is a brake system that utilizes an electric motor to boost braking power. It operates on principles similar to vacuum brake boosters and incorporates an integrated differential travel sensor to detect pedal actuation, sending this information to a control unit for processing [6].

A unique feature of the iBooster is its regenerative braking ability. It can adjust the supporting force in line with hydraulic conditions using software controls, which cover most common braking maneuvers. This system can build up pressure independently, offering benefits for automatic emergency braking systems and driver assistance systems. Moreover, in conjunction with Bosch's Electronic Stability Program (ESP®), the iBooster can provide the required braking system redundancy for automated vehicles [6].

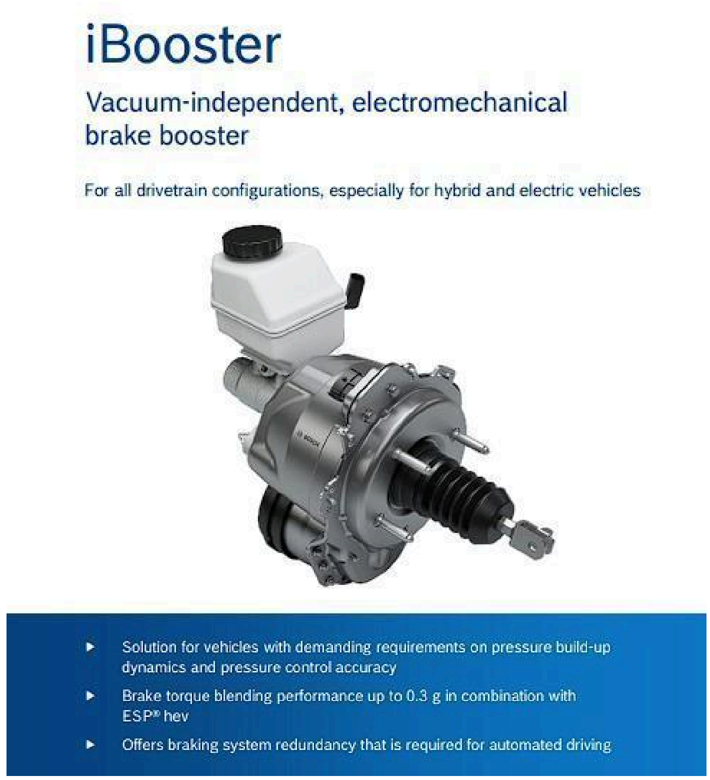


Fig 2: iBosch Booster Emergency Brake [6]

However, the iBooster has specific limitations that make it less applicable to the project's scope. It requires a constant online connection for operation and its dimensions, which are equivalent to an 20.32cm + 22.86-cm (8 + 9 -inch) vacuum brake booster, are larger than the project's specifications. Moreover, with a supporting force of up to 6.2 kN, it significantly surpasses the required stopping force of 1.5 kN. Therefore, while the iBooster exemplifies advanced braking technology, a more tailored solution is necessary for the kart's requirements.

WABCO MAXX Brake Series

The WABCO MAXXUS and MAXX22T are high-performance braking systems designed for heavy-duty vehicles and trailers, respectively. The MAXXUS is engineered for superior downhill performance, minimal fading or pulling, and increased durability. It features a reinforced monobloc caliper and a bi-directional adjuster mechanism for maintaining optimal running clearance under various conditions. The MAXX22T, on the other hand, is a lightweight, innovative air disc brake optimized for trailer applications. It boasts a payload-increasing design and supports trailer applications up to 10 tons axle-loaded. Like the MAXXUS, the MAXX22T also incorporates an adjuster mechanism.

Despite their advanced features and robust performance, both the MAXXUS and MAXX22T systems significantly surpass the required stopping force of 1500N for the kart application. Their braking torques stand at 23,000 Nm and 21,000 Nm respectively, and their disc dimensions of 430x45 mm are considerably larger than the kart rotor's 22cm diameter. The substantial size and power of these systems make them unsuitable for implementation in the autonomous kart project. Therefore, a braking solution tailored to the specific requirements of karting—a system that is compact, lightweight, yet efficient and reliable—is necessary.

Comparative Analysis

In examining the existing solutions, it became clear that neither the Bosch iBooster nor the WABCO MAXX brake series fulfill the unique requirements of the project, particularly in the context of autonomous kart racing. This in-depth comparison has highlighted the need for a bespoke solution.

The Bosch iBooster, although technologically advanced, requires continuous online connectivity for operation. This, coupled with its larger dimensions and excessive supporting force, significantly surpasses the project's specified needs. In essence, the iBooster's architecture is not conducive to an offline, autonomous kart application.

Similarly, the WABCO MAXX brake series, while high-performing and robust, are designed for heavy-duty vehicles and trailers. Their formidable size and braking torques far exceed the dimensions and stopping force required for the kart. Their superior performance in larger vehicles does not translate to efficiency in a smaller, lighter kart platform.

Given these limitations, it became evident that existing emergency brake systems were ill-suited for autonomous karting. The complex requirements for an offline, remote, fail-safe emergency brake system necessitated the development of a unique solution tailored specifically to these demands. This solution had to take into account the size, weight, and power constraints of a kart, yet maintain the efficiency and reliability inherent to its larger counterparts.

The kart relies on its existing rotor for the braking system. The brake system theoretically outputs 114Nm of braking torque on the brake rotor. Similarly, a normal force of 1490N newtons can act on the rotor.

Statement of Requirements

The Statement of Requirements includes a primary objective – the Emergency Brake – as well as two secondary objectives: the Brake Pressure Sensor and Steering Setup. As the Emergency Brake represents the primary objective of the project scope, this report primarily focuses on the principles, designs, and analyses related to the Emergency Brake.

Emergency Brake

The project mandated the creation of an emergency brake system for an autonomous go-kart with the following attributes:

- Capable of bringing the kart to a stop from a maximum speed of 8.94m/s (20 MPH) within 10 meters and within 5 seconds. Wheel lock is acceptable as an Anti-lock Braking System (ABS) will be incorporated in future iterations of the project.
- Ensure user safety by avoiding the use of levers or connectable parts that could be forgotten and pose a potential risk.
- The system should not inflict damage to the evGoKart structure even after multiple uses. Consideration of a damper system to absorb shock and prevent damage is recommended.
- The use of an actuator to automatically load the emergency brake mechanism is preferred for effective and consistent activation.

Brake Pressure Sensor

For the brake pressure control system, the following requirements have been established:

- The system should be designed to provide data enabling closed-loop control of brake fluid using the STM32 microcontroller (MCU) Analog Digital Converter (ADC). If required, prototype signal processing should be implemented if the signal is too large or small for the MCU ADC.
- Use a pressure sensor with either analog or digital output that can cover the entire range of pressure provided by the brake master cylinder during human braking.
- Provide a thorough characterization of brake forces at the disc brake caliper versus fluid pressure.
- Determine theoretical brake pressure required to stop the evGoKart from an ideal speed of 8.94m/s (20 MPH) within 10 meters and within 5 seconds.

Steering Setup

For the Bench Top Steering Mechanism, the requirements include:

- A frame should be created to mount the provided Toyota Corolla EPAS and enable software development.
- The assembly must look professional.
- The assembly must not have sharp edges that are hazardous to users.
- The EPAS torque sensor should be characterized, detailing output voltage vs. torque.

Deliverables

Upon completion of the project, the following will be delivered:

1. An Emergency Brake System capable of:
    - Bringing the kart to a halt from a max speed of 8.94m/s (20 MPH) within 10 meters and within 5 seconds.
    - Ensuring user safety and protecting the evGoKart structure from damage.
2. Brake Pressure System, comprising:
    - A brake pressure control system using the STM32 microcontroller (MCU) ADC.
    - A pressure sensor with the required range and type of output.
    - Detailed characterization of brake forces at the disc brake caliper vs. fluid pressure.
3. Bench Top Steering Mechanism including:
    - A frame for software development using Toyota Corolla EPAS.
    - Characterization of the EPAS torque sensor.
4. Comprehensive documentation, including:
    - Detailed report on test performance with data.
    - User and maintenance manual.
    - Technical manual with schematics, datasheets, CAD drawings, and component explanations.
    - Digital versions of all documents, CAD model files, electrical schematic files, and circuit board layout files on a CD or a cloud storage link.
    - Fully documented report

Chapter 2: Description of Final Design Solution

Functional Requirements

The Emergency Brake System for this autonomous go-kart project is mandated to provide fail-safe deceleration, capable of stopping the kart from a maximum speed of 8.94m/s (20 MPH) within a span of 10 meters. It is expected to ensure robust performance and user safety, employing an automated actuation mechanism without jeopardizing the structural integrity of the evGoKart through continuous use.

Design Solution

The final design of this project is an Emergency Brake System tailored for an autonomous kart. The system is composed of several key components: a steel lever, an electromagnet, a brake caliper with brake pads, a brake rotor, and a spring. These components, seen in figures 5 and 6, are strategically positioned and interconnected to form a reliable, fail-safe braking mechanism that operates offline and can be activated remotely. The flowchart pictured in figure 3 displays the general overview of how the system was intended to operate. What follows was an in depth description of the design made.

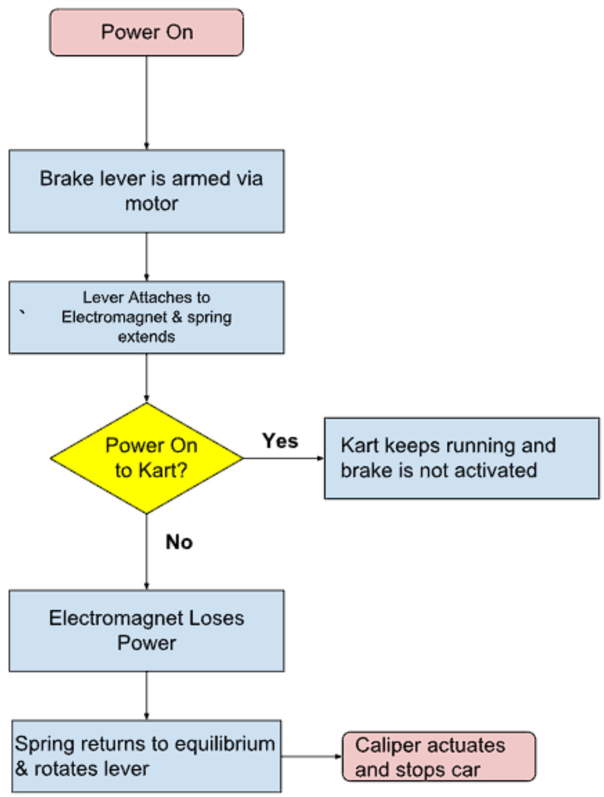
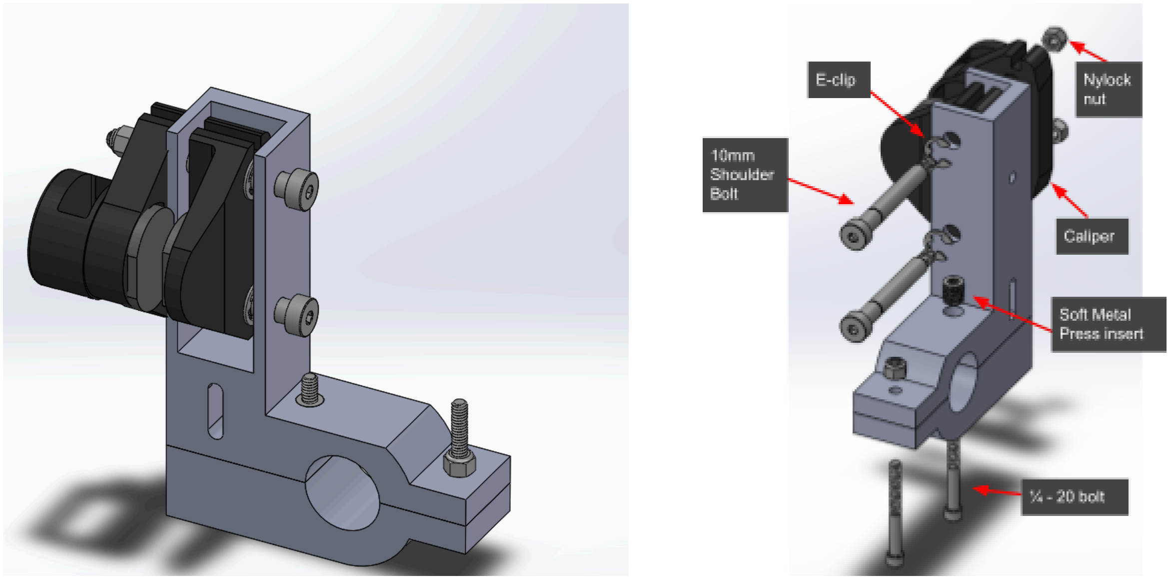


Fig 3: Flow Chart of Emergency Brake Steps

The steel lever, in figure 5a, positioned near the rear bumper, serves a pivotal role in engaging and disengaging the brake. At rest, the lever pulls on the brake caliper via a brake cable, causing the brake pads to clamp onto the brake rotor, thereby preventing the kart's movement. The electromagnet, mounted to the kart's frame, as seen in figure 4b, via a robust PLA-CF mount, attracts the steel lever when powered, consequently loosening the brake caliper and allowing free movement of the kart.

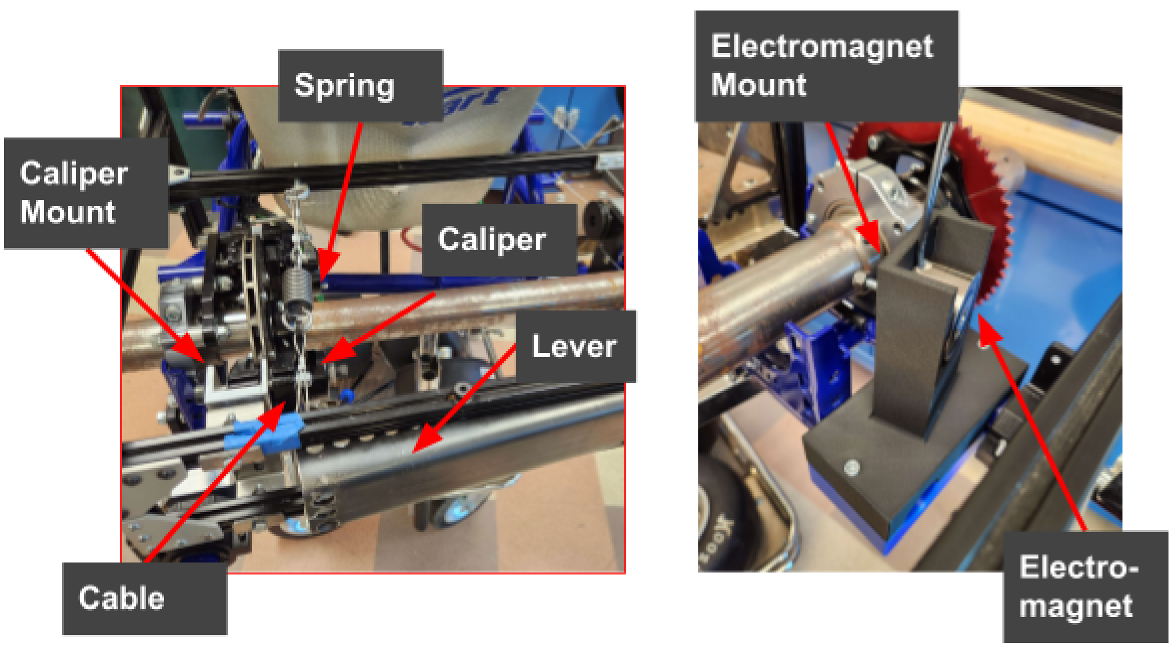
The brake caliper was mounted to the frame via an aluminum mount(fig 4a). This mount allowed the caliper to float and engage or disengage depending on the state of the system. The brake caliper houses the brake pads that interact with the brake rotor ro produce the necessary friction to halt the kart. The brake rotor, attached to the kart’s wheel axle, is an essential component of the braking mechanism, and its size and dimensions have been optimized for kart applications.



(a) (b)

Fig 4: Caliper mounted to CNC machines aluminum mount in (a) assembled and (b) exploded views

The spring, which connects to a hook attached to the frame and to the brake caliper via the brake cable, serves to return the system to its rest state, thereby engaging the brake when power to the electromagnet is cut. This design ensures that a fail-safe braking action takes place even in case of a power outage or system malfunction.



(a) (b)

Fig 5: Final Design with key components Annotated

The system's components were selected and designed with a keen eye on durability, operational reliability, and efficient performance. While the electromagnet's activation and deactivation manage the braking action, a shock absorber is incorporated to mitigate the impact of the spring's rapid return to its rest position.

The entire brake system, weighing no more than 11.3kg (25 pounds), contributes negligible weight to the kart and has minimal impact on its performance. Each component has been carefully selected and positioned to maintain the kart's balance and ensure its stability. The brake system is designed to operate under most non-extreme weather conditions and has been engineered to prevent unintended activation due to vibrations and impacts.

The design considers easy maintenance, with the most wear-prone components - the spring, brake cable, and brake pads - being easily replaceable and widely available. Although the service life of the system is expected to be long, regular inspections and timely replacements are recommended to ensure optimal performance and safety. The unique design of this Emergency Brake System truly meets the functional requirements of the autonomous kart, promising reliable performance and safety.

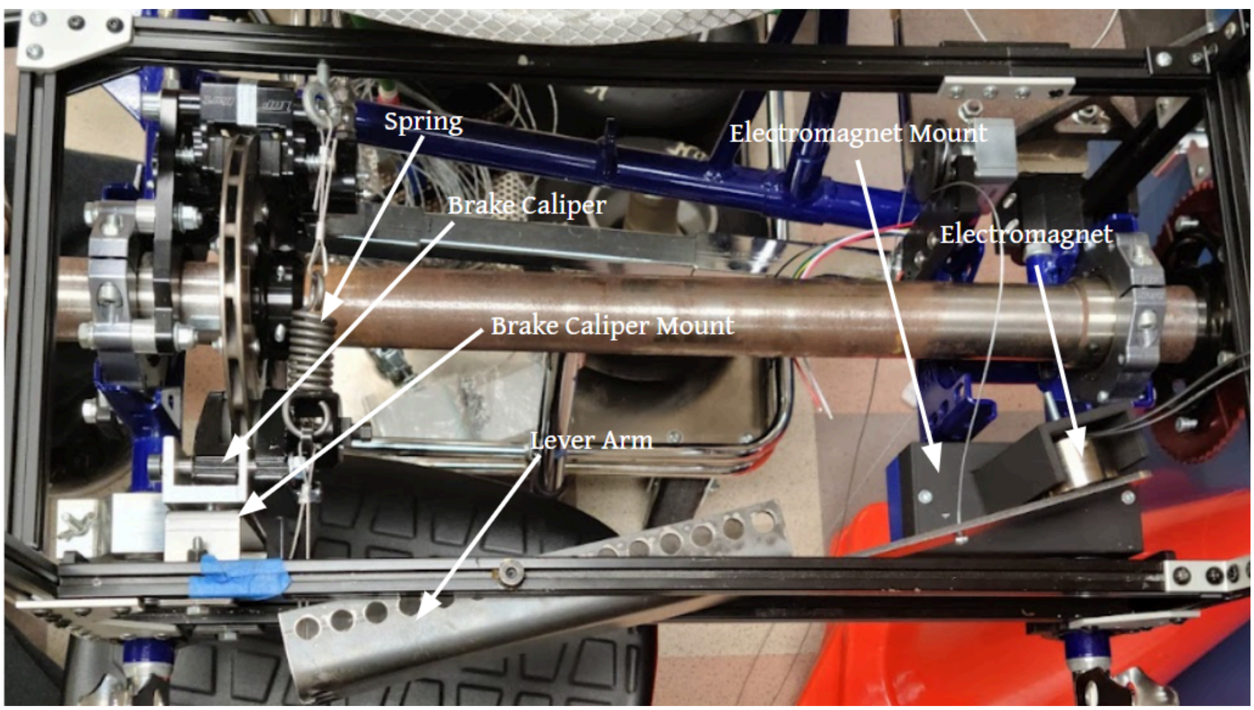


Fig 6: Top View of Final Design with Key Components Annotated

Chapter 3: Design of Key Components

3.1: Spring

Overview

The spring served a vital role in the emergency brake system of the evGoKart project. Once the power to the kart is turned off, the spring acts as a triggering mechanism, initiating the deployment of the emergency brake. This reaction forces the brake lever into a locked position, thus creating a rapid deceleration that enables the kart to stop within the specified limit. The spring must be able to withstand substantial forces to ensure consistent and reliable braking performance, particularly during high-speed operations.

Functional Requirements

The following are the functional requirements for the spring component:

- Should stretch at least 25.4 millimeters (1 inch).
- Total stretch length must not exceed 203.2 millimeters (8 inches).
- Must hold at least 300N of force.

Choice Justification

Table 1: Spring Comparison Table

Component Name	Max Load N (lbf)	Max Deflection mm (in)	Price ($)	Length mm (in)	Spring Rate N-m (lb-in)
OLIREXD 300lbs Porch Swing Springs	1334.47 (300)	Not Specified	9.99 (2 units)	107.95 (4.25)	N/A
SELEWARE 400 lbs Hammock Spring	1779.29 (400)	Not Specified	15.98	180.34 (7.1)	N/A
Century Spring Unit 672	1223.2 (275)	24.63 (0.97)	20.79	127 (5)	32.032 (283.505)
McMaster-Carr 3630N432	563.99 (126.79)	25.4 (1)	10.62	76 (2.992)	12.128 (107.340)
McMaster-Carr 3630N454	808.019 (181.65)	51.5 (2.028)	12.65	127 (5)	8.58 (75.946)

After comparing springs, the one that was chosen was the McMaster-Carr 3630N432 spring. This allowed for a compact and robust spring that provided the necessary amount of force that the caliper needed to apply onto the rotor.

3.2: Electromagnet

Overview

The electromagnet served a critical role in the operation of the emergency brake system. It exerts a holding force that keeps the spring-loaded lever in place under normal conditions. When power to the kart is shut off, the electromagnet disengages, allowing the brake system to activate. For this purpose, it is necessary for the electromagnet to hold at least 222N without overheating, ensuring safe and consistent operation.

Functional Requirements

The functional requirements for the electromagnet component are:

- Must exert a holding force of at least 222N to maintain the spring-loaded lever's position.
- Must maintain operation for at least 30 minutes. A full race lasts no longer than 30 minutes
- Must operate without overheating, ensuring consistent performance.

Choice Justification

Table 2: Electromagnet Comparison Table

Component Name	Duty Cycle (min)	Price ($)	Pulling Force N (lbf)	Power Requirements (W)
EM300-12-212	Continuous	95.81	1779.29 (400)	15
EM200-12-211	Continuous	53.21	622.751 (140)	7
Uxcell 12V DC 800N	7	25.49	800 (224.809)	7

The EM200-12-211 electromagnet, manufactured by APW Company, was selected despite its higher cost, primarily due to its significant pulling force and continuous duty cycle. This model's superior strength was initially deemed necessary, considering the demands of the early design iterations. However, with the optimization of the system over time, the requirement for such a high force had diminished. The electromagnet can now be operated at a lower voltage, which subsequently reduces the operational temperatures, maintaining them around room temperature (25 °C). Subsequent tests at full voltage (12V), alongside integration into the kart frame, have demonstrated enough heat-dissipation to maintain a temperature not exceeding 55 °C, thereby confirming that it will not overheat during operation. This adjustment enhances the overall safety and longevity of the system, validating the choice of the EM300-12-212 model.

3.3: Electromagnet Mount

Overview

The electromagnet mount is an integral part of the emergency brake system. This component secures the electromagnet to the kart frame, preventing it from dislodging or shifting during kart operation. Given the critical nature of this component, the mount needed to withstand forces exerted by the electromagnet, which are estimated at 222 N (50 lbf). To maintain a reliable safety margin, the mount should be designed to bear at least 300 N.

Functional Requirements

The functional requirements of the electromagnet mount are:

- Ability to withstand forces of at least 300 N to ensure safety and reliability.
- Stable construction to avoid interference with other components.
- The manufacturing process should be feasible, and the cost of the material should be justified by its strength and durability.
- Properly angled with respect to lever to minimize gap distance

Choice Justification

Table 3: Mount Material Comparison Table

Material	Manufacturing Difficulty	Price	Yield Strength (MPa)
6061-T6 Aluminum	Hard	High	275
PAHT-CF	Normal	Medium	70 (at 100% infill)
PLA	Easy	Low	25 (at 100% infill)

The material chosen for the electromagnet mount is PAHT-CF, a carbon fiber reinforced variant of PAHT (High Temperature Polyamide). Despite its lower yield strength compared to the 6061-T6 Aluminum, this material exhibits sufficient strength to meet the specified functional requirements. Its selection was further justified by its relatively easier manufacturing process and lower cost, making it accessible and an appropriate choice for the project. The choice of PAHT-CF will also provide more room for design flexibility and changes in later iterations, given its ease of manufacturing compared to aluminum. Though PLA also met component requirements, the selection of PAHT-CF was requested by the sponsor.

3.4: Caliper

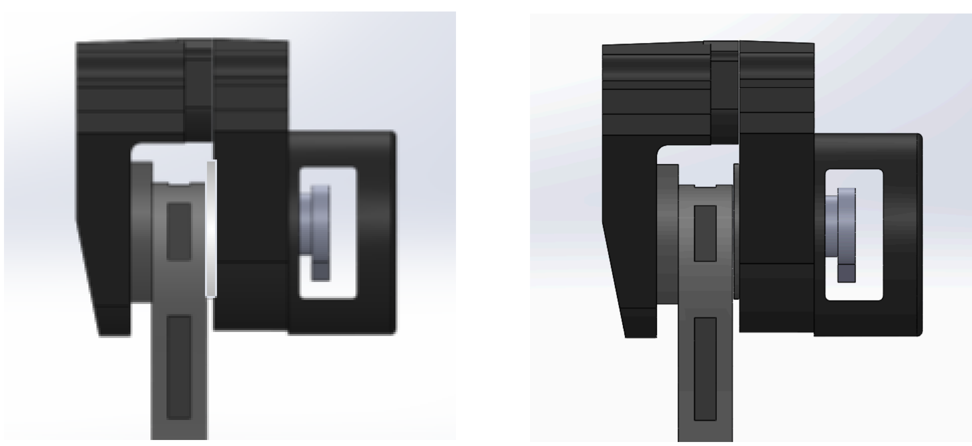
Overview

The caliper (Fig 7) is a fundamental component of the emergency braking system, consisting of a lever and an internal structure connected to a set of brake pads. Its primary function is to apply pressure on the rotor, thereby enabling the vehicle to decelerate or come to a halt. When the emergency brake system is actuated, either manually or through the automatic fail-safe, the caliper clamps onto the rotor. This action results in the generation of friction, causing the vehicle to slow down or stop. For effective operation, the caliper must consistently generate the required friction and be resilient enough to withstand the thermal stresses involved in the process.

Functional Requirements

The caliper needed to:

- Apply adequate pressure on the rotor to generate the necessary friction to halt the vehicle within 10 meters.
- Withstand the heat generated during braking without losing structural integrity or functionality.
- Be able to disengage swiftly from the rotor when the braking system is deactivated, allowing the vehicle to resume motion without undue resistance.
- Maintain a robust and reliable operation over an extended period, necessitating minimal maintenance and replacement.



(a) (b)

Fig 7: Rotor free (a), caliper engaged and pressure on rotor (b)

Choice Justification

Because the emergency brake was designed to be mechanical, a way to actuate the brake pads mechanically was needed. This caliper has a lever that ramps the brake pads towards the rotor unlike how a piston would in a traditional hydraulic caliper. This was also readily available online, e.g. Amazon, and was easy to purchase and get shipped.

3.5: Caliper Mount

Overview

The caliper mount's (Fig 8) role in the emergency braking system is pivotal. This component is designed to securely hold the caliper, ensuring its correct alignment with respect to the rotor. This positioning is vital for the braking system's functioning, as it facilitates a smooth application of pressure on the rotor during braking. Moreover, the caliper mount must be sturdy and resilient enough to withstand the physical stresses associated with the caliper's operation, including the forces exerted during the brake's engagement and disengagement.

Functional Requirements

The caliper mount must:

- Offer a firm and stable support for the caliper, ensuring it remains in its proper place throughout the braking operation.
- Withstand the forces exerted during the braking process without deformation or failure, maintaining the integrity of the system.
- Be designed and positioned such that it enables easy installation and removal of the caliper when necessary, facilitating maintenance tasks.
- Not interfere with the rotor's movement or the overall operation of the braking system.

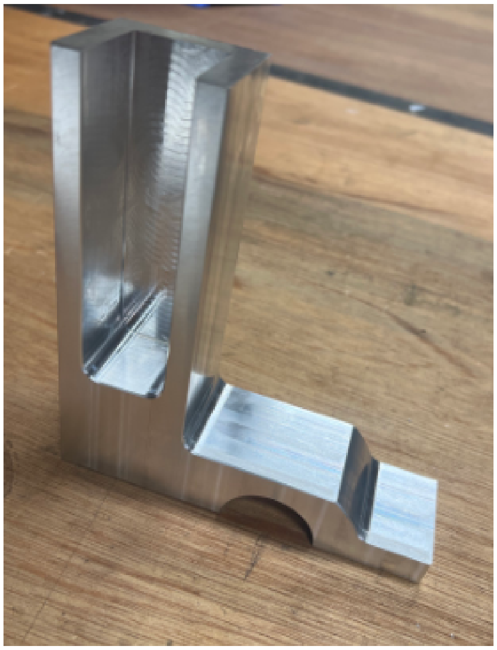


Fig 8: Bracket Caliper Mount Machined From Aluminum

Choice Justification

Finite Element (FE) Analysis (Appendix D) indicated that the caliper mount would endure 35 MPa of stress upon activation of the emergency brake. Given that PLA-CF's rated yield strength is a comparable 36 MPa, there is a risk of failure if this material is used. Hence, the team chose to machine this component from aluminum. This material was not only readily accessible for the project but also presented easier machinability relative to other metal options. The design for the mount was initially created in Solidworks and subsequently transformed into a drawing for verification by a machine shop specialist prior to manufacturing.

3.6: Lever

Overview

The lever (Fig 9) is a crucial element of the emergency braking system, facilitating the translation of applied forces into the mechanical motion necessary to engage the braking mechanism. Fabricated from a sheet of 3/8 inch steel, the lever serves as the intermediary between the motor, spring, and electromagnet components. It spans approximately 4 feet, extending from the left side to the right side of the kart, and is designed for maximum mechanical advantage to ensure efficient operation of the system.

Functional Requirements

- Able to endure the stresses imposed by the emergency brake system without mechanical failure
- Must maintain consistent operation despite fluctuations in external forces or environmental conditions
- The holes for cable attachment and pivot location adjustment must be precisely formed and located to ensure effective interaction with the spring and electromagnet components
- The flat end of the lever must allow secure and reliable connection to the electromagnet

Choice Justification

The lever was laser-cut from a sheet of 3/8 inch steel due to its excellent durability and rigidity, which are crucial for withstanding the forces inherent in the braking system. The size and shape of the lever were determined to maximize mechanical advantage and thereby optimize the performance of the braking system. The selection of steel and the specific design elements, such as the placement of holes for cabling and pivot adjustments, contribute to the robust and adjustable functionality of the system. Cutting such a thick material can be challenging without a plasma cutter, but the results justify the effort, providing a lever that offers superior performance and adaptability.

Fabrication Techniques

A laser-cutting process was used to create the lever, yielding precision and accuracy in the shaping of the steel sheet. This approach was chosen for its ability to handle the rigidity of the 3/8 inch steel and for the precise holes it could produce for cabling and adjustments. The process began by cutting the main shape and punching holes for the cable and pivot location. A smaller piece was then bent into a c-channel, adding to the overall stability and versatility of the lever design.

Fig 9: Fully Bent Lever Arm Laser Cut Out of Steel

3.7: Motor

Overview

As an integral part of the emergency brake system, the motor functions as the actuating mechanism. Specifically, it is mounted in line with the flat end of the steel lever and possesses a spindle that enables it to effectively control a cable attached to the lever. This careful positioning and functional setup allow the motor to activate or deactivate the emergency brake system through a controlled pulling action on the cable. The motor's capability to consistently and reliably perform this action is crucial to the overall efficacy and safety of the system. Consequently, the selection, installation, and operational parameters of the motor have to be meticulously considered in the context of the entire emergency braking setup.

Functional Requirements

The motor needs to:

- Generate sufficient torque to pull the cable linked to the steel lever effectively.
- Ensure a consistent and reliable operational cycle for the activation and deactivation of the emergency braking system.
- Withstand the physical demands of its operational cycles without succumbing to premature wear or failure.
- Allow for a straightforward integration process with the frame and the steel lever to maintain the structural integrity of the system.

Fig 10: Worm Gear Motor Used For Final Design

Choice Justification

A high voltage worm gear motor was selected as the choice for the motor in this project. This choice was based on two key considerations: power and the need for bidirectional movement.

The high voltage motor was preferred due to its ability to provide greater power output, crucial for effectively initiating the emergency braking mechanism. In addition, the need for backward and forward movement of the brake necessitated the use of a worm gear motor. This design allows the motor to be self-locking when the gear is stationary, ensuring that the brake remains engaged when not powered, and also facilitates reversible movement, enabling the brake to be disengaged when required. This combination of power and functionality made this motor an ideal choice for the project's requirements.

Chapter 4: Prototype Performance

Theoretical Predictions

- It was predicted that at 8.941 m/s (20 MPH), 11.64 kg-m (84.18 lbs-ft) was needed to stop the kart within 10 m.
- Electromagnet had a maximum temperature of 60℃
- Brake pressure sensor had a maximum reading of 3.3V at any force
- PLA-CF strength at 100% infill and rectilinear layering pattern matched the spec sheet of 36 MPa.

Test Conditions

Emergency Brake:

The team affixed a 0.5578 m (1.83 ft) aluminum bar to the kart's axle end, and a force gauge was subsequently linked to the end bar to measure the torque exerted onto the axle. The kart was immobilized during the test, and the cage accommodating the emergency brake was secured in place to mitigate any potential movement. The torque measured correlated to the torque being applied by the caliper when the emergency brake was active.

Electromagnet Testing:

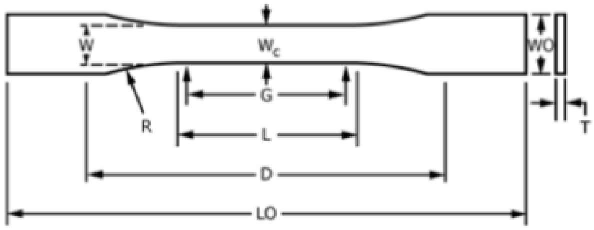
Two distinct tests were administered: one in an open-air setting, and another with the electromagnet installed in its dedicated mount. In both scenarios, the electromagnet was powered with a 12V supply and sustained a continuous cycle for an hour. The temperature reading at the hour's conclusion was obtained using a thermometer gun. The tests utilized exterior magnet temperature to maintain consistency with the APW Company Spec Sheet (Appendix B-A).

Brake Pressure Sensor Testing:

For assessing the brake pressure sensor, a pressure sensor transducer was used to capture the actual reading from the brake pressure. The force gauge was attached to the application point to ascertain the amount of force exerted during the test. Forces were tested in increasing increments up to 300N, beginning at 0N.

PLA-CF Testing:

Dogbones crafted from PLA-CF with varying infills (50%, 75%, 100%) and dimensions as depicted in Fig 11 were created using a 3D printer and subsequently subjected to tensile testing using an Instron machine. This test produced a force versus displacement graph which, in conjunction with the known dogbone specifications, was utilized to determine the maximum stress the material could withstand.



	mm (in.)
W—Width of narrow section[E,F]	13 (0.50)
L—Length of narrow section	57 (2.25)
WO—Width overall, min[G]	19 (0.75)
WO—Width overall, min[G]	...
LO—Length overall, min[H]	165 (6.5)
G—Gage length[I]	50 (2.00)
G—Gage length[I]	...
D—Distance between grips	115 (4.5)
R—Radius of fillet	76 (3.00)

Dogbone tensile test specimen for plastics. Thickness $T = 3.2 \pm 0.4$ mm.

Fig 11: Dogbone used for testing

Results

Emergency Brake:

The emergency brake system accommodated up to 18.437 kg (40 lbs) using a 0.5578 m (1.83 ft) bar, corresponding to a torque of 10.12 kg-m (73.2 lbs-ft).

Electromagnet Testing:

The electromagnet's temperature peaked at 58.9℃ after an hour of operation, surpassing 60℃ only after an hour and a half when tested in an open-air environment. Within its mount, the electromagnet's temperature reached a maximum of 51℃.

Brake Pressure Sensor:

A linear correlation was observed between the voltage reading and the applied force, registering over 3.3V when a force of approximately 300N was applied. The specific relationship between voltage and force is illustrated in Fig 12.

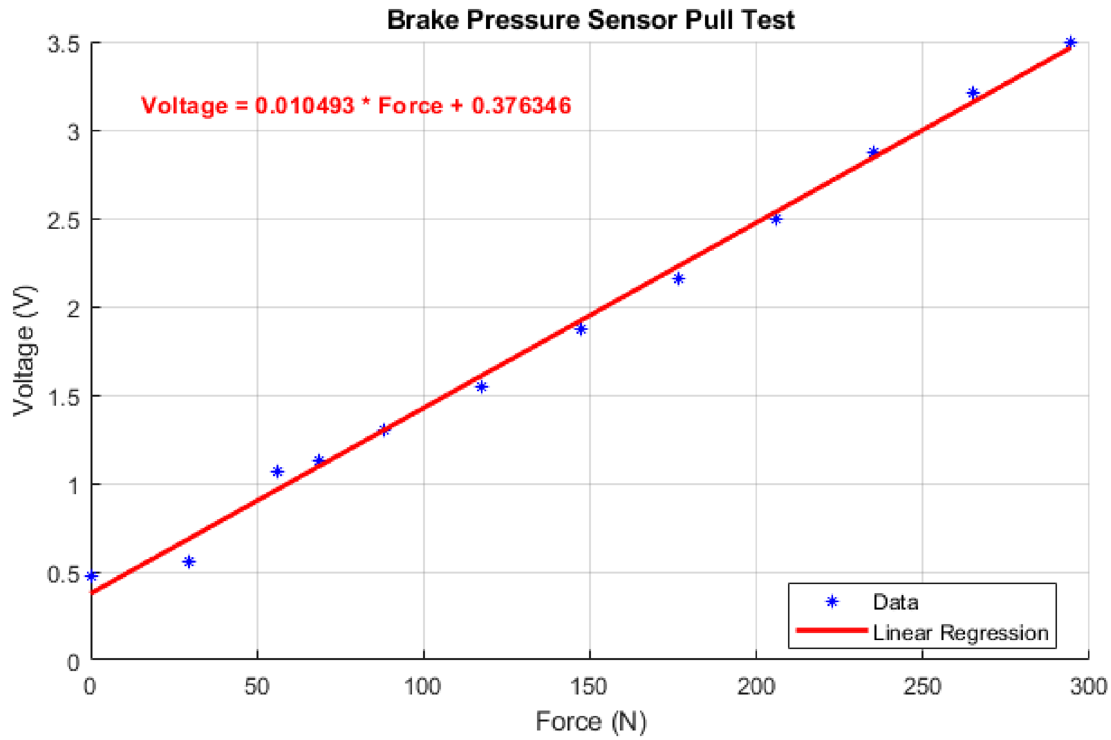
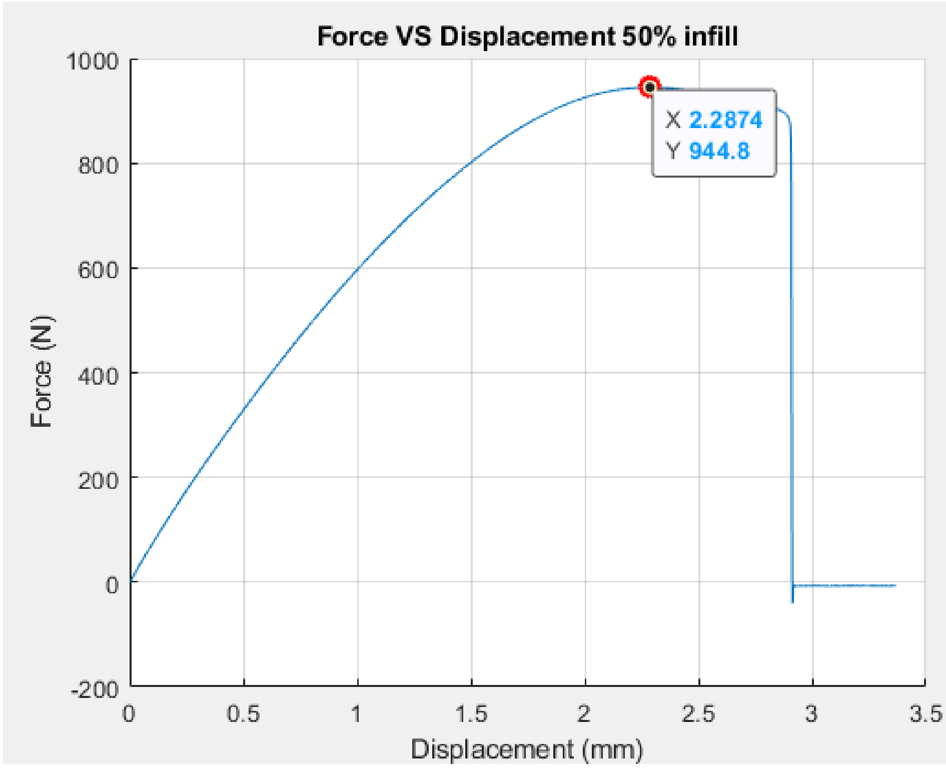


Fig 12: Graph characterizing Voltage and Force

<u>PLA-CF Testing:</u>

Fig 13 presents the Force vs Displacement graphs derived from the Instron testing at various infill percentages. With a 100% infill and rectilinear pattern layering, the maximum stress was determined to be 38.7 MPa. Conversely, at a 50% infill using the same layering pattern, the maximum stress dropped to 22.7 MPa.



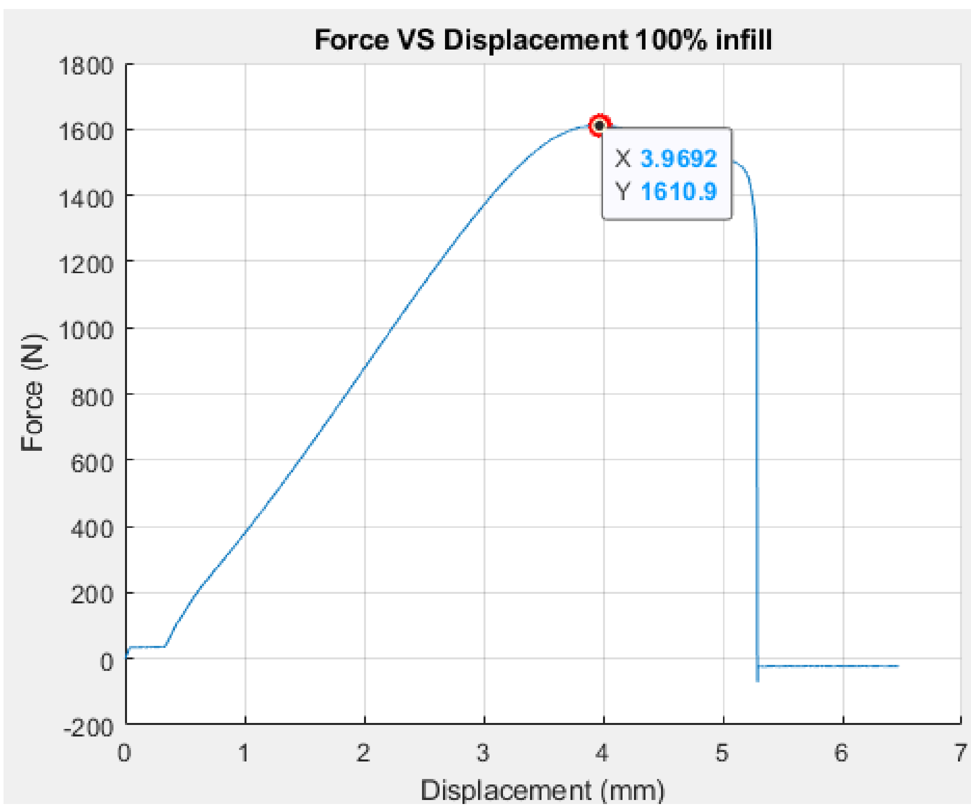


Fig 13: Force V Displacement graphs of 50% infill PLA-CF (top) and 100% infill PLA-CF (bottom) showing maximum stress

Results Evaluation

Emergency Brake:

The end result showed that the current iteration could not stop the kart within 10 m if it was traveling at 8.94 m/s (20 MPH), but can at speeds lower than 17 MPH. Though the 10.12 kg-m (73.2 lbs-ft) reading fell short of the ideal 11.64 kg-m (84.18 lbs-ft) value, it nevertheless demonstrates that the system met AKS guidelines of being able to stop within 10m if traveling at 17mph.

Electromagnet:

While in a vacuum the electromagnet went to a higher temperature than what was expected, any form of heat dissipation allowed it to go under its maximum temperature of 60℃. Note that the electromagnet was not connected to the lever arm during this test, meaning the magnet could potentially be at an even lower temperature while the emergency brake is actuated.

Brake Pressure Sensor:

The brake pressure sensor could only read up to 3.3V, so it was recommended for the future to either not exceed 300 N of force pushing on the brake to prevent the sensor from frying, or to add some low-pass filter so that the brake pressure sensor never goes above 3.3V.

PLA-CF:

The Instron testing showed that at 100% infill, the PLA-CF material had a slightly higher yield strength than what was expected from the manufacturer, meaning that PLA-CF was a suitable material to 3D print for the electromagnet mount, which only needed 5 MPa [Appendix D]. 50% infill showed that while lower infill did reduce the yielding strength, it only reduced it by 58.66% despite the infill being halved. Still, the yield strength of 22.7 MPa exceeds that required of the electromagnet mount, so using less infill is acceptable for lower printing time and material.

Chapter 5: Design Recommendations and Conclusions

Design Recommendations

Spring Selection

The spring used in the design provides adequate force, but the selection process could be refined for future designs, particularly for karts with different builds than the one used in this project. The process should:

- Consider springs that are better suited for given kart frames. Some factors to note include:
  - Kart weight and stopping force required (to determine strength of spring)
  - Kart dimensions (to determine maximum spring length)
- Install a safety guard around the spring in case of failure.

Lever Design

The design of the lever, while functional, could be improved. In particular, the lever used for this project was constructed out of heavy 3/8-inch steel. Recommendations for this component include:

- Evaluate different materials that might offer a better strength-to-weight ratio. Recommended material: 1/8-inch steel.
  - less expensive
  - lighter
- Determine the hole placement on the lever to allow for more adjustability and precise control of force distribution.

Motor Selection

The motor selected for the EBS was suitable, but other options might provide better performance or efficiency. Future design considerations should:

- Include a broader range of motors in the selection process, such as lighter units that are more cost-efficient.
- Consider motors in the context of lever material, which can be specific to each kart project.

Safety Considerations

The Emergency Brake System employs a spring-loaded lever which is rapidly retracted when the system is activated. This violent action can exert substantial force on the kart frame and components. Thus, several safety considerations are taken into account:

- **Force Management:** The forces exerted by the lever and spring should be distributed as evenly as possible across the kart frame to avoid structural damage. Also consider the use of shock absorbers. Regular inspections should be performed to ensure no undue stress or strain is being placed on the frame. Shock absorber may cause a delay in the response of the emergency brake.
- **Mounting Safety:** The mounting systems for the lever and electromagnet need to be robust to withstand the sudden release of energy when the brake is activated. The mounts should be checked after every race for any signs of fatigue or loosening.

- **Spring Safety:** The spring should be checked after every race to ensure that it remains tightly secured to the frame. A safety cage or guard may be installed around the spring to prevent any damage to kart infrastructure should the spring fail.
- **Brake Activation:** The braking action should be smooth yet swift to minimize any potential jerking of the kart that could destabilize it. It's crucial to ensure that the braking action does not cause the kart to tip over or skid uncontrollably.

Impact on Society

Education

The EBS project is designed to be open-source, allowing it to be replicated and adapted by other kart teams or individuals interested in kart racing or vehicular safety mechanisms. This freely accessible design encourages learning, fosters understanding of key mechanical principles, and stimulates innovation in vehicle safety. The project offers real-world application and comprehension of engineering principles including force distribution, electromagnetism, and mechanical design. This promotes hands-on experience and an understanding of these concepts that goes beyond textbook learning, and does so in a relatively fun and engaging manner.

Safety and Innovation

By focusing on safety, the EBS project contributes to the ongoing discussion and awareness of vehicle safety, potentially influencing safer designs in karting and other small, motorized vehicles. This endeavor focuses on reducing risk of injury and promoting safer recreational and professional karting practices. Moreover, innovative approaches to braking systems like the EBS could inspire further research and development in similar fields, leading to more advanced, efficient, and safer braking technologies.

Professional Responsibilities

Safety

One of the primary professional responsibilities associated with the Emergency Brake System (EBS) project was ensuring the safety of all team members and potential users. This was done by adhering to a rigorous testing protocol that included wearing safety glasses and other personal protective equipment, and standing at a safe distance during live tests. Additionally, safety was incorporated into the design itself. A high factor of safety was used in all calculations to guarantee the reliability of the system under various circumstances. The components used in the EBS, like the spring and the electromagnet, were carefully chosen to ensure they can safely withstand the forces they will be subjected to during operation.

Financial Responsibilities

Financial responsibility was a crucial aspect of this project. The team was entrusted with managing the project budget effectively and efficiently. All expenditures were carefully tracked and updated in financial documents to ensure transparency and maintain control over the project costs. The team also consistently communicated with the project sponsor to keep them updated on the progress and financial status of the project. This ongoing dialogue ensured that the project stayed within budget while fulfilling all its objectives.

Project Management

Project management was a vital professional responsibility in the execution of the Emergency Brake System (EBS) project. Effective management helped keep the team on track, ensuring all tasks were completed within the planned timeline. The team implemented a structured schedule for weekly meetings and demonstrations, allowing for consistent updates and progress checks. These scheduled gatherings with the sponsor fostered an environment of open communication and enabled the team to address any challenges promptly.

To balance the workload and make optimal use of the team's diverse skills, tasks were distributed evenly among team members. Each member was assigned responsibilities that aligned with their strengths and areas of expertise. This strategic distribution of tasks helped ensure each aspect of the project received the attention it required. Through the use of a Shared Google Drive, the team maintained a constant overview of project progress, regularly checking against planned milestones. This vigilant tracking allowed the team to promptly identify any deviations from the plan and make necessary adjustments, resulting in seamless execution of project tasks.

Lessons Learned

The Emergency Brake System (EBS) project offered many insightful lessons and posed unforeseen challenges that the team had to navigate throughout the project timeline.

One key learning point was that the process of design, testing, and implementation often took significantly longer than anticipated. Whether it was designing the individual components, machining certain parts, or assembling the overall structure, each step presented its own set of complexities. For instance, some parts did not function as expected in the initial testing phase, necessitating revisions and additional testing. For example, the caliper mount was initially placed in a fixed position, until the team realized it was a floating design. Similarly, designs that were theoretically sound and backed by simulations sometimes did not perform as intended in a real-world setting. These experiences underscored the importance of building in additional time for unforeseen issues, as well as the value of iterative design and testing processes.

The team also faced a steep learning curve in understanding new concepts, tools, and techniques. For instance, no team member had previous experience with certain components or software tools used in the project, such as the STM32 Microcontroller. This necessitated self-guided learning, often taking additional time and effort. However, this challenge also facilitated a richer understanding of the project and contributed to the team members' professional growth.

In terms of general project management, the project highlighted the significance of collaboration in tackling complex tasks. Coordinating meetings, dividing tasks, and ensuring seamless integration of different parts of the project were challenging but necessary for the project's success. Each member's unique contribution was essential in shaping the final design. Despite the difficulties, the collaborative experience enhanced creativity, problem-solving abilities, and fostered a supportive environment.

Conclusions

The Emergency Brake System (EBS) is a functional, adaptable, and efficient solution that significantly enhances safety in karting. Each component, from the robust spring to the efficient electromagnet and responsive motor, has been thoroughly tested and designed for durability and performance.

Its automatic activation feature minimizes manual intervention, making the system user-friendly. Furthermore, the system's adaptability to various kart models is a testament to its versatility. This versatility, coupled with the system's open-source design, offers a valuable educational resource for other karting teams.

In essence, the EBS is more than a capstone project; it is a leap forward in karting safety. By striking a balance between functionality, durability, and adaptability, it proves itself an essential safety upgrade for kart racing enthusiasts and teams alike.

References

[1] Center for Sustainable Systems, University of Michigan. 2021. "Autonomous Vehicles Factsheet." Pub. No. CSS16-18. https://css.umich.edu/publications/factsheets/mobility/autonomous-vehicles-factsheet

[2] https://www.autodata-training.com/au/2021/07/13/automotive-engineering-fundamentals-the-advantages-of-hydraulic-brake-systems/#:~:text=Hydraulic%20disk%20brakes%20also%20provide,in%20wet%20and%20muddy%20conditions.

[3] https://engineering.purdue.edu/evGrandPrix/

[4] https://www.goodyearautoservice.com/en-US/learn/calipers

[5] Salvatore Curto, Alessandro Severino, Salvatore Trubia, Fabio Arena, Lucio Puleo; The effects of autonomous vehicles on safety. *AIP Conference Proceedings* 30 March 2021; 2343 (1): 110013. https://doi.org/10.1063/5.0047883

[6] https://www.bosch-mobility.com/en/solutions/driving-safety/ibooster/

Appendix A: Bill of Materials

Table A.1: Bill of Materials

Bill of Materials					
Part Name	Purchase Link / item number	Quantity	Unit Cost	Cost	Week
APW Company EM200-12-211 Round Electromagnet Unit 6473	https://apwcompany.com/em200-12-211/?cgkit_search_word=em200	1	$53.21	$53.21	1
Century Spring Corp Extension Spring Unit 672	https://www.mwcomponents.com/shop/672cs?microsite=century-spring	2	$20.79	$41.58	1
Wilwood 120-2281 Mechanical Spot Brake Caliper	https://www.amazon.com/Wilwood-120-2281-Piston-Mechanical-Caliper/dp/B002G37IRM	1	$163.53	$163.53	1
HR Steel ASTM-A36 Steel Angle 10' x 2" x 2" x 1/8"	https://www.industrialmetalsupply.com/hr-steel-astm-a36-steel-angle/sa2001210	1	$29.27	$29.27	1
Sleeve Bearing	https://www.mcmaster.com/2938T6/	4	$0.91	$3.64	3
Shoulder Screw	https://www.mcmaster.com/91259A434/	2	$13.24	$26.48	3
Nylon Insert Locknut	https://www.mcmaster.com/90630A115/	1 Pack	$4.11	$4.11	3
Press Fit Insert	https://www.mcmaster.com/products/inserts/thread-size~1-4-20/threaded-insert-type~press-fit/for-use-in~metal/	1 Pack	$22.74	$22.74	3
Socket Head Screw	https://www.mcmaster.com/90128A254/	1 Pack	$5.97	$5.97	3
Brake Cable	https://a.co/d/4Ws0bWS	1	$6.99	$6.99	4
McMaster Eyelets	https://www.mcmaster.com/orders/	1	$17.15	$17.15	5
Worm Gear DC Motor	Amazon Link	1	$26.87	$26.87	5
Routing Eyebolt with Nut	9489T48	1 Pack of 10	$2.86	$2.86	5
Galvanized Steel Eyebolt with Nut	3016T14	2 Each	$4.90	$9.80	5
High-Strength Steel Nylon-Insert Locknut	90630A110	1 Pack of 25	$4.49	$4.49	5
Extended-Length Drill Bit	https://www.mcmaster.com/orders/	1	$19.21	$19.21	6

High-Strength Multipurpose Neoprene Sheet	https://www.mcmaster.com/orders/	1	$16.56	$16.56	6
Alloy Steel Shoulder Screws	92981A307	4 Each	$4.46	$17.84	7
External Retaining Ring	98541A118	1 Pack	$8.61	$8.61	7
High-Strength Steel Nylon-Insert Locknut	97260A102	1 Pack	$8.57	$8.57	7
Alloy Steel Shoulder Screws	92981A309	2 Each	$4.83	$9.66	9
Neoprene Roller	60885K71	2 Each	$19.22	$38.44	9
Side-Mount External Retaining Rings	98543A117	1 Pack of 100	$13.80	$13.80	9
Alloy Steel Low-Profile Socket Head Screws	90665A158	1 Pack	$9.15	$9.15	10
Self-Adjusting Shock Absorber	3740K12	1 Each	$61.35	$61.35	10
Flange Mounting Block for Shock Absorber	6600K62	1 Each	$30.32	$30.32	10
Steel Hex Mounting Nut for Shock Absorber	6600K75	2 Each	$3.62	$7.24	10
Wire Rope Compression Sleeve	3755T13	1 Pack	$11.53	$11.53	10
			Total Cost	$670.97	

Appendix B: Individual Component Analyses

B.1: Emergency Brakes Activation Switch

Overview

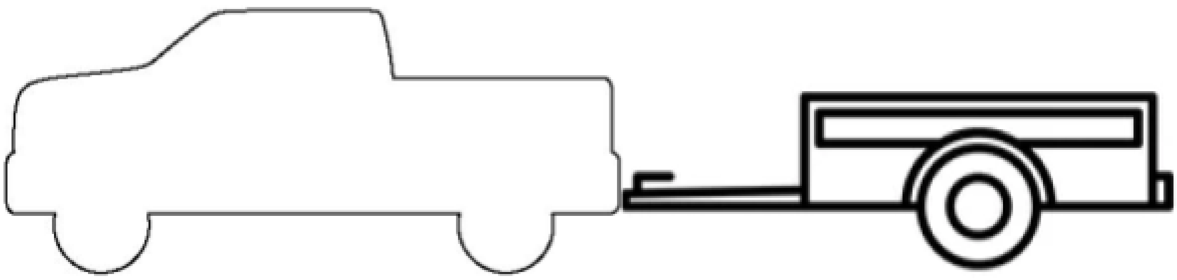
The current autonomous go kart by Triton AI is capable of navigating a course without a driver in the cockpit. Finding a way to introduce a rider is a goal for the club. Many considerations for the drivers safety have to be made before this can happen however. This being an interface where the driver can take control of the car and then let the car take back control. Implementation of a steering wheel and brake systems are goals for this project, but finding a suitable braking system for emergencies is the main part for this quarter of 156A. If something were to go awry, the user must be able to shut off power to the whole car, and in turn activate an emergency brake to stop the car and prevent any more accidents. Finding a way to activate this mechanical brake is only one component of the whole braking system.

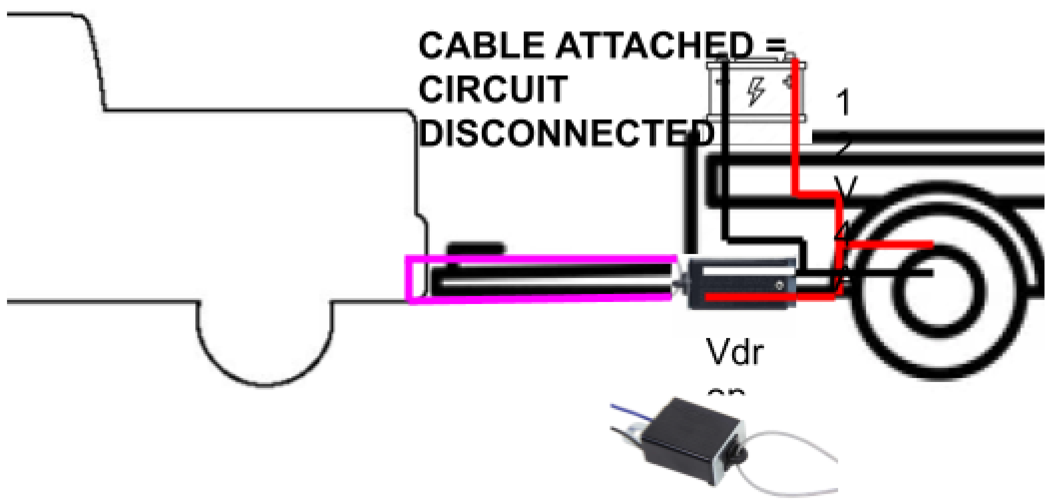
Description of Component

The trailer emergency brake is a brake mechanism that is equipped on utility trailers that activate upon emergency situations.The biggest emergency situation would be when the trailer detaches from the hauling vehicle. A break-away cable running from the vehicle is attached to the break-away sensor on the trailer. When the trailer detaches and starts separating from the trailer, the cable experiences a tension force, and at a high enough tension, the cable breaks away from the sensor and activates the brakes.

Figure B.1.1: Example of trailer emergency brake

This is achieved by closing and fully activating the brakes circuit. An electromagnet in the drum brake of the trailer becomes powered and initiated. Usually there is a control in the vehicle that controls the electronic brakes, but in an event where the breakaway cable detaches, it fully activates the brakes and stops the trailer. Because of this, the trailer usually comes equipped with its own battery.





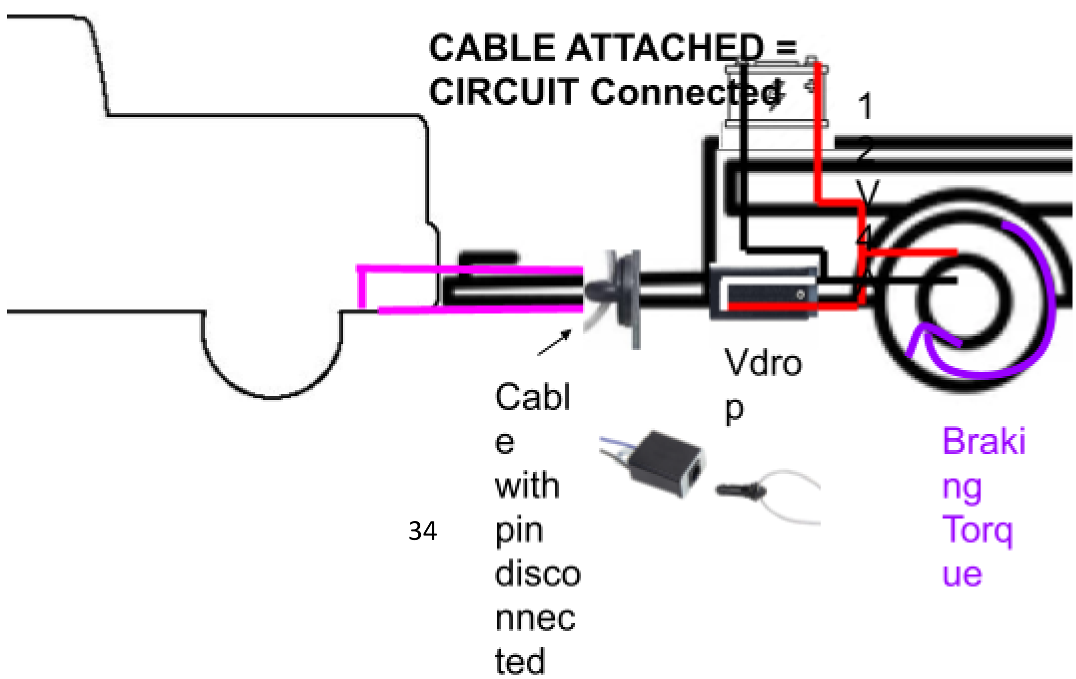
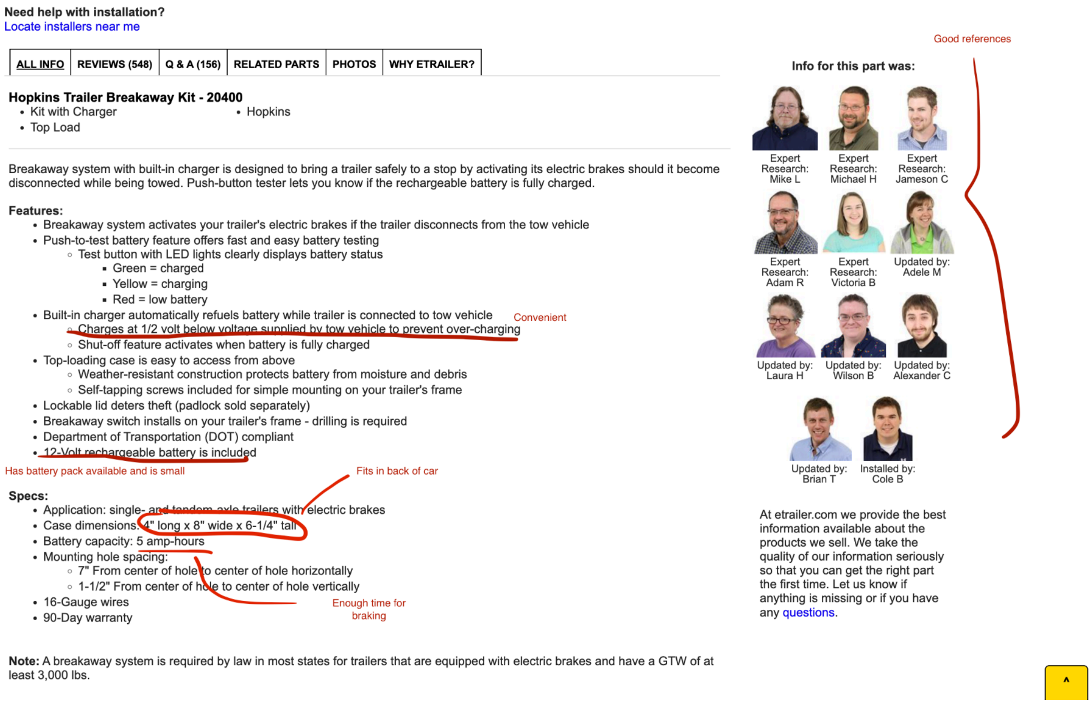


Figure B.1.2: Attachment of emergency brake onto trailer

Fundamental Requirements

- Needs to power 10watt electromagnet for at least 1 minute
- Needs to be small enough to put on go kart
- If not a cable, Some type of relay to activate the switch

Figure B.1.3: [This is a sensor with battery included] from NAPA Auto Parts
Requires a 12V minimum 4amp battery



Need help with installation?
Locate installers near me

ALL INFO | REVIEWS (548) | Q & A (156) | RELATED PARTS | PHOTOS | WHY ETRAILER?

Hopkins Trailer Breakaway Kit - 20400
- Kit with Charger
- Top Load
- Hopkins

Breakaway system with built-in charger is designed to bring a trailer safely to a stop by activating its electric brakes should it become disconnected while being towed. Push-button tester lets you know if the rechargeable battery is fully charged.

Features:
- Breakaway system activates your trailer's electric brakes if the trailer disconnects from the tow vehicle
- Push-to-test battery feature offers fast and easy battery testing
  - Test button with LED lights clearly displays battery status
    - Green = charged
    - Yellow = charging
    - Red = low battery
- Built-in charger automatically refuels battery while trailer is connected to tow vehicle
  - Charges at 1/2 volt below voltage supplied by tow vehicle to prevent over-charging
  - Shut-off feature activates when battery is fully charged
- Top-loading case is easy to access from above
  - Weather-resistant construction protects battery from moisture and debris
  - Self-tapping screws included for simple mounting on your trailer's frame
- Lockable lid deters theft (padlock sold separately)
- Breakaway switch installs on your trailer's frame - drilling is required
- Department of Transportation (DOT) compliant
- 12-Volt rechargeable battery is included

Convenient

Has battery pack available and is small

Fits in back of car

Specs:
- Application: single- and tandem-axle trailers with electric brakes
- Case dimensions: 4" long x 8" wide x 6-1/4" tall
- Battery capacity: 5 amp-hours
- Mounting hole spacing:
  - 7" From center of hole to center of hole horizontally
  - 1-1/2" From center of hole to center of hole vertically
- 16-Gauge wires
- 90-Day warranty

Enough time for braking

Note: A breakaway system is required by law in most states for trailers that are equipped with electric brakes and have a GTW of at least 3,000 lbs.

Good references

Info for this part was:

Expert Research: Mike L | Expert Research: Michael H | Expert Research: Jameson C
Expert Research: Adam R | Expert Research: Victoria B | Updated by: Adele M
Updated by: Laura H | Updated by: Wilson B | Updated by: Alexander C
Updated by: Brian T | Installed by: Cole B

At etrailer.com we provide the best information available about the products we sell. We take the quality of our information seriously so that you can get the right part the first time. Let us know if anything is missing or if you have any questions.

Figure B.1.4: Specs of Hopkins Trailer Emergency Brake

Keywords

- Emergency Brake
- Trailer Brakes
- Trailer emergency brake
- Utility Trailer
- Relays
- Cable
- Break away switch

Contacts

- Autozone and NAPA Auto Parts Associates
- E trailer reference
- Email and then call

- Become knowledgeable about website
- Ask to speak to an application engineer (otherwise you will get to sales)
- Introduce yourself as a UCSD students working on project xyz.
    - Ask questions if you do not understand their reasoning.
- Ask about pricing, availability, samples, and academic discounts.
- Ask for contact information, so you can follow up via email.
- At the end the call asking about their strengths relative to competitors.
    - Sometimes it is price, sometimes capability, support, etc.
- You will learn more from a call than the website
    - Companies will be hesitant to put cons on their website, but more likely to discuss.
    - Engineers can provide case studies and provide advice for your application.

ROGER: HORIZON GLOBAL CORPORATION
-normally open switch: need to make it closed: normally open relay to activate
Not recommended: MADE OF PLASTIC AND IS NOT FOR MULTIPLE USES
ASK DEALERS FOR DISCOUNTS: AMAZON, autoshop stores

Hopkins Trailer Solutions
90day warranty -
Ask other retailers about their pricing

Made in taiwan:

B.2: Linear Actuators

Background

This report draft investigates the use of linear actuators for use in an automatic braking system. The idea is to find a linear actuator that defaults to a certain position when power is lost.

A linear actuator is a mechanical device that applies linear force when it is actuated. This can come in many different configurations, from a mechanical screw, to a magnetic solenoid. Each of these configurations have different properties, advantages, and disadvantages that make them better at different things.

The functional requirements of the linear actuator in our project are that it defaults to a certain position when power is lost, and that it can exert enough force to operate the emergency brake. A second configuration was also designed that would require the linear actuator to default to a certain position when power is lost, and exert enough force to maintain a pin blocking a spring powered slide. This would require a lot less force than the previous configuration.

Summary

In this investigation, I discovered different types of linear actuators. More importantly, I was able to find different ways that linear actuators can be returned to their default positions in the event of a loss of power. For example, a pneumatic linear actuator that uses air pressure to apply force will naturally default to an unextended position when air pressure is lost. This can be made to happen on power loss by attaching the air pump to the power source such that on power loss the air pump opens and releases the air in the system. Other types of linear actuators instead do not return to their default positions on loss of power. In fact, many linear actuators are designed to do this, because in most industry uses of linear actuators, they are being used on an assembly line where all motion must stop in an emergency. These linear actuators are typically ball screw actuators and have specialized braking systems in place to prevent movement when there is no power. The last type of linear actuator that I found was a magnetic solenoid actuator. These actuators have the disadvantage of having short stroke length and relatively low force compared to the other options. However, they are fast and are able to quickly move to default positions when power is lost.

Information Gathering

Keywords used: Linear Actuator, Pneumatic linear actuator, spring actuator, solenoid, linear actuator brake

Articles found:

https://www.progressiveautomations.com/blogs/products/inside-an-electric-linear-actuator
https://www.thomsonlinear.com/en/support/articles/Comparing-electro-hydraulic-actuators-and-hydraulic-cylinders-eu
https://www.thomsonlinear.com/en/support/articles/Electromechanical-Linear-Actuators-Prove-that-High-Power-Can-Come-in-Small-Packages
https://www.thomsonlinear.com/en/training/linear_actuators/wrap_spring_basics

https://www.hindawi.com/journals/js/2022/7707600/

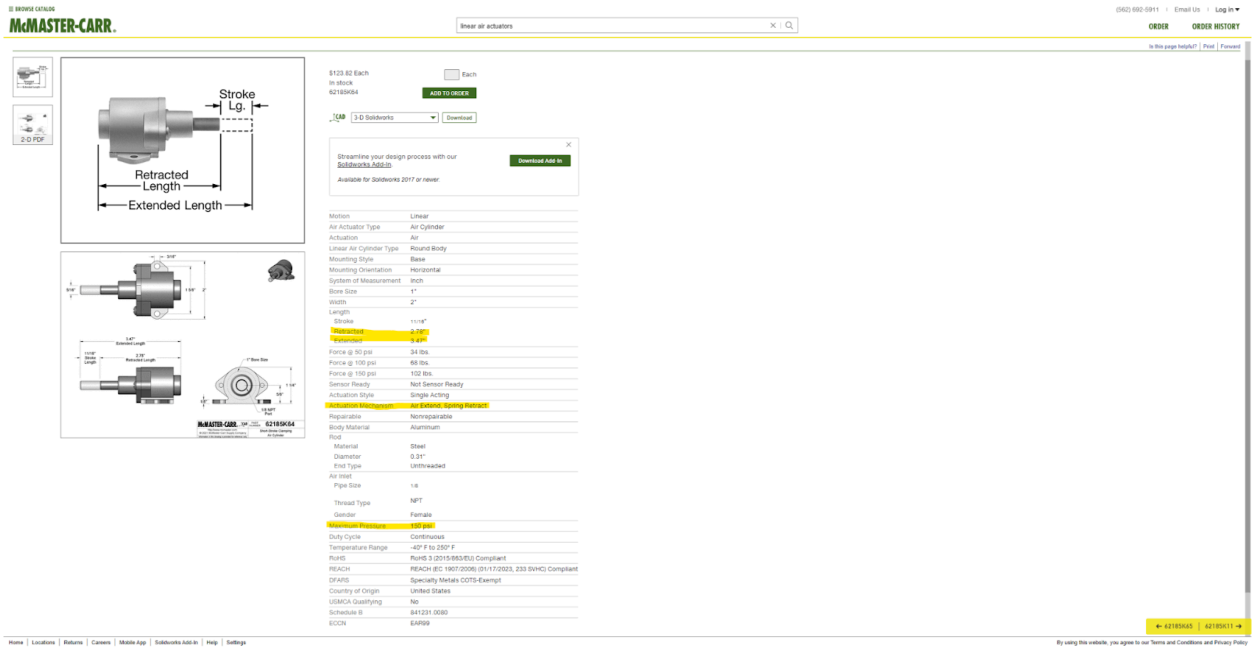
Detailed Description of Findings

Table B.2.1: Comparison of various solenoids

Product	Type	Cost	Stroke length	Max force	Link
Short-Stroke Clamping Air Cylinder	Pneumatic, Single Acting	$289.38 Each	1”-2”	93 lbs.	https://www.mcmaster.com/62185K12/
Linear Solenoid	Continuous, Push, DC power	$46.30 Each	½”	50 oz.	https://www.mcmaster.com/70155K121/
Linear Solenoid	Continuous, Push, DC power	$38.09 Each	1”	18 oz.	https://www.mcmaster.com/70155K611/

These are the applicable linear actuators found. There are two linear solenoid options and one pneumatic option. The main difference between these two options is how they generate motion. The pneumatic option uses air pressure to generate its pushing force, while the linear solenoids use an electromagnet to generate its force. The pneumatic options are able to generate much higher maximum forces, as shown in the table. However, they are much more expensive and require extra hardware to make them work, such as an air pump and pneumatic valves. Linear solenoids are instead powered by electromagnets which makes them much cheaper and easier to set up, but they provide much less linear force. Linear solenoids also have a much lower stroke length as magnets naturally lose a lot of force the farther away they are from each other.

Appendix



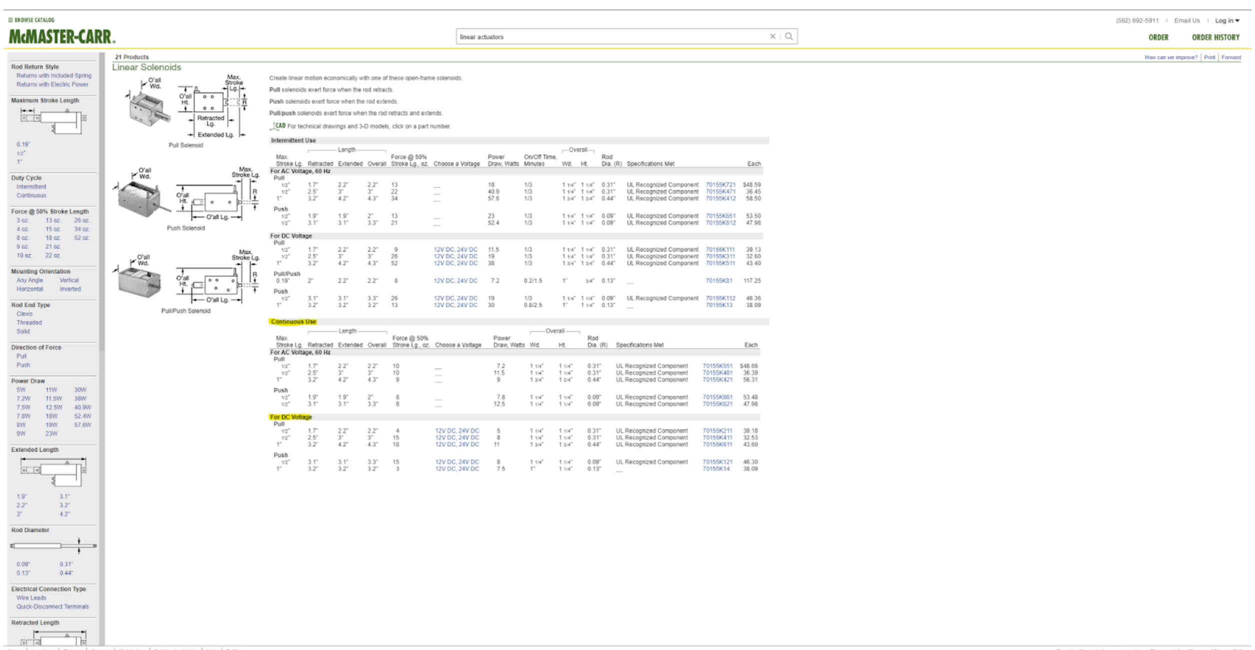


Figure B.2.1: Solenoids purchasable from McMaster Carr

B.3: Calipers and Wiring

Calipers and Wiring Component Analysis

1. **Brief project description of the component, tool, or topic being researched.**

Calipers, and the wiring that connects them to the manual braking mechanism within the car, are the main way to force a car to stop. Specifically, the calipers house brake pads and pistons, and are attached to the rotor of a wheel so as to not be in direct contact with the wheel. They tend to be on the smaller side since they need to fit on the rotor and to reduce total weight.

Refer to Figure 1 below for how calipers are attached. Once the braking mechanism is activated, braking fluid is sent to the calipers, which create pressure on the pistons within the calipers, thus forcing the brake pads to clamp onto the rotor in order to provide a braking force on the rotor, generating friction and slowing down the vehicle.

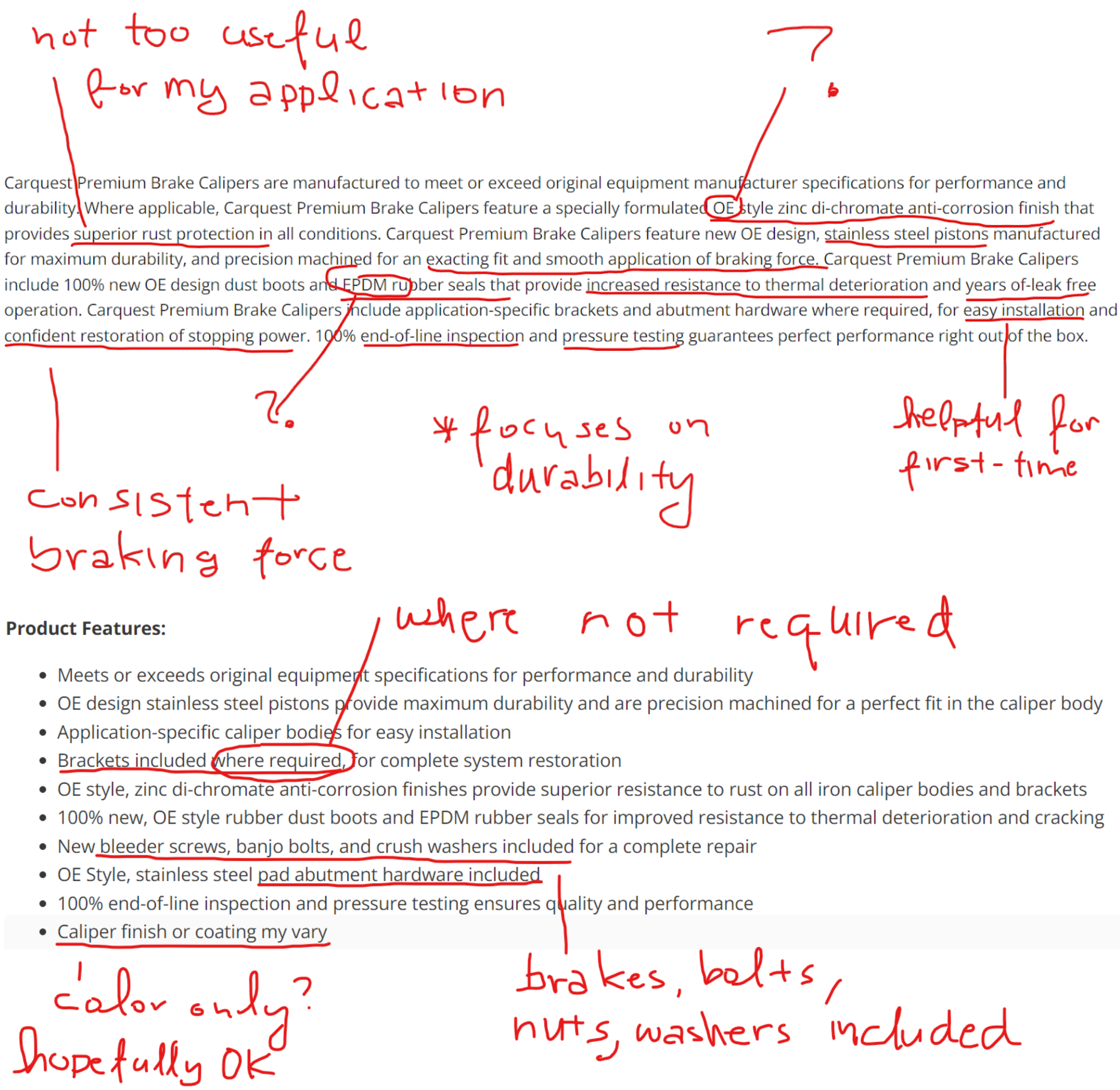
Figure B.3.1: How Calipers and Brake Pads are Attached (Appendix.A)

2. **The Functional Requirements (need) of the component or area of research in the project**

Given that our task is to employ an emergency brake for a kart, understanding how the braking system works for a larger vehicle, such as a car, will be instrumental in designing our own brake. Things such as the location of calipers, the material of the brake pads/calipers, type of braking fluid, methods to attach wiring from braking mechanism to calipers, etc, are all important factors to learn and understand in-depth in order to optimize the braking mechanism for our own emergency brake.

3. **One written document such as product description or published article which has been marked up and summarized**

From Appendix.E:



Carquest Premium Brake Calipers are manufactured to meet or exceed original equipment manufacturer specifications for performance and durability. Where applicable, Carquest Premium Brake Calipers feature a specially formulated OE style zinc di-chromate anti-corrosion finish that provides superior rust protection in all conditions. Carquest Premium Brake Calipers feature new OE design, stainless steel pistons manufactured for maximum durability, and precision machined for an exacting fit and smooth application of braking force. Carquest Premium Brake Calipers include 100% new OE design dust boots and EPDM rubber seals that provide increased resistance to thermal deterioration and years of-leak free operation. Carquest Premium Brake Calipers include application-specific brackets and abutment hardware where required, for easy installation and confident restoration of stopping power. 100% end-of-line inspection and pressure testing guarantees perfect performance right out of the box.

Product Features:

- Meets or exceeds original equipment specifications for performance and durability
- OE design stainless steel pistons provide maximum durability and are precision machined for a perfect fit in the caliper body
- Application-specific caliper bodies for easy installation
- Brackets included where required, for complete system restoration
- OE style, zinc di-chromate anti-corrosion finishes provide superior resistance to rust on all iron caliper bodies and brackets
- 100% new, OE style rubber dust boots and EPDM rubber seals for improved resistance to thermal deterioration and cracking
- New bleeder screws, banjo bolts, and crush washers included for a complete repair
- OE Style, stainless steel pad abutment hardware included
- 100% end-of-line inspection and pressure testing ensures quality and performance
- Caliper finish or coating my vary

Figure B.3.2: Annotating specs found on brake caliper website

4. **A list of who you will contact for a phone call or email (individual or company name). Contacts need to be made, and replies received by the Final report. Extra credit is provided for phone calls.**

Phone calls and emails: contact suppliers (Powerstop, Advance Auto Parts, OEM Mopar, ACDELCO), kart teams (other schools in go kart competition ie. KSU)

5. **A list of keywords used in the literature searching process so far.**

Keywords: “Brake calipers”, “brake calipers wiring”, “pads included”, “mounting hub”, “mounting bracket”, “cast iron”, “aluminum”, “thermoplastic”

Appendix

a. https://www.team-bhp.com/forum/technical-stuff/188088-brake-caliper-location-how-do-engineers-decide-its-placement.html
b. https://www.powerstop.com/resources/helpful-tips-installing-new-brake-caliper/

c. https://www.lesschwab.com/article/complete-guide-to-disc-brakes-and-drum-brakes.html
d. https://www.goodyearbrakes.com/calipers/material-calipers/brake-caliper-material-types/
e. https://shop.advanceautoparts.com/p/carquest-premium-brake-caliper-18-4194-front-right-remanufactured-anti-corrosion-coated-18-4194/5620805-p?product_channel=local&store=9882&adtype=pla&product_channel=local&store_code=9882&gclid=CjwKCAiA3pugBhAwEiwAWFzwda6iUQ2aozBkSIgcotd1DIBp3vKWssDITA4f8011E2sacULLLveJAhoCj1kQAvD_BwE&gclsrc=aw.ds

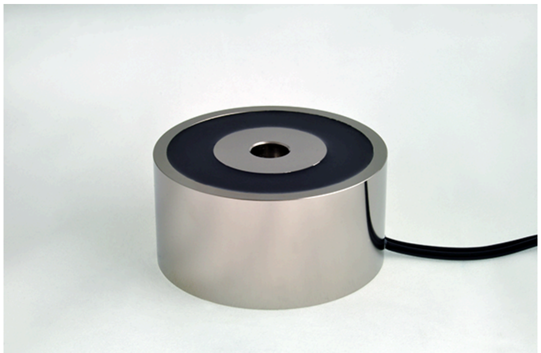
B.4: Brake Activation System

Background

The TritonAI eV GoKart brake activation system is a critical safety feature designed to automatically engage the emergency brakes when the kart loses power. This system comprises two main components: an electromagnet and a spring-loaded lever. The electromagnet remains powered throughout the kart's operation and only deactivates when the power is cut. Upon deactivation, the electromagnet releases the spring, which in turn activates the braking system, functioning as a fail-safe switch that engages the brakes during power loss.

The brake activation system must meet specific performance criteria, including the ability to engage brakes capable of decelerating a 500-pound kart from 40 MPH to a complete stop within 10 meters. The spring must be withstand the forces required for this operation without accidental engagement due to vibrations during the kart's operation. Electromagnet selection is also crucial, as it should have a pulling force that exceeds the spring's maximum force. This safety margin ensures that the electromagnet maintains its hold on the spring through fluctuating temperatures, preventing premature release and brake activation.

Figure B.4.1: Electromagnet	*Figure B.4.2: Spring*



Summary of Information Learned

The electromagnet's primary limitation is the constant run time – prolonged use carries the risk of potential overheating and burnout. The duty cycle, typically provided on the manufacturer's specification sheets, indicates the recommended total cycle time for both active and inactive periods. Some electromagnets are designed for continuous use, but cost more and run with lower currents. Considering the intended use of the electromagnet, the brake activation system had two choices with regards to the electromagnetic component: an alternating system of cheap, finite cycle electromagnets or a single, continuous cycle electromagnet. Using an alternating system would increase the complexity of the system and require control methods to cycle through the magnets, and are more prone to overheating risks. On the other hand, using a single, continuous cycle electromagnet is relatively simple and is thus a preferred solution. Although more expensive, it should allow for seamless brake activation with minimal risk.

Another critical aspect of the brake activation system is ensuring that the spring-loaded lever does not inadvertently engage due to vibrations during the kart's operation. As uneven movements on the road can impact the brake activation system, similar challenges are often observed in various structures and vehicles. Vibrations depend on the system's frequency and damping [A2], meaning that increasing the system's stiffness can mitigate the effects of vibrations. As such, selecting a spring with a higher maximum load can enhance the system's resistance to unwanted movements and prevent accidental brake activation.

Information Gathering Approach

Gathering information for this project was split into two sections: a conceptual area that focused on the functionality and theory behind electromagnets and springs, and a technical area that focused on component specifications. It was crucial to first understand the physics of electromagnets and springs before finding suitable components that met project requirements. The keywords and sources reflect this methodology and is split into research-focused queries and purchase-oriented searches. The contacts were prioritized due to experience in developing an emergency brake system for a similar gokart.

Keyword List

- Electromagnet force
- Electromagnet power consumption
- Electromagnet duty cycle
- Continuous duty electromagnet
- Spring vibration
- Spring harmonics
- Hookes law
- Extension/tension spring

Sources List [Appendix A]

- APW Company EM300-12-212 Spec Sheet [A1]
- Forced vibration of damped, single degree of freedom, linear spring mass systems. [A2]
- University of Washington Magnetism Lecture [A3]
- Century Spring 672CS Spec Sheet [A4]

Contact List [Appendix B]

- Sahan Reddy (KSU kart team) [B1]
- Ben Hall (KSU kart team) [B2]

<u>Summary of Contact Conversations</u>

Sahan Reddy:

Sahan Reddy explained that his team used a compression-based spring system attached to an electromagnet. At rest, the system is not compressed. They set up their system by turning on the electromagnet and pulling back the plate the springs are set against. After discussing potential risks, he confirmed that their electromagnet had no issues with overheating or continuous use, even stating that the magnet itself does not even get warm.

Ben Hall:

Ben Hall detailed the equipment they used, providing specifications for their electromagnet (100 lb holding force) and provided a link to the electromagnet page. He also explained how the spring system interacted with their braking system. The spring pulls a cable attached to the lever arm of their band brake, which is not too different from our mechanical caliper system. He also emphasized the issues presented by hydraulic systems, warning against using it due to leaking issues.

Concerns: Finding appropriate equipment for project. Connecting the spring to the magnet via an intermediary magnetic plate.

Plans to address concerns: Maintain contact with KSU Kart Team and request information on their bill of materials, processes, and guidance.

Detailed Description of Findings

Searching for electromagnets and springs online yielded several options, all of which differed in some respect. Considering the project's primary concerns of price, performance, and shipping date, the tables below show a comparison of each component.

Table B.4.1: Electromagnet Comparison Table				
Component Name	Duty Cycle (min)	Price ($)	Pulling Force N (lbf)	Power Requirements (W)
EM300-12-212	Continuous	95.81	1779.29 (400)	15
EM200-12-211	Continuous	53.21	622.751 (140)	7
Uxcell 12V DC 800N	7	25.49	800 (224.809)	7

Table B.4.2: Spring Comparison Table				
Component Name	Max Load N (lbf)	Max Deflection (in)	Price ($)	Length (in)
OLIREXD 300lbs Porch Swing Springs	1334.47 (300)	Not Specified	9.99 (2 units)	4.25
SELEWARE 400 lbs Hammock Spring	1779.29 (400)	Not Specified	15.98	7.1
Century Spring Unit 672	1223.2 (275)	0.97	20.79	5

Continuous Duty Cycle Electromagnet

Pros:

- Constant Runtime
- Lower risk of overheating
- Durable, less wear

Cons:

- Lower Current (Lower Output)
- Expensive

Finite Duty Cycle Electromagnet

Pros:

- Higher Current (Higher Output)
- Cheap
- High temperature tolerance

Cons:

- Finite Runtime
- High risk of overheating
- More wear

Electromagnet Analysis

Electromagnets create magnetic fields by running electric currents through a wire coil wrapped around a ferromagnetic core. The force between an electromagnet and a piece of magnetic material can be expressed [A3] using the following equation, in which F_m represents the magnetic motive force (and is equal to number of turns multiplied by current in amps), μ_0 represents the permeability of free space, A represents the cross-sectional area of the core, and g represents the length of the gap between the magnet and material:

$$F = F_m^{2} \frac{\mu_0 A}{2g^2} \text{ (Eq B.1)}$$

From this, it is evident to achieve the holding force detailed on the EM300 spec sheet [A1] by as close of a margin as possible, these variables must be optimized (primarily gap distance). The final design should have a surface that maximizes the contact area, and the gap distance must be minimized as much as possible to increase the force seen.

Although finite-cycle magnets can produce greater forces and thus provide a margin of error for this optimization, their cons outweigh the benefit provided by higher currents. Additionally, there is no estimate for the length of any given race, so the brake activation system must be able to withstand extended operation times. Given these considerations and the minimal overheating risk of the continuous-duty electromagnet, it is preferable to use it.

<u>Spring Analysis</u>

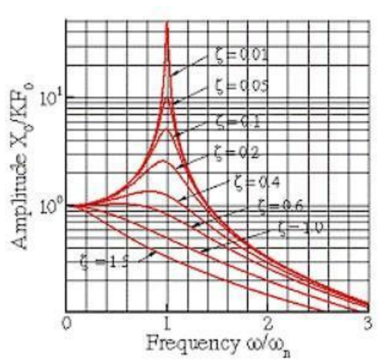
Modeling the spring system as a one-dimensional construct is not realistic due to vibration and the car’s movement, but it is possible to bring the system as close to one-dimensional as possible. This can be done by minimizing movement in the y- and z-directions and constraining the system to a horizontal one, which is achievable by reducing the extent of vibration experienced by the system. As shown on the graph [A2], vibration can be reduced via higher frequency and more damping. Since the vibration amplitude is dependent on F/k, the system should use stiffer springs. This logic suggests using the OLIREXD springs, which are cheap and meet the necessary requirements. However, due to a lack of specifications, it may be preferable to proceed with the Century Spring units, which are accompanied by complete spec sheets [A4].

$$x(t) = X_0 \sin(\omega t + \phi)$$

$$X_0 = \frac{KF_0}{\left\{\left(1 - \omega^2/\omega_n^2\right)^2 + \left(2\varsigma\omega/\omega_n\right)^2\right\}^{1/2}}$$

$$\phi = \tan^{-1}\frac{-2\varsigma\omega/\omega_n}{1 - \omega^2/\omega_n^2}$$

$$\omega_n = \sqrt{\frac{k}{m}}, \qquad \varsigma = \frac{\lambda}{2\sqrt{km}}, \qquad K = \frac{1}{k}$$



Appendix A: Sources

1. APW Company EM300-12-212 Spec Sheet

   https://apwcompany.com/wp-content/uploads/2023/03/4785.pdf

2. Forced vibration of damped, single degree of freedom, linear spring mass systems

   https://www.brown.edu/Departments/Engineering/Courses/En4/Notes/vibrations_forced/vibrations_forced.htm

3. University of Washington Magnetism Lecture

   http://depts.washington.edu/mictech/optics/sensors/week2.pdf

4. Century Spring 672CS Spec Sheet

   https://www.mwcomponents.com/shop/672cs?microsite=century-spring

Appendix C: Steering Wheel EPAS Controller Disassembly

Characterizing Steering Column

I. Overview

A. Over the last decade, engineers have begun shifting from hydraulic motors to electrical motors. In particular, EPAS systems, or electric power assisted steering, have become much more common in industry. Benefits for using electric power steering include less consumption of fuel, convenience in packaging and transportation, as well as consistency in using electricity rather than the unpredictability of fluids found in hydraulic systems. One reported issue is drivers losing the tactile feeling when braking using hydraulic systems compared to electrical systems. However, Porsche has been able to use yaw sensors, steering angles, and other values to change the assistance at a much more frequent rate, essentially eliminating the issue of "feel." This paper will dive into the mechanics of an EPAS system and each of its individual components through the disassembly of a Toyota EPAS system.

II. EPAS System Mechanics

A. An EPAS system typically has an electric motor attached to a steering column, with the other side of the motor attached to the rest of the car assembly, shown in Figure C.1. The Toyota EPAS system discussed in this paper only has the electric motor and steering column. The EPAS system works by sensing how much the steering wheel is turned from an initial position through the steering column, and then adds a torque force that is applied to the steering gear and the rest of the car for the actual turning of the car.

III. Toyota EPAS System Disassembly

A. Figure C.2 shows the full Toyota EPAS system used for the disassembly. In particular, the steering column is sticking out of the entire electric motor and into the page, similar to the electric motor and steering column assembly in Figure C.1. The red highlight shows the first point of disassembly, which had two gears set together (Figure C.3, C.4). These gears are to allow the input torque force from the steering column to be connected to the microcontroller, which is then able to measure and adjust accordingly. The underside of Figure 3 houses both the microcontroller (Figure C.5, C.6) and the electric motor (Figure C.7, C.8). It's important to note that the blue wire in Figure C.2 connects to the microcontroller, which is likely another sensor for the microcontroller to measure speed or something else. The underside of Figure C.4 connects to the steering column, which is also connected to a set of gears leading to the microcontroller (Figure C.9).

B. The microcontroller (Figures C.5, C.6) is responsible for the majority of work, as it receives the signal from the steering wheel (ie. how much the steering wheel has turned, steering angle, yaw coordinates, steering position, etc.) to determine the amount of torque force required to apply to the steering gear to turn the specified amount. Note that the microcontroller is soldered onto the black box and cannot be removed easily.

C. The top of the electric motor has coils sticking out that is meant to be slotted in the housing containing the microcontroller. The motor itself is lined with a multitude of coils that appear to be made of copper. A closer inspection also reveals that the coils are separated and are independent of each other, as well as magnets on the inside of a rotor and coils on the outside, implying a brushless DC motor.

D. Figure C.9 is an image of the steering column and the gears it is attached to. The steering column is set onto a very large gear and is extremely lubed up, which allows for a very accurate initial torque and position reading. The steering column itself acts as a torque sensor when turning, so the end result is a very simple yet effective torque sensor system. The large gear is then connected to smaller gears (Figures C.3, C.4) that are connected to the microcontroller, which allows the microcontroller to read the input torque force and add any additional torque to make the correct turn. As mentioned earlier, the blue wire in Figure C.1 is also likely another measurement the microcontroller needs to make an accurate adjustment.

IV. Brushless Motors VS. Brushed Motors

A. Brushed motors consist of magnets on opposite ends of the motor, and a rotor in the middle that consists of multiple coils. A fixed magnetic field is generated from the current that passes through the coils on the rotor, which causes the rotor to rotate away from the like and towards the unlike. To maintain this, the current polarity needs to be continually reversed to allow continuous rotation. Brushes are implemented to allow power to reach the rotor and is what forces the rotors to turn a certain direction.

B. Brushless motors are opposite in design: it consists of a magnet in the middle and coils on the outside. Because the coils are stationary and on the outside, current is not passed through the coils using brushes. Instead, the magnet rotates based on the magnetic field generated by the coils. To change the magnetic field of the coils, the voltage of each coil can be individually changed, which then allows the magnet to spin in a specific direction at a certain speed. This eliminates the need for brushes to generate power to the rotor, as the current through the coils is changed by changing the voltage of the coils.

C. The electric motor itself is a brushless motor, which is heavily favored over a brushed motor. Multiple reasons contribute to this notion, with two important factors being the efficiency and controllability. Brushless motors can be used continuously at maximum torque, whereas brushed torques only operate at certain times. This allows brushless motors to use smaller magnets to achieve the same or even more torque than the same magnets in a brushed motor. Controllability is the other factor, as brushless motors can be controlled in real-time using a feedback system, as is important in the EPAS system. This allows for precise torque and rotation speed at a very fast rate. One final advantage brushless motors have over brushed motors is its life length. Because brushless motors are contactless, there is less heat generation and noise, and the wear goes down due to it being contactless.

References:

https://www.renesas.com/us/en/support/engineer-school/brushless-dc-motor-01-overview

https://carbiketech.com/epas/

https://www.carthrottle.com/post/electronic-power-assisted-steering-how-does-it-work/

Appendix:

Figure C.1: Simple EPAS System

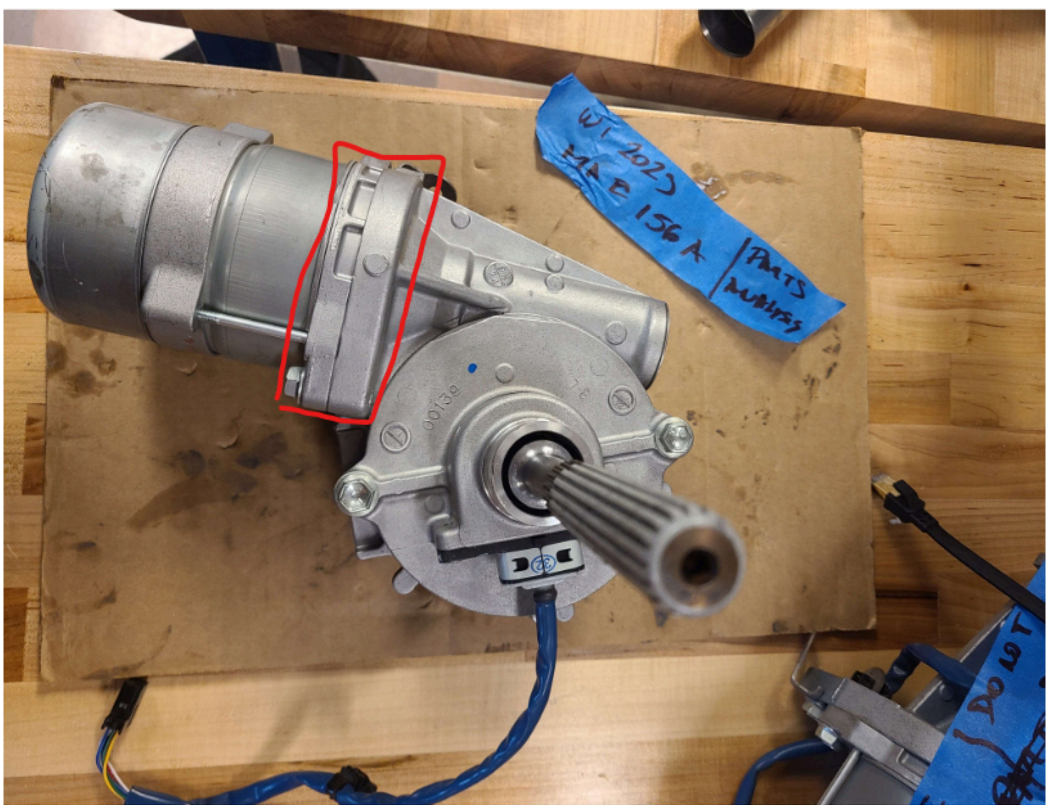


Figure C.2: Toyota EPAS System

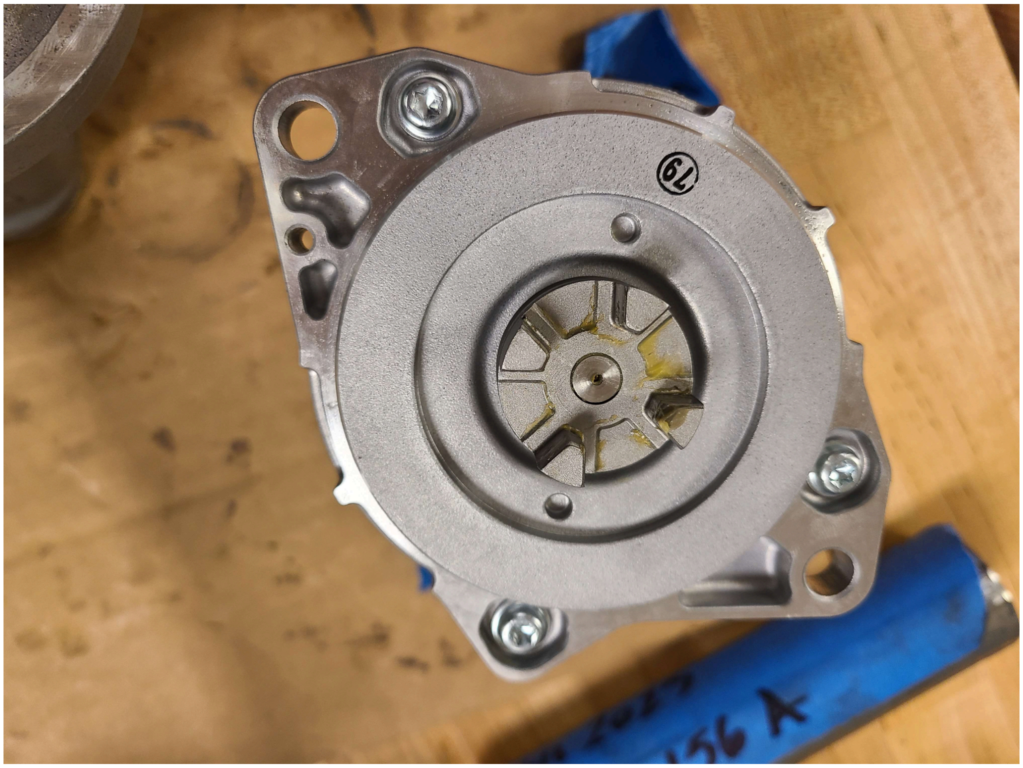


Figure C.3: Left of Red Highlight from Figure C.2

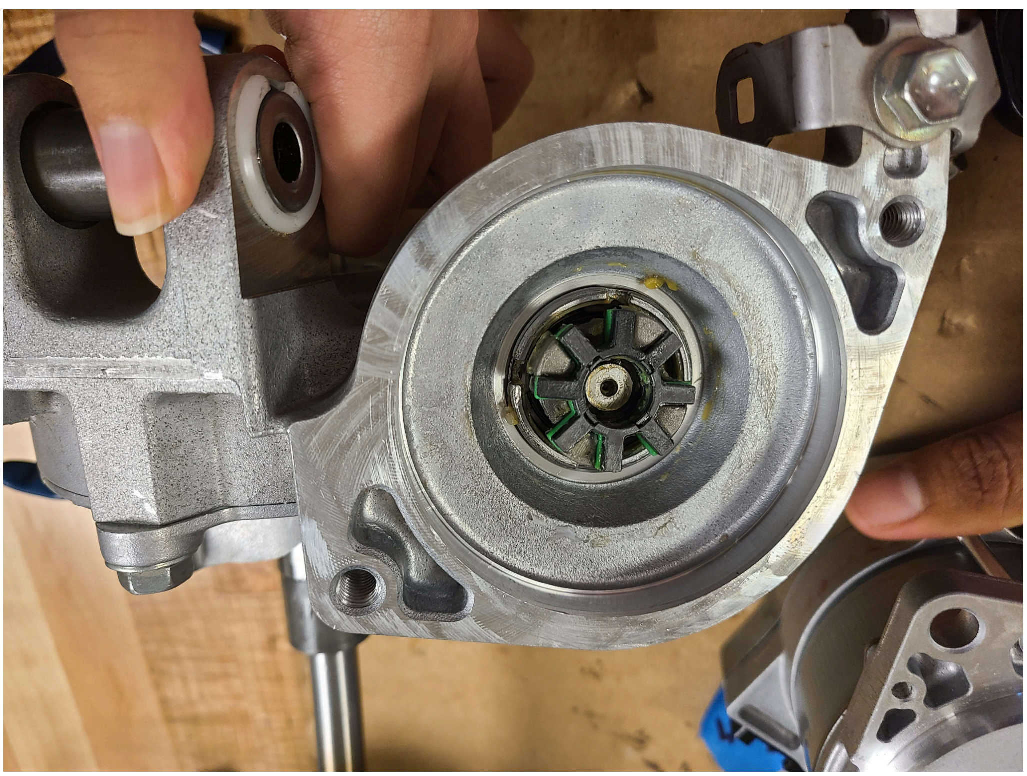


Figure C.4: Right of Red Highlight from Figure C.2

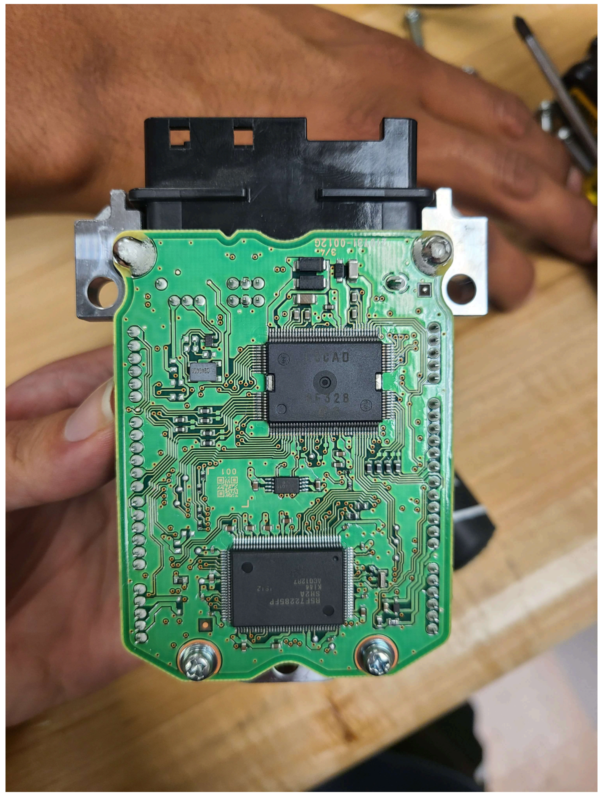


Figure C.5: Top View of Microcontroller

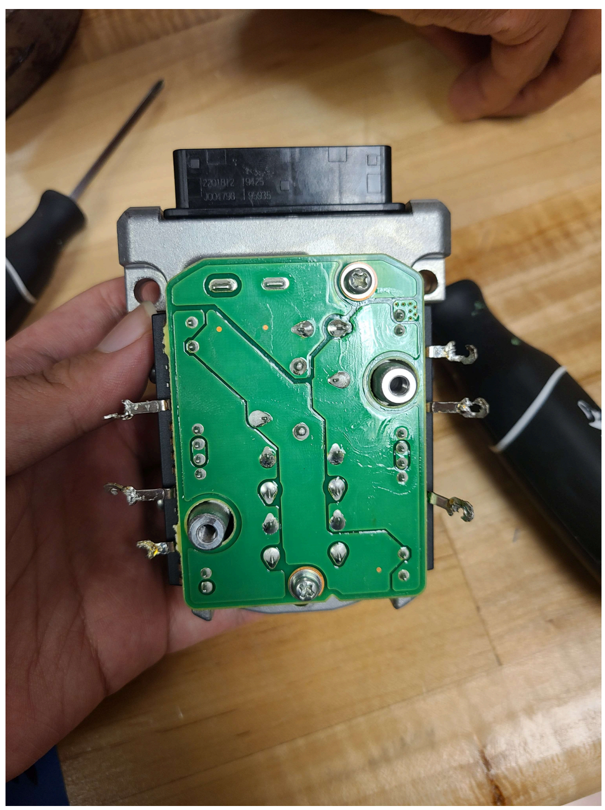


Figure C.6: Bottom View of Microcontroller

Figure C.7: Top of Electric Motor With 6 Coils

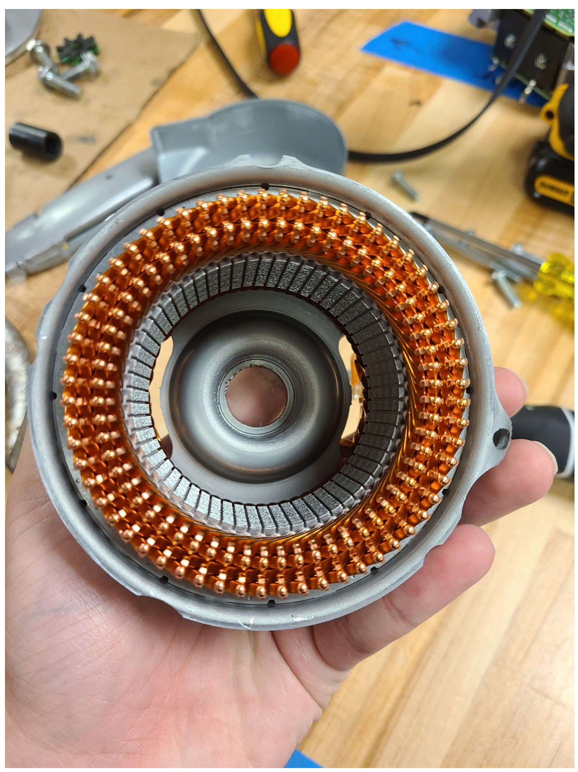


Figure C.8: Inside of Electric Motor

Figure C.9: Steering Column, Gears, and Torque Sensor

Appendix D: Project Management

Task Distribution:

- **Sponsor Liaison**
  - Angel Ramirez
- **Safety Manager**
  - Nicholas Vo
- **Financial Manager**
  - Sebastian Lee
- **Website Manager**
  - Alex Wang

Intermediate Milestones:

- Settled on spring and electromagnet system as emergency brake (04/11/23)
- Ordered springs, electromagnet, and brake caliper (04/13/23)
- 3D-printed first prototype of electromagnet mount (04/23/23)
- Finished laser cutting and bending lever arm (04/25/23)
- Finished machining brake caliper mount (05/03/23)
- 3D-printed final iteration of electromagnet mount in PLA-CF (05/07/23)
- Attached first prototype of emergency brake onto dummy kart and tested (05/14/23)
- Ordered worm gear motor (05/15/23)
- Did Instron testing on PLA-CF with various infills (05/20/23)
- Attached motor and spindle onto dummy kart and turned on motor for testing (05/28/23)
- Revised brake caliper mount to float brake caliper and attach mounting bracket (06/01/23)
- 3D-printed slider mechanism for activating emergency brake for fitness (06/05/23)
- Tested 2nd version of prototype with new and improved parts (06/05/23)
- Ordered dashpots/shock absorbers for potential dampener solution (06/08/23)

Risk Reduction Efforts:

Electromagnet Temperature

A thermometer digital gun was used to measure the temperature of the electromagnet, with two setups considered for this risk reduction. Because the 3D-printed material only had a 55℃ stated temperature before deformation occurred, and the magnet was turned on for a continuous duty cycle (up to an hour), it was important to test whether or not the magnet would affect the electromagnet mount material. The first setup only measured the magnet without any heat dissipation. The second setup measured the magnet while seated within the mount itself, which mimicked a similar environment while the kart was in power.

The result showed that for the first setup, the magnet reached upwards of 58℃ in a vacuum, and posed a problem in that regard. For the second setup however, the magnet only reached 50℃, meaning the material would not deform. This also did not take into account the lever arm connected to the electromagnet, allowing even more heat to be dissipated and the temperature of the magnet to be lower.

Brake Caliper and Electromagnet Mount Stability

The mounts for both the brake caliper and electromagnet needed to be under various amounts of stress, but the exact number was unknown. Thus, a simulation of both mounts under an FEA was performed in Solidworks to determine the amount of stress for this risk reduction. The brake caliper mount had aluminum as its material, while the electromagnet mount had PAHT-CF as its material.

For the brake caliper mount, the FEA showed that it would feel 35.2 MPa of force, which is a significant amount. Therefore, the aluminum material was needed to resist the amount of force being applied. The electromagnet mount only felt 5 MPa of force, and so 3D-printing the mount out of PAHT-CF or even PLA-CF would still leave it structurally intact.

PLA-CF Instron Testing

Another risk reduction test performed was checking if the PLA-CF purchased actually matched the specs on the website. To achieve this, 3 different tests were performed; 3 PLA-CF dogbones were 3D-printed with 50% infill, 75% infill, and 100% infill. These dogbones were then brought to an Instron machine to measure the amount of stress it could withstand.

The results showed that, expectedly, the strength of each dogbone increased as the amount of infill increased. However, the 100% infill dogbone did match the specs on the manufacturer’s website and was actually higher than expected. Therefore, because the electromagnet mount only felt 5 MPa of force, it was decided that PLA-CF could be used as the material for the mount.

Lessons Learned:

An important lesson learned was the fact that documentation is a very important process to keep in mind for the entirety of the project. There were numerous things to make sure to remember and share, such as CAD drawings and models for future iterations, and videos and pictures for the web page. There was also a bill of materials that needed to be kept up to date, and anything forgotten would eventually come back once it was realized that a specific item needed to be shown. Ensuring everything, even the little things, were well documented and kept to allow easy review once the the time came for it was an incredibly valuable lesson to learn for a large-scale project like this.

Appendix E: Executive Summary

Executive Summary

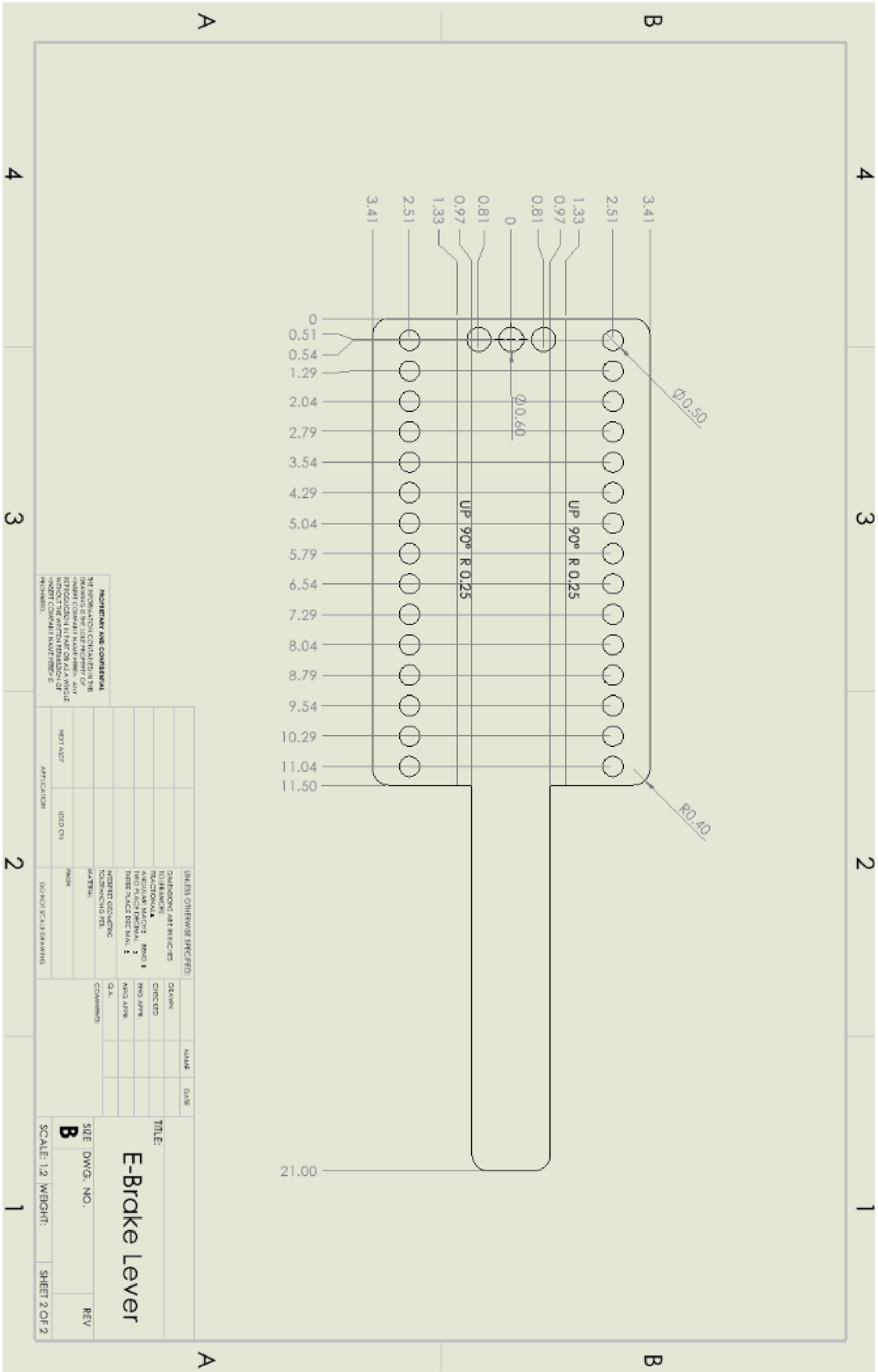
TritonAI at the University of California, San Diego, is a student organization that operates under the leadership of Professor Dr. Jack Silberman. Focused on autonomous driving, TritonAI designs and builds fully autonomous karts for national competitions like the EvGrandPrix. These karts self-drive with the aid of integrated microcontrollers and camera systems. The organization has achieved remarkable success in recent years, securing 3rd place in 2021 and 2nd in 2022 at the EvGrandPrix.

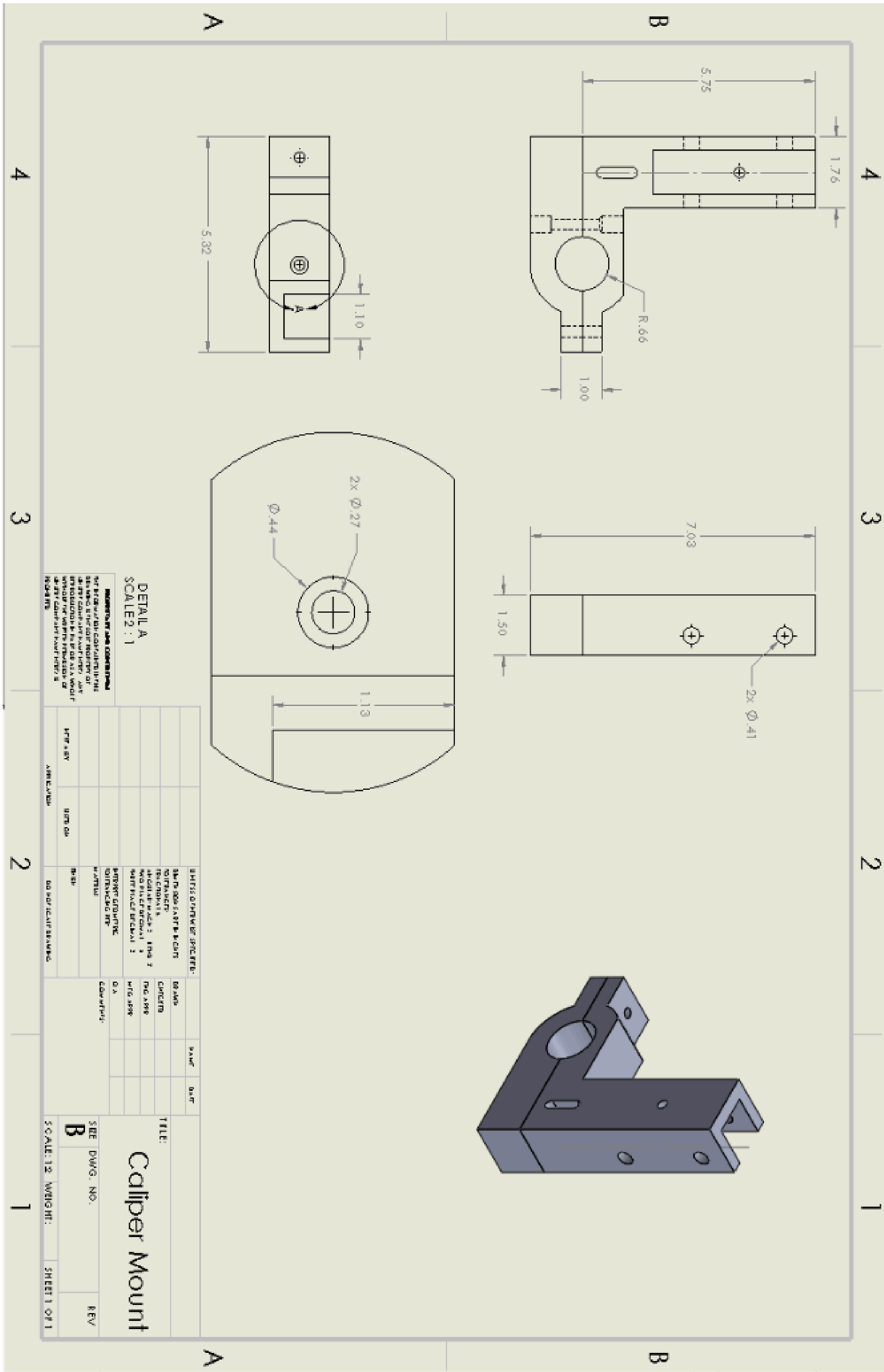
The primary objective of the project was the development and installation of an emergency braking system, designed to permit the override of the kart through human intervention and provide an extra layer of precaution when racing. Specifically, the challenge was to design a brake that would automatically activate when the kart's power supply was interrupted. This interruption can happen intentionally, as a driver flips an existing switch near the seat, or as an emergency shut-off system in the event of a malfunction in the power supply.

The finalized design for the brake activation system utilizes an electromagnet as the primary mechanism to engage the emergency brake. When the kart is in operation, the electromagnet is powered on, keeping the emergency brake disengaged. This brake comprises a lever arm, a brake caliper attached to a brake rotor, and a pre-tensioned spring connected to the brake caliper and lever arm via a brake cable.

During the kart's operation, the lever arm, held in place by the active electromagnet, maintains a position that prevents the brake caliper from clamping onto the rotor. This ensures the kart moves freely. However, when the kart's power is cut, the electromagnet is automatically deactivated. This then releases the lever arm, allowing the pre-tensioned spring to return to its rest position. The movement of the spring pulls on the brake caliper and lever arm, causing the caliper to clamp onto the rotor, thereby halting the kart. Through this process, the emergency brake system is designed to engage automatically in the event of a power loss, ensuring the kart's safe and controlled deceleration.

Appendix F: Technical Drawings





5.75
1.76
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Caliper Mount
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REV
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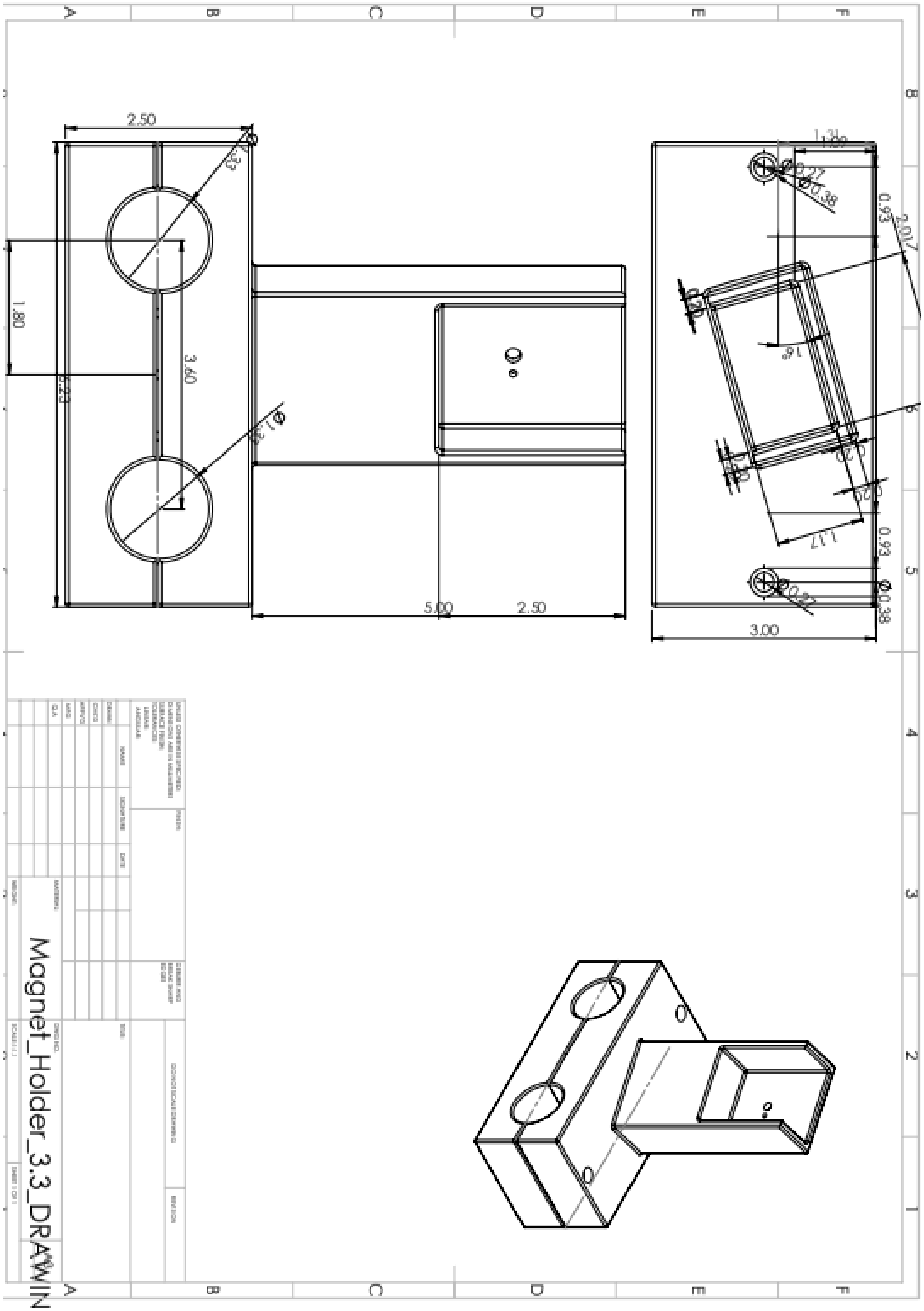
SHEET 1 OF 1


Magnet_Holder_3.3_DRAWIN