E-Bike Conversion Kit

Group 2 Final Report

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Abstract

The E-Bike Conversion Kit is a product created by Group 2 of Dr. Oguejiofor's Design & Communications II course. The goal of this project was to create a user-friendly alternative for those looking into transitioning their existing bike to an electric powered or electric assisted bike. While also remaining a cost-effective alternative to the new electric bikes that are available to be purchased on the market. Currently, there is not many readily available kits that can convert a normal bike into an electric assist one for individuals who do not have any previous knowledge of how to do so. The product was created by first researching what is currently available on the market and deciding a benchmark to compare the E-Bike Conversion Kit to once completed. A theoretical design was determined after an extensive amount of research, analysis, and design into creating the cost, durability, and functionality of the product. Some of the courses applied throughout the project have been Statics, Strengths of Materials, and Dynamics. These courses aided with the calculations and computer analysis of the component enclosure and supports. Circuit analysis helped with the calculations required for battery capacity, charge time, range, and choosing the best option for a motor. Engineering Economics aided with determining a manufacturing and proposed market cost of the E-Bike Conversion Kit. A prototype would have been constructed if not for the sudden departure from campus due to the COVID-19 pandemic. The E-Bike Conversion Kit is an excellent example of application engineering with the goal of building a similar workable product at a cheaper cost with alternative design methods, which in this project, was done successfully.

Acknowledgements

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Introduction

Background

In the world currently, there is an ever-growing concern and issue with climate change and increasing carbon emissions. From our reliance on carbon emission vehicles, which is steadily growing, to manufacturing and production needs, humanity is ever increasing its ecological footprint in a time where we are trying to minimize it as much as possible. This increase in carbon emissions has led humanity to consider alternative options for reducing their ecological footprint which has led to developments in areas such as green transportation. Some of these green transportation alternatives include electric vehicles and electric bikes. However, as much as this technology has developed in electric bikes specifically, there is still not a low cost, consumer-friendly product available to transform a regular bicycle into an electric bike (e-bike). Current versions of conversion kits are far too complicated for the average consumer with little to no technical knowledge to perform the installation. The market is lacking an easy to install and cost-effective alternative for everyday individuals to purchase and operate. Furthermore, for those who buy a brand-new electric bike, there is environmental waste associated with the disposal of their current bicycle, assuming they had a bicycle that they are replacing. The proposed solution to this problem is to create an affordable, user-friendly conversion kit to turn their regular bicycle into an electric bike.

Goal

The engineering problem that the design group will address is in reducing the environmental waste created by the disposal of a bicycle when the consumer purchases a new e-bike along with reducing the difficulty in setup and installation of current electric bike conversion kits. The reduction of this environmental impact will be accomplished by utilizing the current bike that the consumer owns, rather than purchasing a brand-new electric bike that inevitably ends with the disposal of their current bicycle in some way. Furthermore, new electric bikes can cost more than $2000, which is not affordable for most families that are looking to use an electric bike as part of their everyday life. Although other options for e-bike conversion kits do exist, they are not very user-friendly. The existing kits in the market are essentially a bag of parts, with unclear instructions for installation or have descriptions that state "all the buyers should have experience to install it. If not, please do not buy it" [1].

For the semester project in Design & Communications II, the design group has decided on designing a conversion kit to convert an ordinary pedal bike into an electric bike. This cost-effective and user-friendly solution could provide an opportunity for individuals that are looking to try an e-bike but have never had the chance due to technical knowledge or financial capabilities. If designed and implemented correctly, the use of an e-bike can be an alternative to an automobile due to its eco-friendly design, relatively low cost, and minimum maintenance.

The group's goal for the conversion kit is to have it be installed by anyone, without prior technical knowledge or experience. The objective of the conversion kit is to be cheaper than the cost of e-bikes currently on the market with comparable specifications to make it a desirable product. Currently there are a few major brands that sell e-bikes. Some of the big companies are as follows: Giant Manufacturing Co. Ltd., Specialized Bicycle Components, Inc. and Bosch e-Bike Systems who supply the electrical components to 84 smaller e-Bike manufacturing companies, and many more. These companies offer an all in one solution with no option of converting an existing bicycle to an e-bike.

Figure 1- Specialized Turbo Levo Hardtail [2]

The bike pictured above is a Specialized Turbo Levo Hardtail, it is the cheapest option offered from Specialized Bicycle Components, Inc. with a price tag of $3699.00 CAD [2]. The bike comes with a 250W electric motor and a battery capacity of 400Wh, with an estimated range of 40 km - 89 km and a top speed of 32 kph [2]. The Specialized Turbo Levo Hardtail is going to be the benchmark for the project, and the group will be designing a product that will be more cost-effective while just as capable as the Turbo Levo Hardtail. The reason the Levo Hardtail was chosen is because Specialized Bicycle Components, Inc is a reputable bike brand and since it is the cheapest option available it would be considered entry level for anyone who is looking to own a e-bike.

To accomplish the goals of this design project, various type of analyses need to be conducted using prior knowledge gained through numerous engineering courses. Statics, Strengths of Materials, and Dynamics aided with the calculations and computer analysis of the component enclosure. Circuit analysis helped with the calculations required for battery capacity, charge time, range, and choosing the best option for a motor. Engineering Economics aided with the determining a manufacturing and proposed market cost of the E-Bike Conversion Kit. A prototype would have been constructed if not for the sudden departure from campus due to the COVID-19 pandemic. The E-Bike Conversion Kit is an excellent example of application engineering with the goal of building a similar workable product at a cheaper cost with alternative design methods.

Research

This problem requires an engineering research because it is engineers that can look at a problem and consider all aspects that are involved in creating an effective solution. The elements that will be considered in making a solution for this conversion kit are; structural analysis of the component enclosure and how it will be mounted, the configuration of parts, and testing of the product. Furthermore, keeping a low cost for the conversion kit should be considered a design goal, making it available to a variety of consumers of many technological backgrounds and financial situations. The main target demographic is consumers that frequently use a bike as a method of transportation or users who live in areas where there is a large quantity of carbon emission vehicles and traffic. This will allow prospective buyers to be more inclined to consider this conversion kit to put on a bike that they already own, rather than purchasing a new e-bike.

The plan for the placement of the parts is to have most of them enclosed in a box that sits on a rack above the rear wheel. This will provide a secure enclosure for the parts, and keep them out of sight, giving the e-bike a less bulky and sleek look. The rack will be expected to withstand the weight of the motor and the torque that the motor will produce.

The goal is to secure this rack to the bike in such a way that it does not require any drilling or other modifications to the original bicycle. It will be mounted to two locations on the bike frame, one horizontally just below the seat, and once vertically to the center of the rear axle. In *Figure 2* below, the proposed idea for the mounting of the rack can be seen. For the mechanical drive system to be able to take mechanical power from the motor to the wheels, a chain is planned to run through the motor and down to the rear wheel, where an additional axle gear will be placed.

Figure 2 - Example of a rear-wheel rack [3]

Figure 3 below shows a general mockup of where the hardware will be mounted, according to the ideas during the research phase.

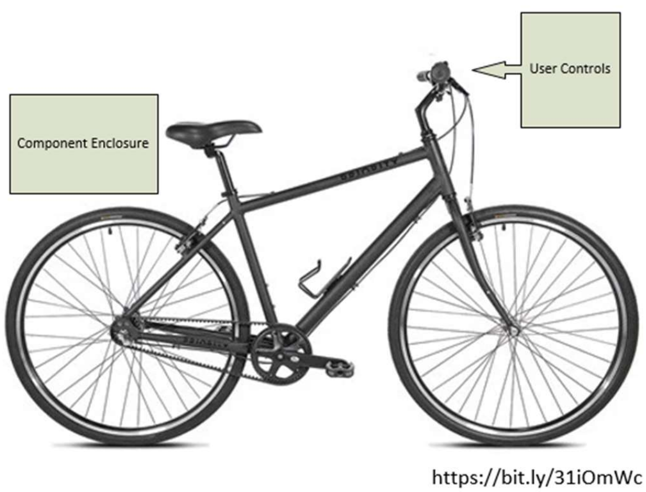

Figure 3- E-Bike Concept Drawing

To pick the ideal motor to use, it was required to calculate and estimate several parameters. A few difficulties that were encountered were regarding the power needed to move the bike. A free body diagram of the forces that are acting on the bike while on level ground can be located below in *Figure 4*.

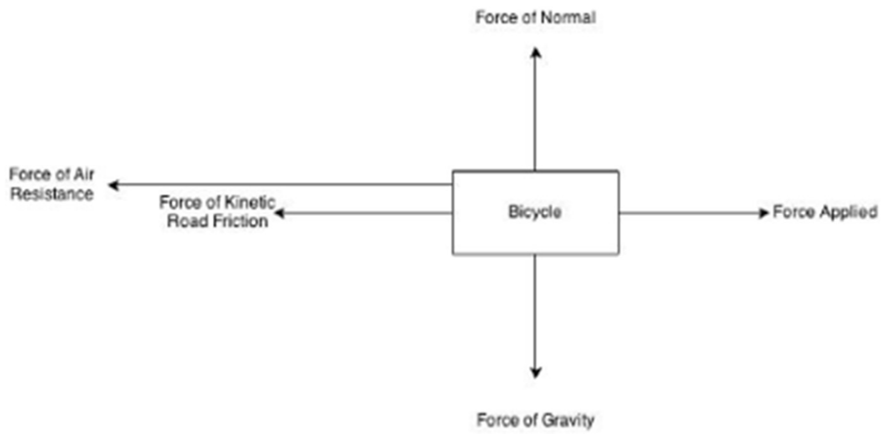

Figure 4 - Free Body Diagram for Bike on Level Ground [4]

After several researches, it was figured out that for a bike to move forward, it must overcome three primary forces:

- **Force of Gravity (F_g):** When the bike is moving uphill, its fighting against gravity, but when it is going downhill, gravity works on its favor. This incline/decline can be calculated by measuring the steepness of a hill in terms of percentage grade **G**: rise divided by run, multiplied by 100. The loads on the bike also play a role, as the heavier the bike, and the person riding the bike (the cyclist) are, the more energy to be must spent to overcome gravity. The combined weight of the cyclist and their bike is **W** (lb). The gravitational force constant **g** is 32.174 (ft/s^2) [5].

  The formula for gravitational force acting on a cyclist, in Imperial units, is:

$$F_g = 32.174 * \sin(arctan(G \ * 100)) * \ W$$

- **Rolling resistance (F_{rr}):** Friction between the tires and the road surface slows the bike down. The bumpier the road, the more friction it will experience; the higher quality the tires and tube, the less friction it will experience. As well, the heavier the cyclist and their bike are, the more friction it will experience. There is a dimensionless parameter, called the coefficient of rolling resistance, or C_r, that captures the bumpiness of the road and the quality of your tires [6].

The formula for the rolling resistance acting on a cyclist, in Imperial units, is:

$$F_{rr} = 32.174 * \cos(\arctan(G * 100) * W * C_r$$

- **Aerodynamic drag (F_{drag}):** As the bike is moving through the air, the bike and body need to push the air around the cyclist. As a result, the air exerts a force against the cyclist as they ride. There are a few factors that dictate how much force the air exerts against the cyclist. The faster a cyclist ride, velocity **v** (ft/s), the more force the air pushes against them. Also, the cyclist and the bike present a certain frontal area **A** (ft^2) to the air. The larger this frontal area, the more air must be displaced, and the larger the force the air pushes against the bike and cyclist. The air density ρ (lb/ft^3) is also important; the denser the air, the more force it exerts on the cyclist. Finally, there are other effects that the cyclist is in control of, which contributes slightly to the aerodynamic drag. For example, the slipperiness of the cyclist clothing and the degree to which air flows laminarly rather than turbulently around the cyclist and the bike. These other effects are captured in another dimensionless parameter called the drag coefficient, or C_d [7].

The formula for the aerodynamic drag acting on a cyclist, in Imperial units, is:

$$F_{drag} = 0.5 * Area * \rho * v^2$$

The total force resisting the cyclist, or F_r (lb), is the sum of these three forces [4]:

$$F_r = F_g + F_{rr} + F_{drag}$$

For each foot cycled forward, the cyclist spend energy overcoming this resistive force. The total amount of energy that the cyclist must expend to move a distance **D** (ft) against this force is the **Work** (Joules):

$$Work = F_r * D$$

When the cyclist is moving forward at velocity **v** (ft/s), then they must supply energy at a rate that is sufficient to do the work to move a certain distance each second. This rate of energy expenditure is called power, and it is measured in Horsepower (hp). The power **Pw**(hp) that must be provided to the bike's wheels to overcome the total resistive force **F_r** (lb) while moving forward at velocity **v** (ft/s) is:

$$Pw = F_r * v$$

The cyclist is the motor providing this power. The power that must be provided to the bike's wheels comes from them, but not all of the power that they deliver make it to the wheels. Friction in the drive train (chains, gears, bearings, etc.) causes a small amount of loss, usually around 2%, assuming the drivetrain is clean and nicely lubricated. The percentage of drivetrain loss is **Loss** (percent). So, if the power that the cyclist provide is **P** (hp), then the power that makes it to the wheel is:

$$P = (1 - Loss) * 100 * P$$

Putting it all together, the equation that relates the power produced by the cyclist to the steady-state speed travelled is:

$$P = (1 - Loss * 100) - 1 * \left(F_g + F_{rr} + F_{drag}\right) * V$$

$$P = (1 - Loss * 100) - 1 * \left((32.174 * W * (\sin(\arctan(G * 100)) + C_r * \cos(\arctan(G * 100)))\right) + (0.5 * C_d * Area * \rho * v^2)) * v$$

Using this formula, the estimated power needed to get and maintain the velocity of the bike at the desired conditions can be calculated:

Assuming

- ⇒ Flat, smooth surface, clean lubricated drivetrain
- ⇒ Cyclist weight: 165lbs
- ⇒ Bike weight: 17lbs
- ⇒ Velocity: 20mph ≅ 30ft/s
- ⇒ Frontal area: 5.500 ft^2
- ⇒ Rolling coefficient: 0.005
- ⇒ Drag coefficient: 0.630
- ⇒ Drivetrain Loss: 2%
- ⇒ Air density: 0.077 lb/ft^3

The power **P** that a cyclist required to apply to maintain a speed of 20ft/s(20mph) is 0.231hp (180watts). With the same conditions, assume going up a hill with the steepness of G= +3%, the power required would increase to 0.536hp (400watts).

After these calculations, it was concluded that the mechanical output of the motor differs according to the desired amount of speed that the cyclist wants to travel on and the surrounding conditions. According to the conditions, it was decided that a 250W - 500W motor is more than capable of accomplishing the job.

Selecting the appropriate electrical components for an e-bike is crucial in designing a well-functioning and user-friendly e-bike. In Nova Scotia, legislation states that the largest capacity of an electric motor for an e-bike can be no more than 500 watts and is incapable of assisting at speeds above 30 km/h on the level ground [8]. Because of this, the design will be using no more than a 500-watt motor to comply with legislation.

When choosing an electric motor and electronic controller, it will be best to select equipment that is compatible with each other. This will minimize the number of issues within the system. The best choice of motor is going to be a brushless Direct Current (DC) motor. The brushless DC motor offers many advantages for an e-bike system. The first is that there is no maintenance or brush replacement after thousands of hours of service [9]. The second reason is that there are no fine metal particles and debris because there are no brushes [9]. Lastly, the brushless DC motors have very efficient rotor speed control over a conventional DC motor. They are the ideal solution for a bike that will have varying speeds.

Since this is an electric bike, there will need to be a way to store energy locally on the bike to power the electrical equipment. The best solution for this is the use of batteries. Through some research, there are four common types of battery chemistries, lead-acid, nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and Lithium-Ion Phosphate (Li-ion). When comparing battery technologies, there are numerous amounts of properties to consider, but for the e-bike application, the following properties of each battery chemistry are the most important to consider: energy density, toxicity, life cycle, and maintenance requirement. All this information is tabulated below in *Table 1* with the specifications [10].

Table 1 - Battery Comparison

Specifications	Lead-Acid	NiCd	NiMH	Li-Ion
Energy Density (Wh/kg)	30-50	45-80	60-120	90-120
Life Cycle (80% Discharge)	200-300	1000	300-500	1000-2000
Maintenance Requirement	3-6 Months (Topping Charge)	30-60 Days (Discharge)	60-90 Days (Discharge)	Not Required
Toxicity	Very High	Very High	Low	Low

After looking at the data from the table above, it is clear to see that with the long-life cycle, high energy density, low maintenance, and low toxicity, the Li-Ion would be a viable choice for the project. This will allow the batteries to take up a smaller area within the kit while providing enough energy to power the electrical equipment.

Since this will be an electric bike, the user needs a way of controlling and operating the electrical components. The user controls for the e-bike will be accomplished by using switches/throttle on the handlebars. Please reference *Figure 3* for the proposed location. This is the most natural way for the user to control the e-bike. This will be accomplished by either a resistive switch, display, or a combination of the two.

Design

The electrical, mechanical, and structural aspects of the E-Bike Conversion Kit were designed with the aid of two programs. The first was Autodesk Inventor which is a computer aided design (CAD) application that is used in 3D design and analysis of projects and the ability to perform stress analysis of structures. The second was Autodesk AutoCAD which is another CAD application that specializes in two dimensional drawings. These two programs were selected as it was being used in class CAD labs along with being accessible on the school computers.

Component Enclosure

To be able to protect the motor and the battery components from various weather and road conditions, along with making the product user-friendly and easy to setup, a well-designed enclosure was needed. Before beginning the design process of the enclosure in Inventor, Mr. Steve MacDonald was consulted to seek advice on what is possible to do when constructing an enclosure with the ability to withstand the torque produced by the motor and the various weather conditions. A box like component enclosure, with a lid, was decided upon, to keep the components safe and give the conversion kit a sleek appearance. Please reference Appendix I for detailed AutoCAD drawings of the entire E-Bike Conversion Kit and *Figure 5* below for a 3D model of the component enclosure.

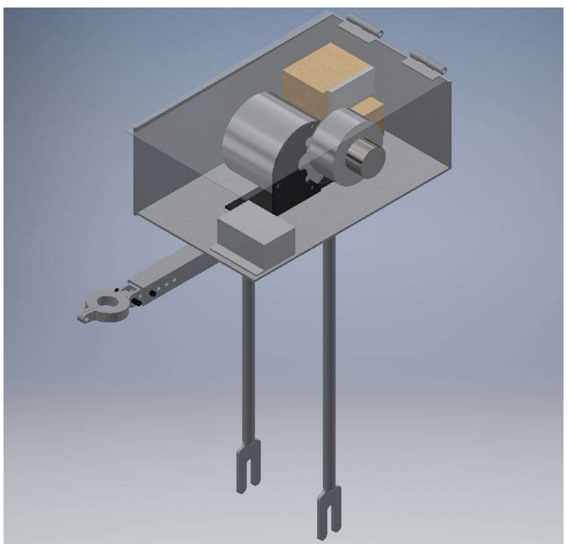

Figure 5 - 3D Rendering of Component Enclosure

Material

The material that was decided on for the vertical and horizontal supports, the hinges and the base and walls of the enclosure was 1/8-inch 304 stainless steel. This was selected as the desired build material due to its high ultimate tensile strength of 505 MPa, [11] along with being very corrosion and weather resistant. It is important to have a durable and corrosion resistant material that can easily be welded as the base compared to a material like aluminum 6061-T6 which only has a moderate ultimate tensile strength of 310 MPa [12]. A comparison between 304 Stainless Steel and Aluminum 6061-T6 can be found in *Table 2* below. Seeing as this component enclosure was going to have to support the torque from the motor along with the weight of all the various components, the 304 stainless steel was ultimately decided as the material of choice for the component enclosure. After using inventor to test different thicknesses of stainless steel to determine the best fit for the component enclosure through the stress analysis feature, the 1/8-inch thickness was determined to provide the most support and rigidity for the component enclosure.

Table 2 – Material Comparison Between 304 Stainless Steel and Aluminum 6061-T6

	304 Stainless Steel	**Aluminum 6061-T6**
Physical Properties		
Density	8 g/cm^3 or 0.289 lb/in^3	2.7 g/cm^2 or 0.0975 lb/in^3
Mechanical Properties		
Ultimate Tensile Strength	505 MPa	310 MPa
Yield Tensile Strength	215 MPa	276 MPa
Modulus of Elasticity	193-200 GPa	68.9 GPa
Elongation at Break in 50 mm Specimen	70 %	12 %
Poisson's Ratio	0.29	0.33
Shear Modulus	86 GPa	26 GPa
Electrical Properties		
Electrical Resistivity	7.2e-005 Ω*cm	3.99e-005 Ω*cm
Thermal Properties		
Coefficient of Linear Thermal Expansion (20°C)	17.3 μm/ m*°C	23.6 μm/ m*°C
Coefficient of Linear Thermal Expansion (250°C)	17.8 μm/ m*°C	25.2 μm/ m*°C
Specific Heat Capacity	0.5 J/g °C	0.896 J/g °C
Thermal Conductivity	16.2 W/ m*K	167 W/ m*K
Melting Point	1400 – 1455 °C	582 – 652 °C

The material that was decided on for the lid of the component enclosure was a PVC plastic because it is lightweight (roughly a density of 0.050 lb/in^3 [13]), and durable. This means that the lid would be able to sufficiently protect the contents of the enclosure from weather or dirt, along with it being light enough that the consumer can easily lift if needed and lowering the weight and cost of the entire product. Another consideration and reasoning behind choosing PVC as the lid material was, as the lid was not an essential component of the enclosure itself, it did not make sense for it to be made of a heavier material as that would contribute to a heavier and more expensive component enclosure.

Dimensions

The dimensions of the box were chosen based on the size of the components and their arrangement within the component enclosure along with giving allowable tolerances for each component to ensure that one component was going to be at risk of damaging another component. The desired interior dimensions of the enclosure were 12.5”x 7.5” x 4.75”, based on the size of the parts that were stated. Seeing as the 304 stainless steel that is being used is 1/8-inch in thickness, the exterior dimensions of the component enclosure are 12.75” x 7.75” x 4.875”.

Support Design

After completing the design of the component enclosure, the next step in the design process was the enclosure supports and their respective attachment mechanisms. After looking at already existing conversion kits and rear-wheel racks and considering the overall weight of the enclosure and torque produced by the motor, it was decided that having both horizontal and vertical supports would be necessary.

For the horizontal support, a fixed support was decided on to prevent any horizontal motion of the enclosure. This support was welded onto the bottom of the enclosure and attached to the bike just below the seat. This support was designed to be adjustable, having an outer piece, with a smaller piece inside that could be extended or retracted, based on the horizontal length from the center of the rear wheel to the seat of the bike. The support can be adjusted by up to 2 inches, in 0.5-inch increments, so it is compatible with all average adult sized bikes. After the support design in inventor, the next step was to design the attachment mechanism. For adjustability purposes, a clamp was designed that would fit the average size adult bike and adjust to be slightly smaller or larger depending on the bike on which it is being installed. The clamps inner diameter of 1 inch was decided on by researching average diameters of the cylindrical rod under the seat of a bike [14] , and measuring the seat post of the reference bike, which had a diameter of 1 which is the standard. The clamp would need to be adjustable to fit bikes with a slightly smaller or larger diameter.

After the design of the horizontal support, designing the two vertical supports was the next step. The vertical supports would be attached to the component enclosure in the center, on both sides. The lengths of the vertical supports were measured from the reference bike, and an additional length adjustment was added at the ends to make the supports adjustable, and work on different bike sizes. The diameters of the curves are measured by a default bolt size therefore making it compatible with other bikes as well.

Component Placement

A detailed inventor assembly of the component enclosure along with the placement of each part can be found in appendix I. The placement of the components is discussed in detail and can be found at the beginning of the component enclosure section. The placement of each component within the enclosure itself was somewhat of a concern as the motor was only able to go in one specific spot and everything else had to fit around. The motor had to be aligned with the back axle of the bike, specifically with the opposite side of the bike gears as this was going to be where a chain ran that would in turn the wheel and thus creating electric power to move the bike. Another thing to consider when the positioning of the parts was not positioning the batteries too close to the motor or the chain in the case that there was an accident and to ensure that the batteries were not damaged. For this reason, the battery pack was placed as far away from the motor as possible, resulting in the battery pack being in one corner of the component enclosure. This corner was on the opposite side of the bike seat post, which does result in more weight being at a farther distance from the fixed support of the seat post and thus greater torque. However, to ensure the safety of the component enclosure and that there are not any accidents including the possibility of a short circuit if the chain was to break and short the terminals, it was decided to have the battery pack in this corner. The motor controller was placed in a corner near the motor as it was easy connection for the wiring along with being out of the way from the other components.

Securing Components

Positioning of the components is one task but, to ensure that while in motion the components of the conversion kit do not move, securing each of them to the enclosure is just as important. The motor was secured using a bracket that is able to fit on the motor side of the motor component and then goes underneath the motor and welded to the base of the enclosure. The motor controller was secured by welding it to base of the component enclosure. To secure the battery pack and the wires to the base and walls of the component enclosure, steel strapping was used and one end was riveted to the base of the component enclosure while the other end was pulled tightly to restrict movement of the battery pack and wiring and riveted to the walls of the box. The PVC lid was to be secured by two hinges which were designed in Inventor. The hinges would be welded onto the side of the enclosure and screwed onto the PVC lid.

Weight of Enclosure

The weight of the entire component enclosure, including the horizontal and vertical supports, is an important design aspect to consider as the weight has to be balanced to ensure that the kit is not too heavy for the bike frame itself but, heavy enough to ensure that it is secure and able to perform its functions properly.

304 stainless steel was researched to have a density of 0.289 lb/in^3 and using Inventor, the volume of all 304 stainless steel components was 60.485 in^3. PVC was researched to have a density of 0.050 lb/in^3 [13] and using Inventor, the volume of the PVC lid was 6.297 in^3. Using this information along with the following equation, the weight of the material shown in table 3 can be calculated.

$$Weight = Volume * Density$$

Example calculation for weight of 304 stainless steel:

$$Weight = Volume * Density$$
$$Weight = 60.485\ in^3 * 0.289\ \frac{lb}{in^3} = 17.48\ lb$$

The following, *Table 3*, illustrates the weight of each component along with the entire weight of the E-Bike Conversion Kit:

Table 3 – Weight Breakdown of E-Bike Conversion Kit

Component	Weight (in lbs)
Motor	5.31
Motor Controller	0.28
Battery pack	6.64
Stainless steel box with hinges, and vertical and horizontal supports	17.48
PVC Lid	0.32
Total weight	**30.03**

As one can see, the total weight of the E-Bike Conversion Kit is 30.03 lbs. It is the belief of the group that this weight for a conversion kit is justified in withstanding various weather conditions, the torque generated by the motor, and provide a comfortable biking experience.

Bike Modifications

In order for the conversion kit to be installed effectively, some slight modifications or adjustments need to be made to the user's existing bike. These modifications include adding a back-axle gear to be able to run the chain down from the motor to the axle to ensure motion of the wheels.

The back-axle gear is an additional gear added on the left side of the back wheel, it is located on the opposite side of the bike than the normal chain to allow movement of the second chain running through the chainring to the right back axle gear. This gear's purpose is to transfer the mechanical power from the motor to the wheels by connecting it with a chain that runs through the gear on the motor and generates forward motion, the same way that pedaling produces forward motion.

Electrical Components

DC Motor

After extensive research was conducted for the electrical components, it was concluded that the group wanted to use a 500W Brushless DC Motor, the reason for this was to provide a competent motor that would have the most amount of power that is allowed by legislation [8]. After contacting and browsing retailers' inventories, there were no brushless DC motors available that could be used for the project. So as a group decision, it was decided to change the motor to a 250W Brushed DC Motor, the reason for this was because then the design would have a power output identical to a Specialized Turbo Levo Hardtail, mentioned in the research portion of this report. Then, to ensure that it would be possible to use a 250W Brushed DC Motor, it was then required to contact and browse retailers' inventories to see if any were available for use. Fortunately, plenty were available, so then it was decided that a 250W Brushed DC Motor is going to be used. One downside of switching to a brushed DC motor is that the bike will not be able to recover kinetic energy from the bike.

Next was deciding on an operating voltage for 250W Brushed DC Motor. A design decision that was made before selecting a motor was to find a motor that operates at a higher DC voltage so that the continuous current would be lower value to reduce I^2R heat losses and would allow for a smaller gauge wire to reduce weight. So, the motor that was chosen was the MY1016Z2-250W 24V. This motor, when operating at full load, has a full load amperage (FLA) of 13.7 amps (A). A datasheet for the motor specifications is in appendix III.

DC Motor Controller and Control Accessories

Now, with the motor selected, an appropriate motor controller was needed to be chosen. Luckily, the motor that was selected for the design included a motor controller. The motor controller that was included did not have much documentation. Still, it is rated to operate at 250W with a 24 V ± 4 V motor continuous current rating as high as 21 A ± 1 A. The control is very modular with connections for the battery pack, motor, throttle, brake, and electric lock already prewired. The battery pack and motor are just wired directly to their respective cables. The throttle has a potentiometer wired to it to control the speed of rotation for the motor. The brake circuit turns the motor off when the circuit is closed. This is to protect the motor upon deceleration. The electric lock is a safety feature so that the electric motor can be turned off with a key so that someone who does not own or know how to operate the e-bike safely cannot use it. That is why it was decided to use [15] as the electric lock because it is compatible and comes with a key, this product was available on amazon. For the throttle control, it was decided to use a Bike Throttle Grip. These are available on sites like amazon, the one that was chosen that is compatible with the e-bike controller is [16]. To activate the brake, it was decided on using [17], these were chosen because they are compatible with the e-bike controller.

Lithium-Ion Batteries and Battery Pack Design

With the motor and controller selected, the appropriate batteries needed to be chosen. Lithium-Ion batteries are a product that can be very difficult to find. Luckily there was a supplier in New Brunswick that had different types of lithium-ion batteries in stock. One of the options available was the LG 18650 HE4 2500mAh. This battery has a nominal voltage of 3.6 V, a capacity of 2500 mAh, with a maximum continuous discharge current of 20 A. The watt-hour capacity of each battery was calculated to be 9 Wh, proven with the calculation below:

$$Wh = \frac{2500\,mA * \;3.6\,V}{\frac{1000\,mA}{1\,A}} = 9\,Wh$$

To achieve the same capacity of 400 Wh as the Specialized Turbo Levo Hardtail, the design would need 44.443 batteries, but to keep the capacity of the batteries higher than the Levo Hardtail, this value was rounded up to 45 batteries. The calculation for this is below:

$$Number\ of\ Batteries = \frac{400\,Wh}{9\,Wh} = 44.443\,Batteries$$

Having 45 batteries would give an ideal run time of 1 hour and 14 minutes if the motor was operating at full load with 13.7 A of continuous current, shown below in the equation below:

$$Theoreticl\ Run\ Time = \frac{9\ Wh *\ 45\ Batteries}{24\ Vx\ 13.7A} = 1.23\ Hours\ \approx 1\ Hour\ 14\ Minues$$

Since the motor and the controller operate at 24 V ± 4 V to achieve the rated voltage with the battery pack, the following configuration is used. There was two configuraions of battery cells. One cell type has seven LG HE4 batteries in parallel, while the second type of tell has six LG HE4 batteries in parallel. They are then three of the type one cells and four of the type two cells in series to create the battery pack. The battery pack has a nominal voltage of 25.2 V, and 405 Wh of capacity, calculations for this are below.

$$Pack\ Voltage = \frac{3.6V}{1\ Battery} *\ 45\ Batteries = 25.2\ V$$

$$Battery\ Pack\ Capacity = 9Wh *\ 45\ Batteries = 405\ Wh$$

All these cells are managed by a battery management system (BMS). This controls the charging of the batteries to ensure all battery cells are balanced while charging to prevent cell damage. This also protects the batteries under fault conditions, along with providing undervoltage and overvoltage protection. The BMS chosen is designed to work with 24V Lithium-Ion battery packs that use seven cells in series like our battery pack. The BMS can operate at 20A continuous with overcurrent protection of 60A ± 5A, single battery overcharge protection of 3.75V ± 0.035V, and over-discharge protection of 2.10V ± 0.025V. All these features make the BMS an excellent choice for our application and the chosen batteries for the project. All specifications are in appendix III.

With the E-Bike Conversion Kit having a battery pack, there needs to be a way to charge the batteries and safely hold the batteries together as a single large. To accomplish this, there is a company in the United States called Vruzend, who sells anything relating to lithium-ion batteries. We chose to design the battery pack assembly using a VRUZEND battery kit V2.1, a picture of the pack is in the figure below. This kit would provide an easy way to assemble the lithium-ion battery pack because there is no soldering or spot welding required; it is also customizable and adjustable because it is modular. In the future, this will allow easy service if there was ever an issue with a single battery cell. This modular pack is well suited for the E-Bike kit because each lithium-ion battery is rated for 20A continuous, and each terminal cap (orange and black caps) are rated for 20A continuous [18].

Figure 6 - Vruzend Battery Kit V2.1 [18]

To charge the battery pack, a lithium-ion battery charger was chosen, which is also sold by Vruzend. This product was rated to charge batteries at 24V and 3 amps [19]. This would be connected to the battery pack by using the male barrel connector that comes with the charger and using a female barrel connector wired to the battery pack. The ideal time to charge the 405 Wh battery pack from zero would be 5 hours and 38 minutes, as calculated below.

$$Charger\ Watt\ Hours = \frac{24\ V * 3\ A}{1\ Hour} = 72\ Wh$$

$$Time\ to\ Charge = \frac{405\ Wh}{72\ Wh} = 5.63\ hours\ \approx\ 5\ Hours\ and\ 38\ Minutes$$

Conductor Sizing, Overload Protection, and Grounding

Conductor sizing, overload protection and grounding is a requirement of all electrical design. For the sizing of conductors, it can be assumed that an ambient temperature of 30°C and a maximum ampacity of 13.7 A. Therefore, by rule 4-004 of the Canadian Electrical Code (CEC), the size of the conductors within the enclosure will be in accordance to table 2 of the CEC to be a size of no less than 14 AWG copper wire [20]. To simplify the design, all wires within the enclosure are 14 AWG copper wire.

The overload protection will be accomplished by using a DC fuse that is rated less than 115% of the motor full-load current, as stated in rule 28-306 of the CEC [20]. The reason for choosing 115% is because the service factor of the motor was not given in the motor documentation. This fuse is the protection for the battery pack along with the motor. For an extra factor of safety, the fuse is installed between cells four and five in the battery pack. That way, if an overload was to occur between cell terminals, the overload protection is able to de-energize the circuit. The calculation for the maximum fuse size is below.

$$Maximum\ Fuse\ Size = 13.7A * 1.15 = \ 15.755\ A$$

With the maximum size of the fuse being 15.775A, it was decided that a 300VDC 15A fuse is going to be used. The other reason a size 15A fuse was chosen is that the overcurrent protection cannot exceed the ampacity of the conductor it protects, as stated in rule 14-104 of the CEC [20]. The fuse and fuse holder selected is a Littelfuse KLKR Series, model KLKR015, and a one pole Littelfuse L60030C1C Fuse Holder. Datasheets for the fuse and fuse holder can be found in appendix III.

To ensure the safety of the user, the electrical equipment within the box and the enclosure itself must be grounded. This is to prevent accidental electrocution of the user and to protect the electrical equipment within the enclosure. To ensure that the grounding is complying with CEC standards this enclosure is considered by the design group as industrial control equipment because the function of this enclosure is similar to the standard defined for industrial control equipment as stated below from [21]:

"This Standard applies to control and protective devices, and accessory devices, rated at not more than 1500 V, for starting, stopping, regulating, controlling, or protecting electric motors, generators, heating apparatus, or other equipment used to control an industrial process that is intended to be installed and used in non-hazardous locations in accordance with the rules of the Canadian Electrical Code, Part I."

Therefore, the grounding of this enclosure will be in accordance with [21]. The grounding of this enclosure will be accomplished by terminating a grounding wire from the negative side of the battery pack to a CSA approved 14 AWG copper wire grounding and bonding kit installed to the interior of the enclosure. This ensures that the box is compliant with rule 4.16.1.1 and 4.16.1.5 subrule b, table 31. The reason for using 14 AWG copper wire bonding kit is because within the enclosure there will be a continuous current of 13.7A and in table 31 the smallest conductor that can be used with 13.7 A of continuous current is 14 AWG copper wire.

Stress Analysis

In inventor, there is a tool called “stress analysis” that proved crucial in the design phase of the project with demonstrating how the E-bike Conversion Kit would perform under practical circumstances. After each component of the enclosure was constructed as Inventor part files, they were assembled in an assembly file in the configurations of the final product using various joint and constraint methods. Furthermore, in the stress analysis tool within Inventor, there are numerous components to consider before a successful simulation was run. First, the appropriate material was picked for each different part to closely resemble those of the final product, simulating the weight and strength of each part. Next, gravity was added into the correct plane and a point load was added for the battery pack as there was no material that closely resemble the weight of the battery pack. After this, to test the amount of torque that the assembly would have to handle, the maximum amount of torque that the 250W brushed DC motor produced, 11.5 N*m, was placed on the gear surface of the motor part to simulate the motor at full power. The last part of the setup for the stress analysis was adding the types of supports that would exist. A fixed support was placed for the back-seat post as the horizontal support is attached to a clamp that is fixed on the seat post. Pin supports were added on the bottom of the vertical supports where they would be attached to the bottom back axle as they resisted motion in the vertical and horizontal directions but did not resist a moment. The other pin supports of the assembly were used where the pins would be placed between the two horizontal supports as they allowed for the kit to be placed on different sized bikes.

After running the stress analysis multiple times with various configurations, placements and materials, the design previously mentioned was selected as it handled all the given conditions well and was not compromised in any way. As shown in the stress analysis test results that are located in appendix II, the E-Bike Conversion Kit is able to sufficiently handle any given stress and torque that are produced as a result of the motor or weight of the components.

Cost Analysis

The following cost analysis will be that of the theoretical product, not that of the prototype, based on research and calculations of each component and located below in *Table 4*:

Table 4 - Cost Analysis of Theoretical Design

Component	**Cost $CAD**
Motor [22]	$90.23
Motor Controller [23]	$53.43
45 Lithium-Ion Batteries [24]	$359.55
Battery connectors [18]	$39.99
Battery Management System [25]	$11.39
Chain [26]	$27.82
Stainless steel	$17.65
Throttle [16]	$33.49
Electric brake/speed shifter [17]	$25.49
Ignition switch [15]	$7.18
24V Lithium-ion battery charger [19]	$36.99
Odyssey 13T Freewheel [27]	$29.00
Manufacture Total	**$732.21**

The goal for the cost of this product was to keep the price significantly below that of the Specialized Turbo Levo Hardtail, and in that aspect the E-Bike Conversion Kit was successful in doing so.

E-Bike Comparison

After completing the E-Bike Conversion Kit, it was critical to compare the designed kit to the Specialized Levo Hard Tail. This was to ensure that the project goal was met. Located below in *Table 5* is summarized details of the E-Bike Conversion Kit and The Specialized Levo Hard Tail.

Table 5 - E-Bike Comparison

	E-Bike Conversion Kit	Specialized Levo Hard Tail
Motor Power	250W	250W
Nominal Voltage	24 V	36 V
Battery Capacity	405 Wh	400 Wh
Runtime	1h 14m	Not Listed
Charge Time	5h 38m	3h 15m*
Cost	$732.21	$3699.00

*Charges faster because charger included is 42V and 4A [28]

After comparing the two products the E-Bike Conversion Kit has the same if not better specifications then the Specialized Levo Hard Tail, because of this the goal of the project was met. The only specification that is less is the charge time of the batteries, the reason for this is because the charger included with the Specialized Levo Hard Tail is a faster charger operating at a higher voltage.

Final Product

Seeing as the E-Bike Conversion Kit is a consumer product, included in the purchase of the kit is the following:

- Component enclosure including all of the mechanical and electrical parts installed inside
- Vertical and horizontal supports that are welded to the enclosure and attached to the bike by the user
- Back-axle gear and chain to be installed by the user
- Electric control accessories to be installed by the user

Prototype

Using the results from the Inventor testing, along with working with Steve MacDonald from the machine shop on campus, a prototype was going to be built. The prototype was to have the same component enclosure, placement and securement of all the components; however, it was going to be a slightly scaled down version of the final product, in terms of battery capacity and run-time, due to a budget restriction of $400, set out in the project guidelines. After having Steve build the prototype enclosure and once the E-Bike Conversion Kit was fully built, it was going to be tested. The tests that were going to be performed were a speed test, a battery duration test, and an all-around user friendly/mobility test. Each of these tests are crucial in understanding the performance of the product along with seeing how user friendly the product was. Based on the results and feedback that was received, Inventor would have been used again to modify and fix these concerns.

To prove that the electrical aspects of the project worked as intended, a prototype needed to be built and tested. For the prototype being built, it was decided that a scaled-down battery back using seven cells with two batteries in parallel in each cell would be built. The same type of batteries was used from the original design. The reason for using less was to save costs on the prototype. This battery pack was only 144 Wh and would be just big enough to prove the concept of the E-Bike Conversion Kit. Included in the assembly of the battery pack was the BMS system to ensure the batteries were balanced while charging. After completing assembly, one full charge cycle was completed for the battery pack.

To ensure the controller and motor were going to work as intended, a benchtop test was performed by wiring the motor, the controller, and all accessories as it was specified to the electrical diagrams in appendix III, for the test setup a benchtop power supply to power the equipment. After energizing the equipment, it was found that all functions of the controller and control equipment were working successfully, and we were able to control the motor to meet the requirements of the E-Bike Conversion Kit. Unfortunately, this was as much as the group could accomplish before March 14th.

Setbacks

On March 14th, 2020, St. Francis Xavier University sent out an email stating that they were suspending in-person classes and that the university would be closed to the public due to the COVID-19 pandemic. This brought the aspirations of the prototype and testing to a halt seeing as the students were told to leave campus by March 22nd, 2020. Due to these unforeseen circumstances, the ability to complete the prototype phase was not possible and thus, a portion of the design process was not able to be accomplished. Although it was not possible to physically build and test the prototype, it was still possible to continue using inventor off-campus to complete the stress analysis tests on the prototype.

Conclusion

In conclusion, the E-bike Conversion Kit achieved the goals set out by the design group of being both a user friendly and cost-effective product, compared to any other electric assist bike currently on the market. The final theoretical design was achieved by following the process of designing and testing a consumer product to produce the final theoretical weight of 30lbs and a build cost of $732.21. A need was established for a certain population, that being the need for a user friendly, lower cost alternative for conventional electric bikes and this was then turned into a goal for the final product. After extensive research on various already available non-user-friendly conversion kits and expensive electric bikes as well as the different components needed to be able to achieve the desired goal, a design was brought to life. The design was then tested under various conditions and with different specifications to achieve the best possible product using various types of analyses learned in the engineering course taken so far. Statics, Strengths of Materials, and Dynamics aided with the calculations and computer analysis of the component enclosure and supports. Circuit analysis helped with the calculations required for battery capacity, charge time, range, and choosing the best option for a motor. Engineering Economics aided with the determining a manufacturing and proposed market cost of the E-Bike Conversion Kit.

Due to the unforeseen circumstances of the COVID-19 pandemic, it caused the campus to close and thus halting the prototype and testing phase of the design process. If this project were to continue, the next steps would be construction and testing of a prototype along with any modifications due to the testing would be crucial in completing the design process and procuring the consumer friendly, low cost E-Bike Conversion Kit that this project yielded.

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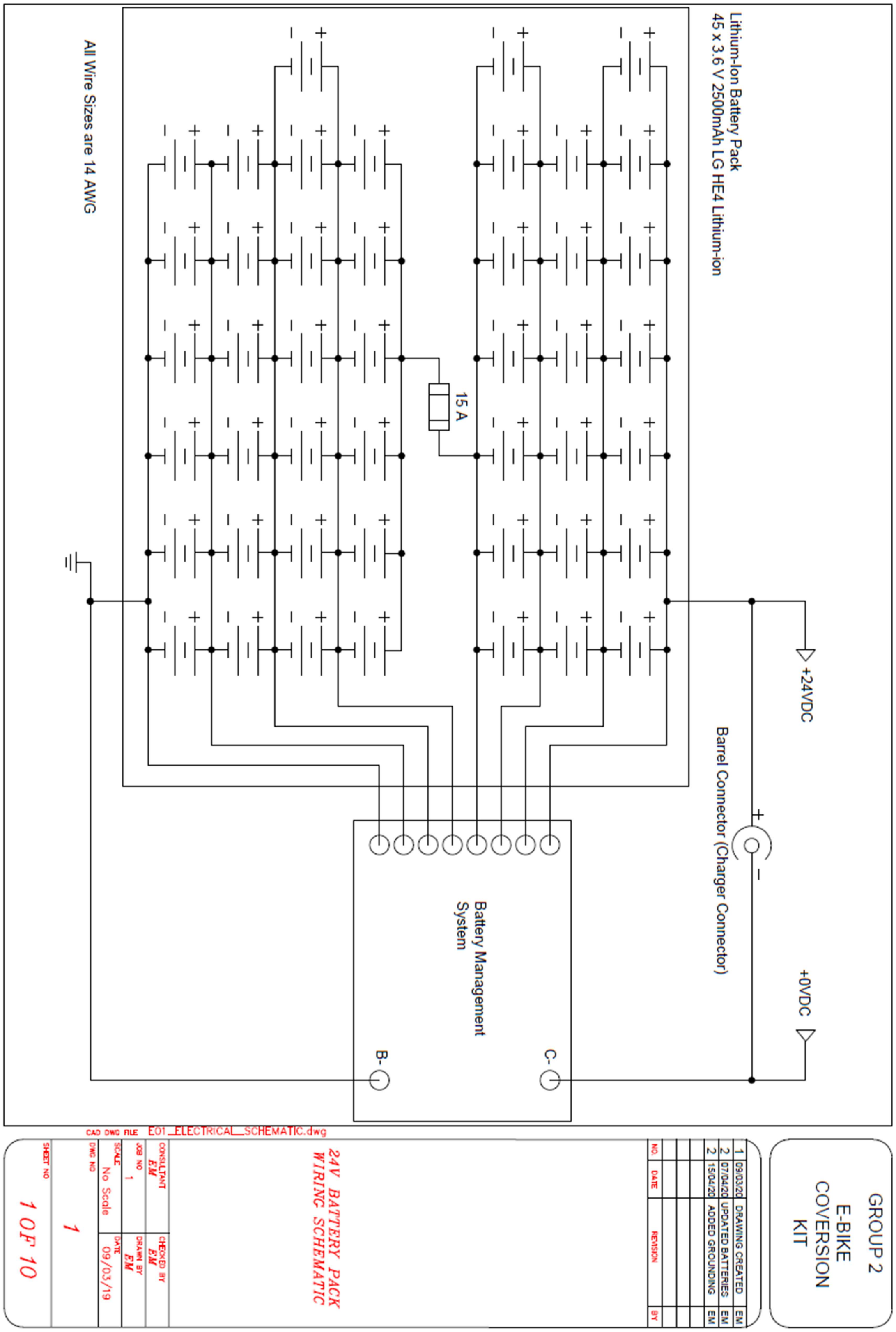
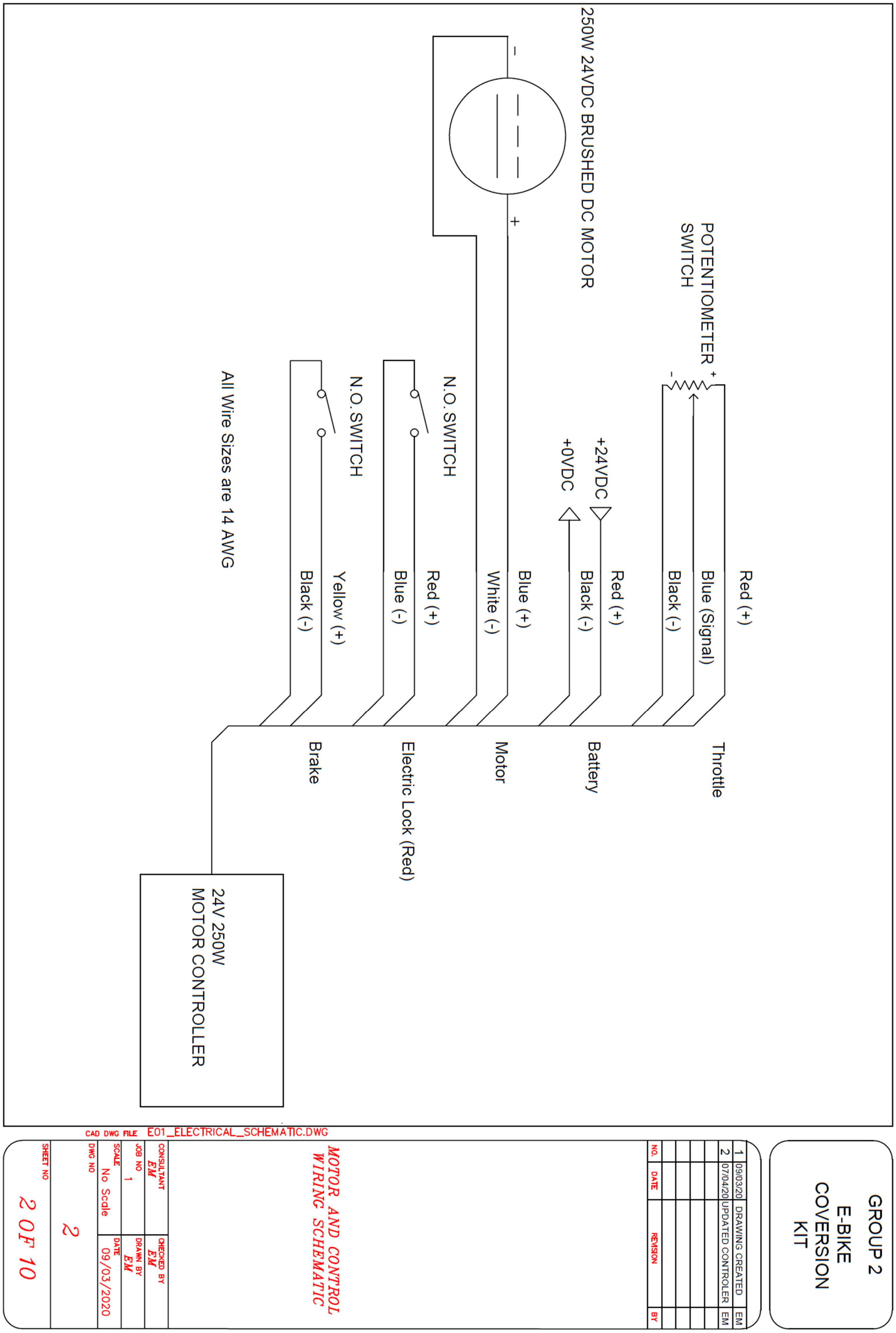
Appendix I – AutoCAD Drawings & Inventor Part Schematics

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+0VDC
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N.O. SWITCH
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Blue (Signal)
Black (-)
Red (+)
Black (-)
Blue (+)
White (-)
Red (+)
Blue (-)
Yellow (+)
Black (-)
Throttle
Battery
Motor
Electric Lock (Red)
Brake
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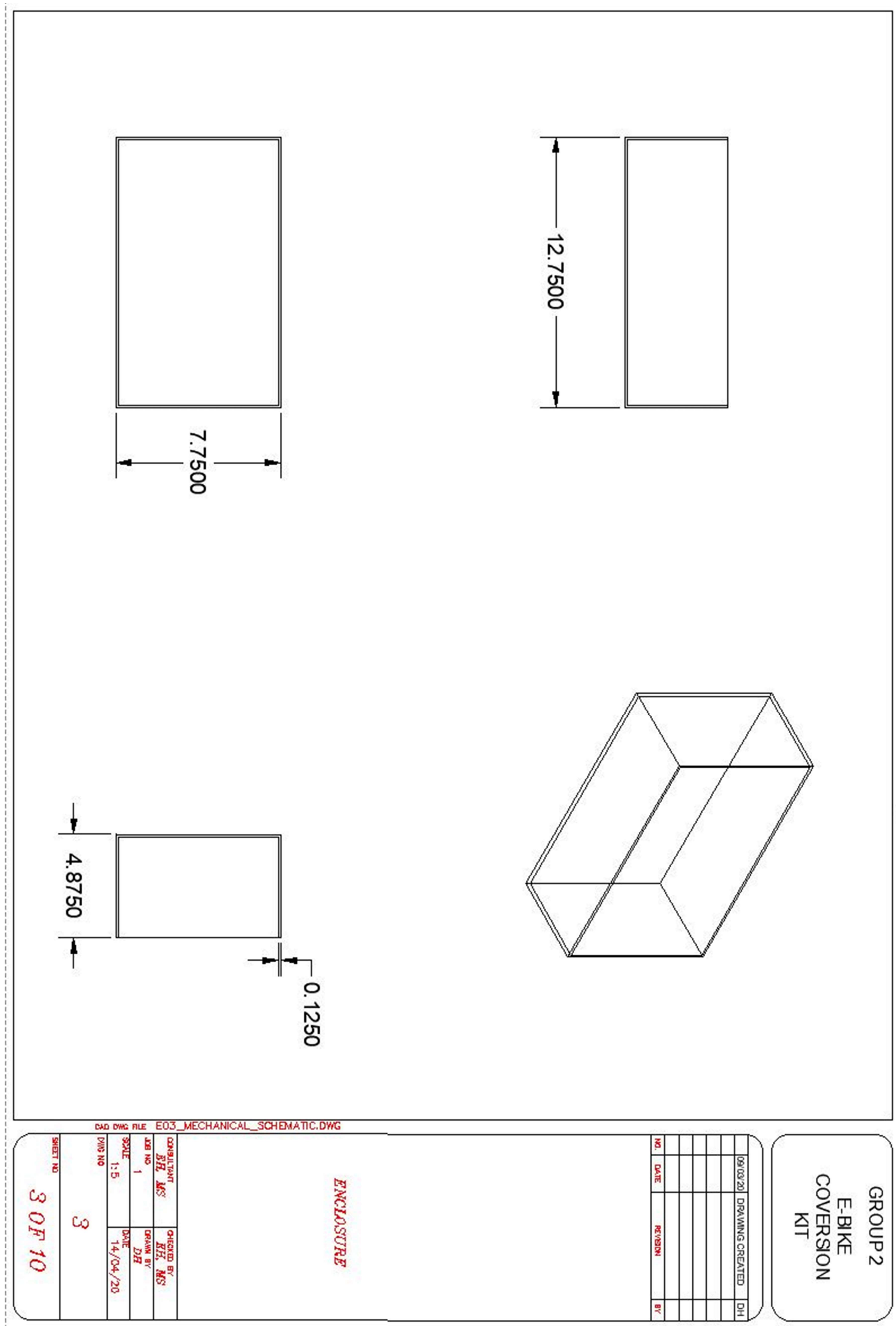
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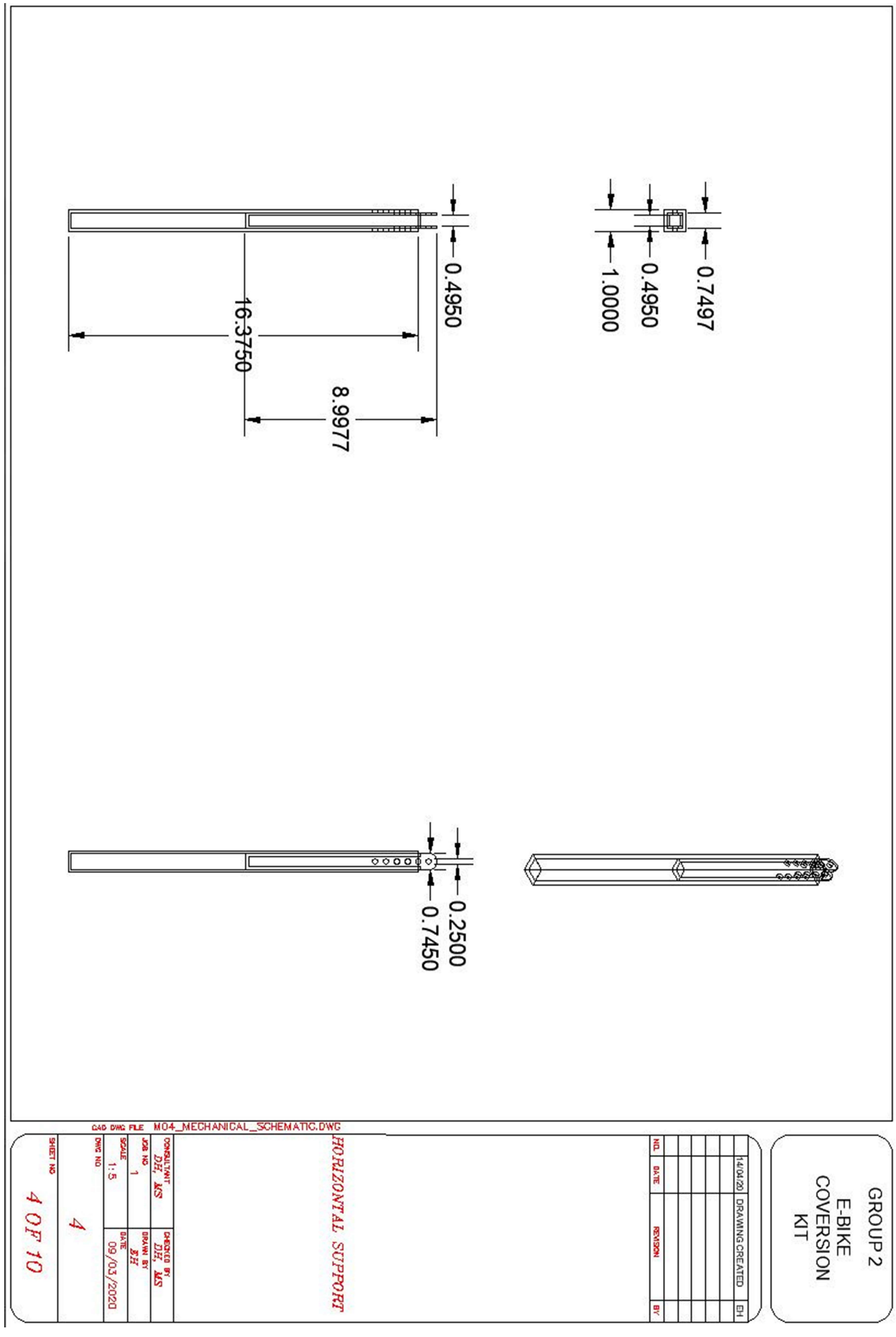
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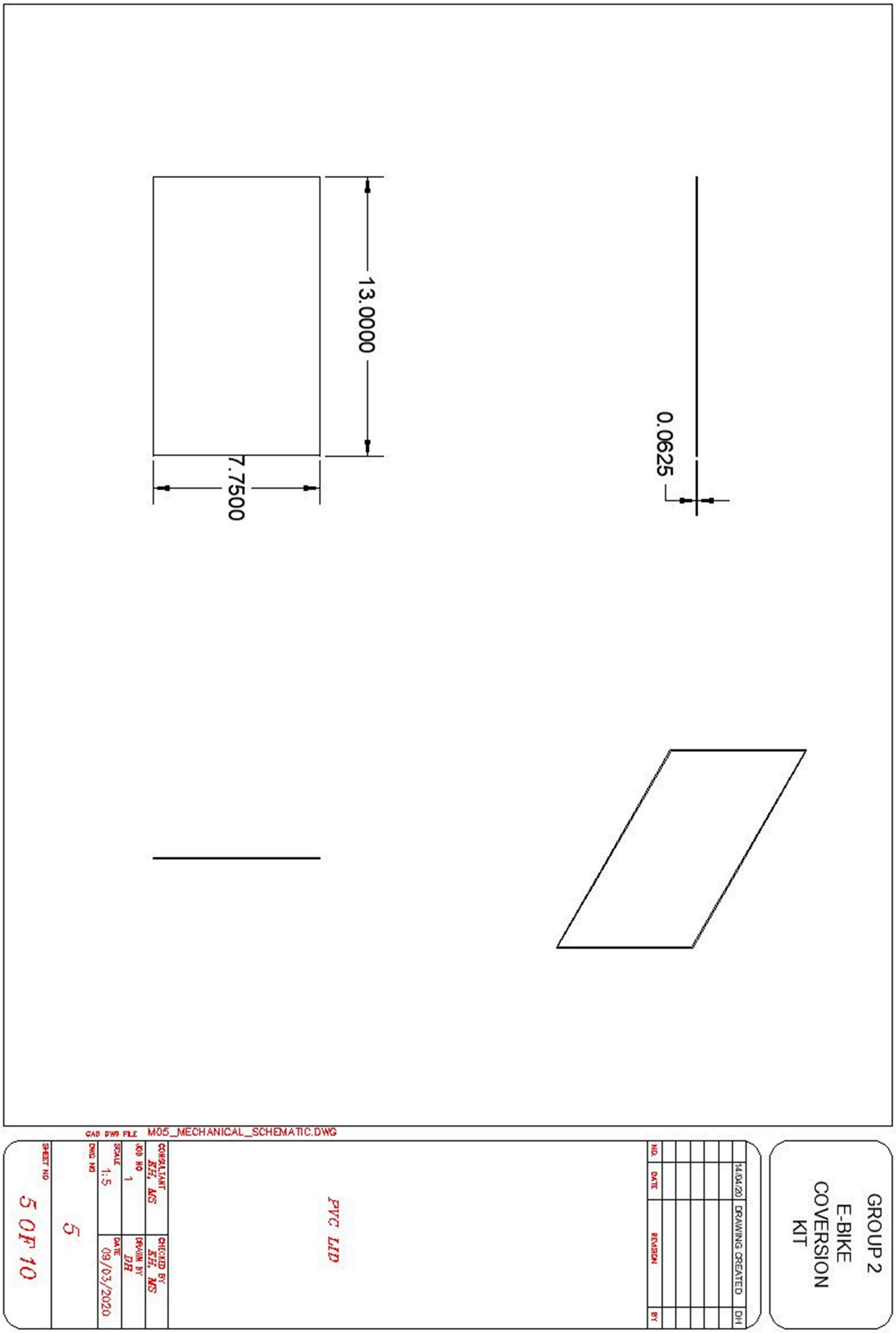
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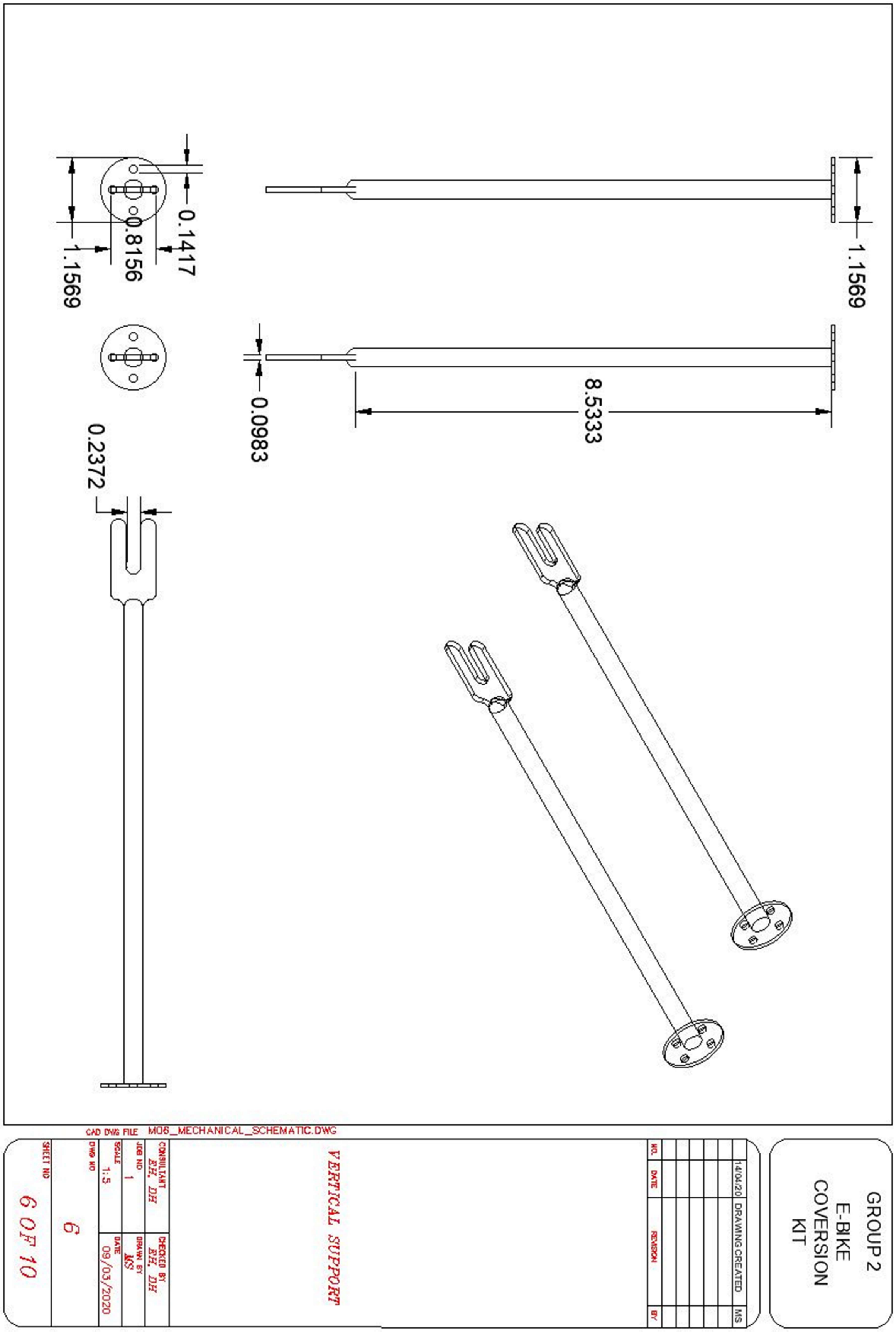
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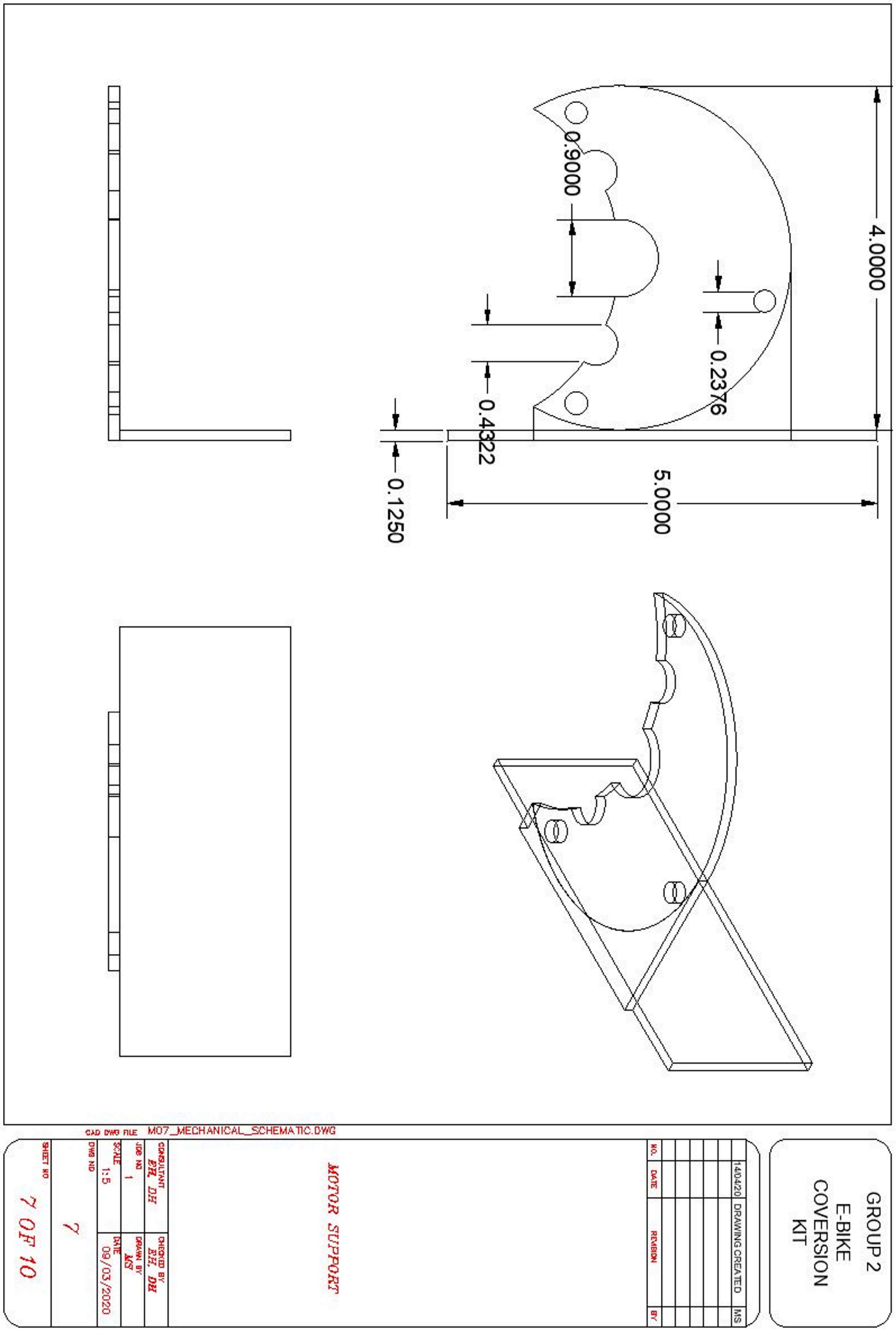

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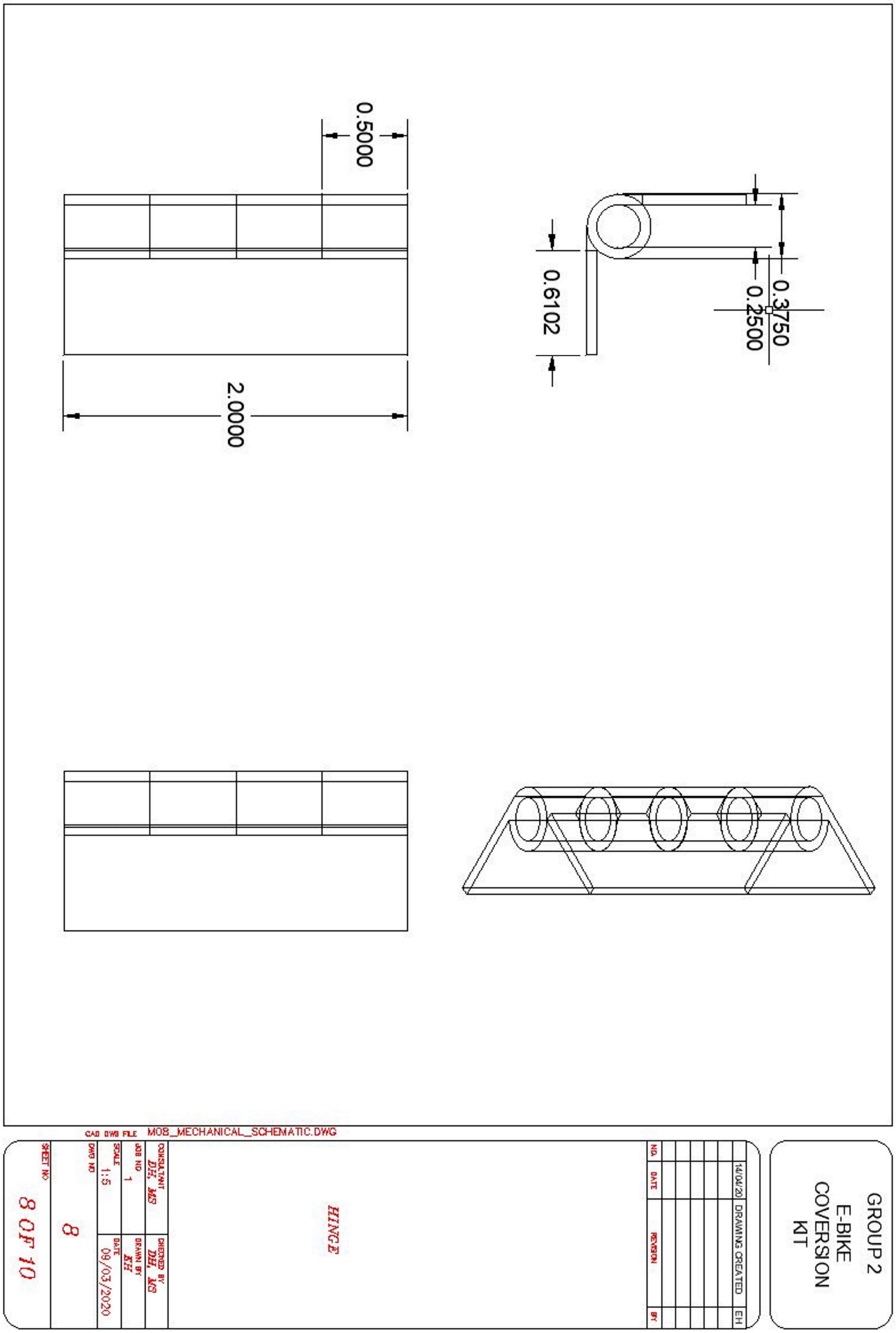
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DATE 09/03/2020
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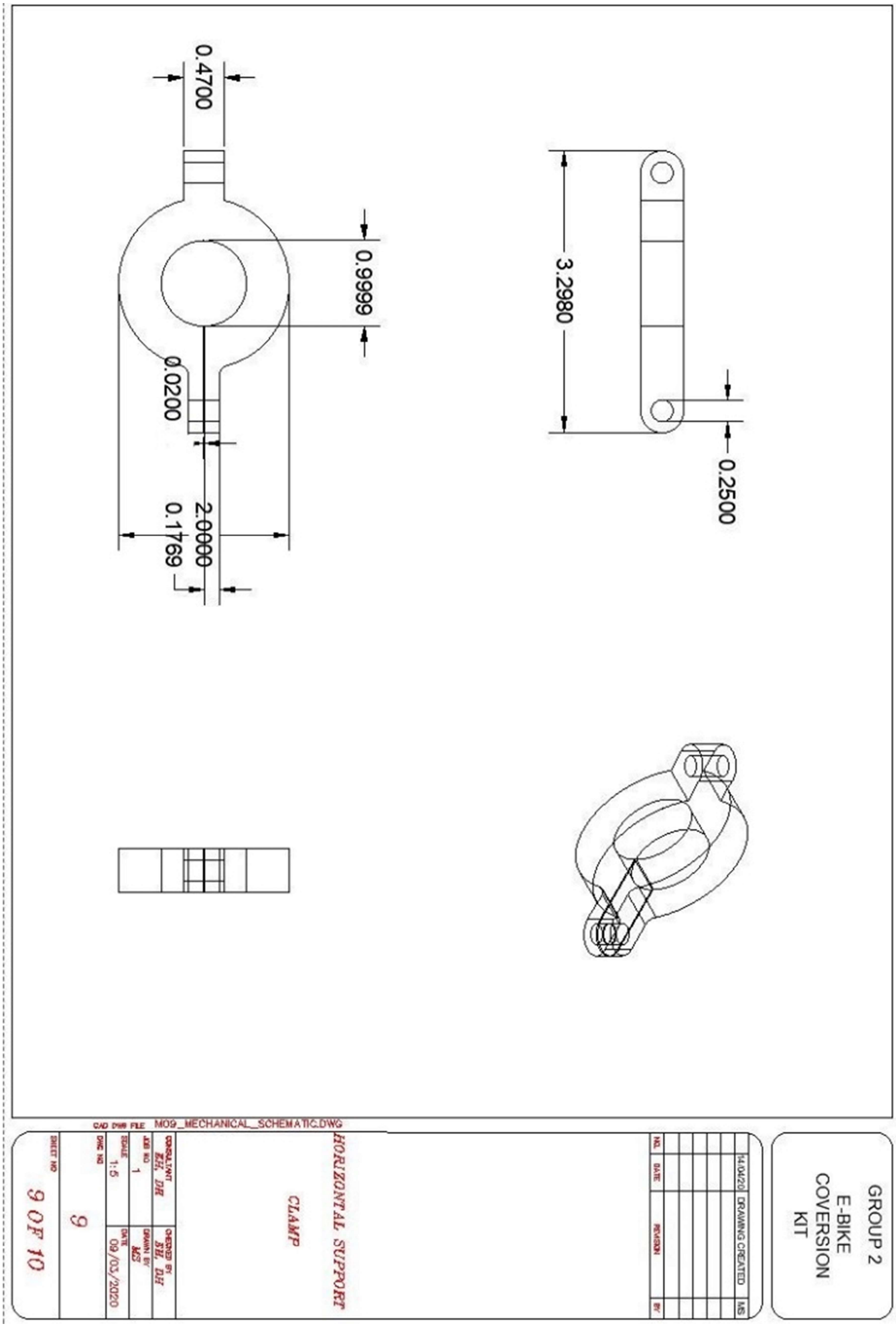
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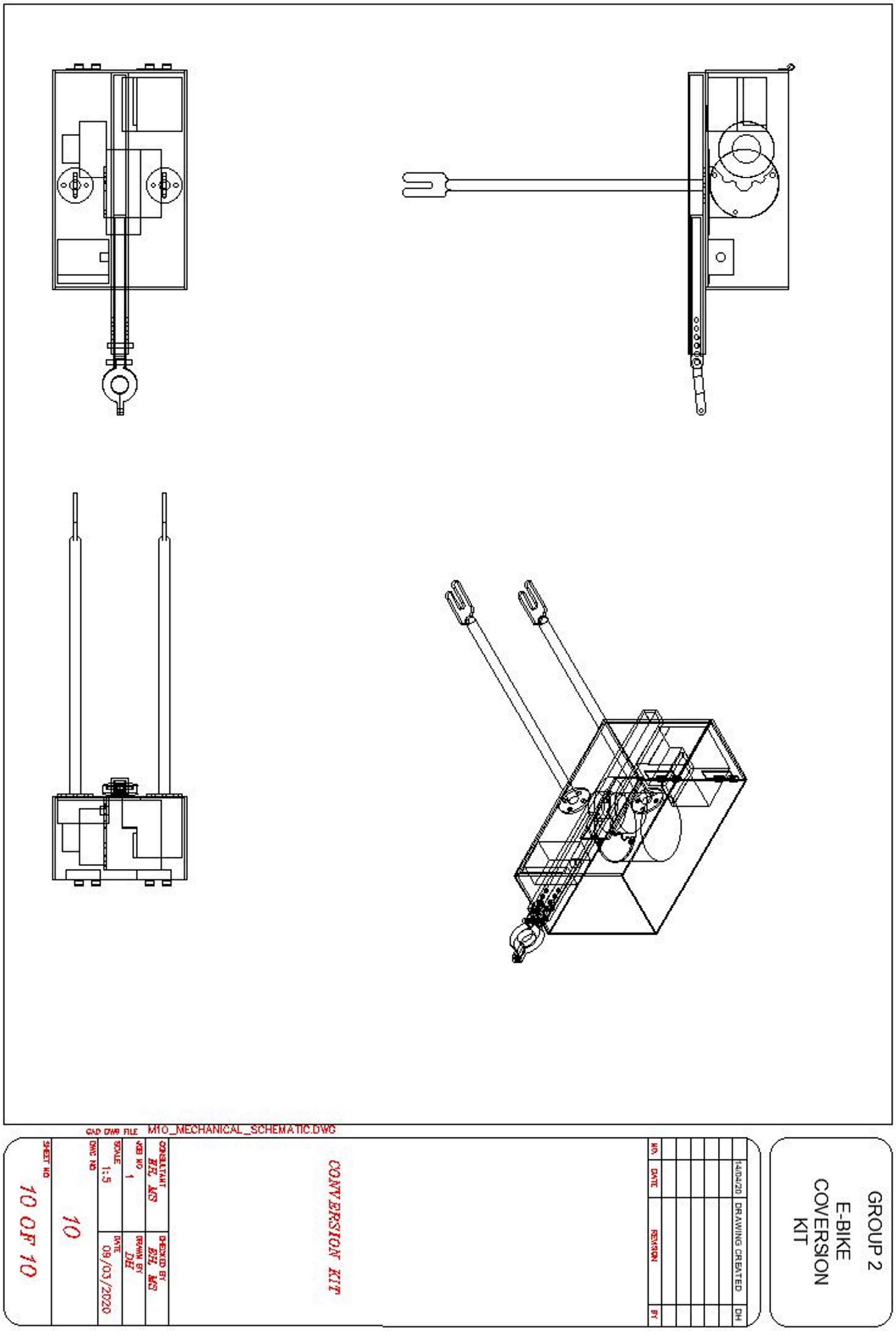
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E-BIKE
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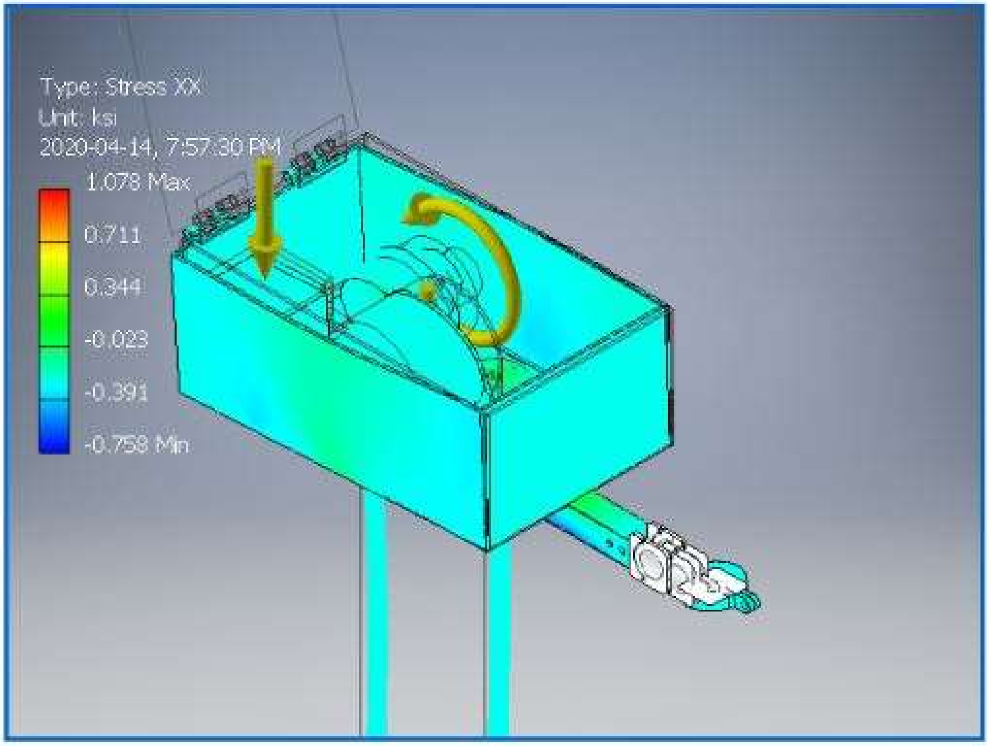
Appendix II – Inventor Stress Analysis

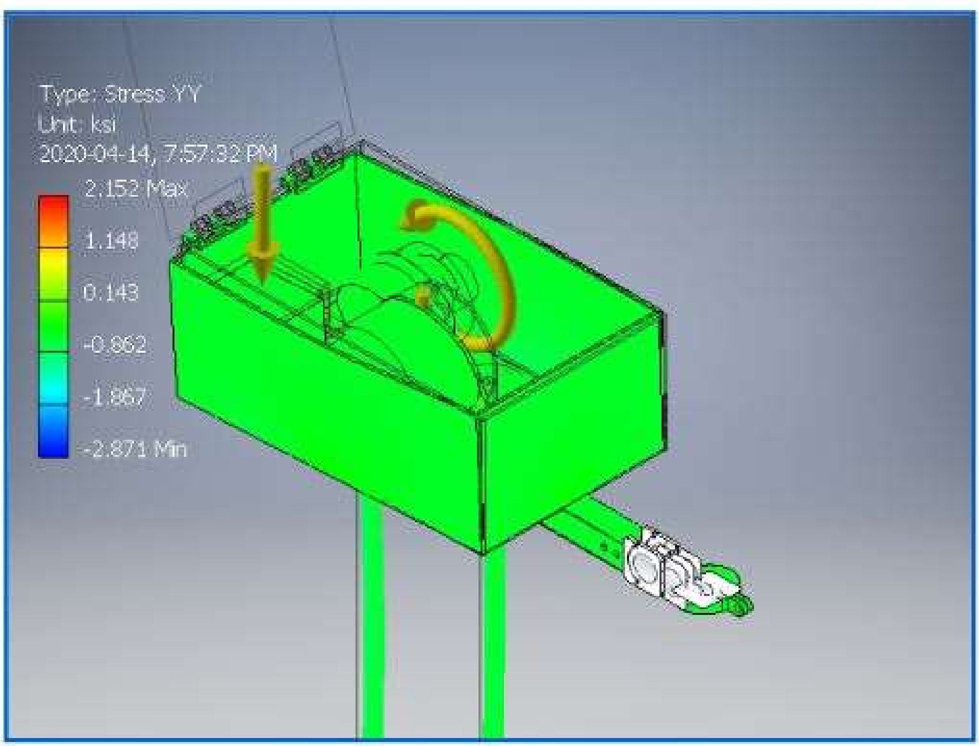
Result summary of the minimum and maximum normal and shear stresses on every face direction.

Name	Minimum	Maximum
Volume	156.506 in^3	
Mass	33.8541 lbmass	
Stress XX	-0.75775 ksi	1.07807 ksi
Stress XY	-0.398123 ksi	0.288821 ksi
Stress XZ	-0.386926 ksi	0.353698 ksi
Stress YY	-2.87125 ksi	2.15246 ksi
Stress YZ	-0.711916 ksi	0.455794 ksi
Stress ZZ	-0.959194 ksi	0.814323 ksi

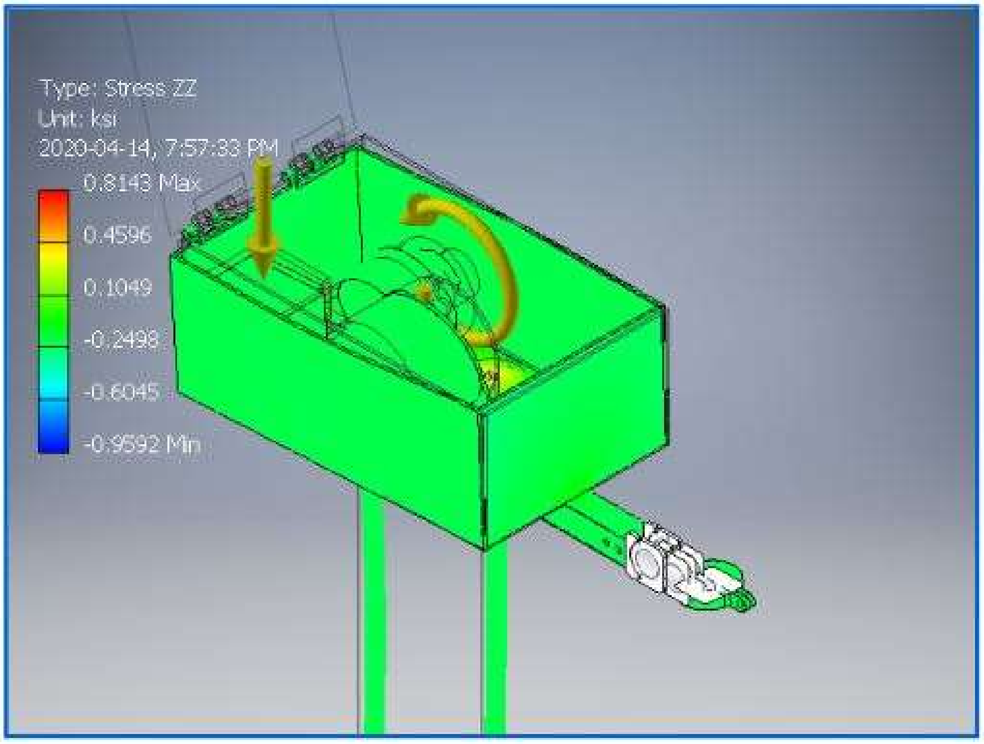
Normal stress in the X-direction:



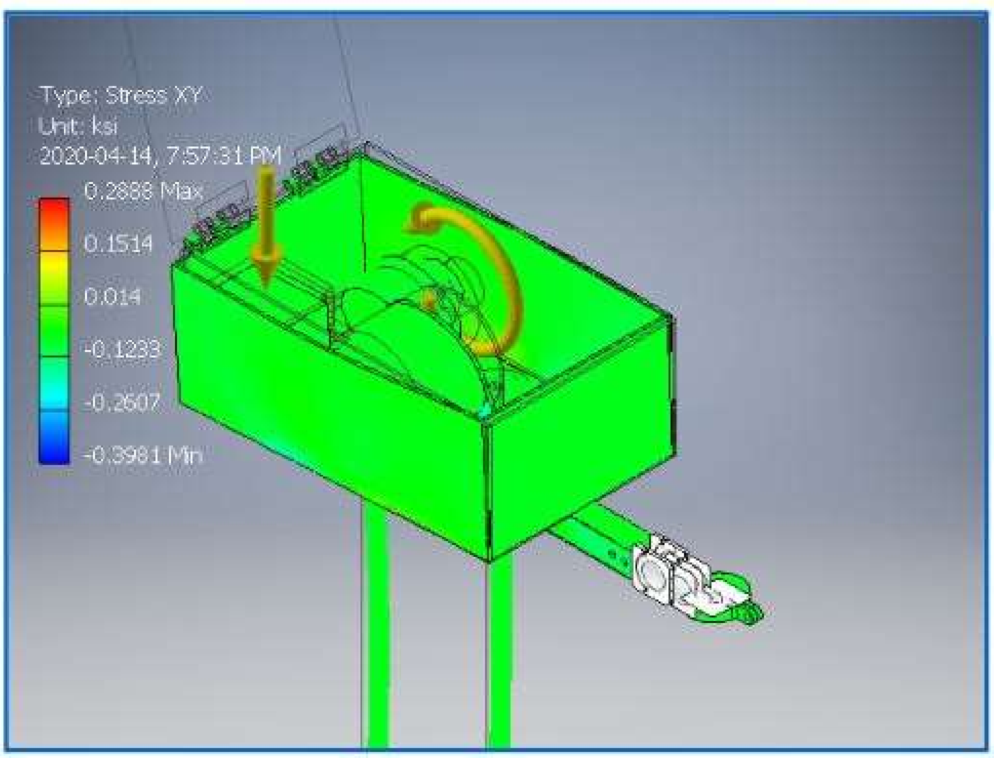
Normal stress in the Y-direction:



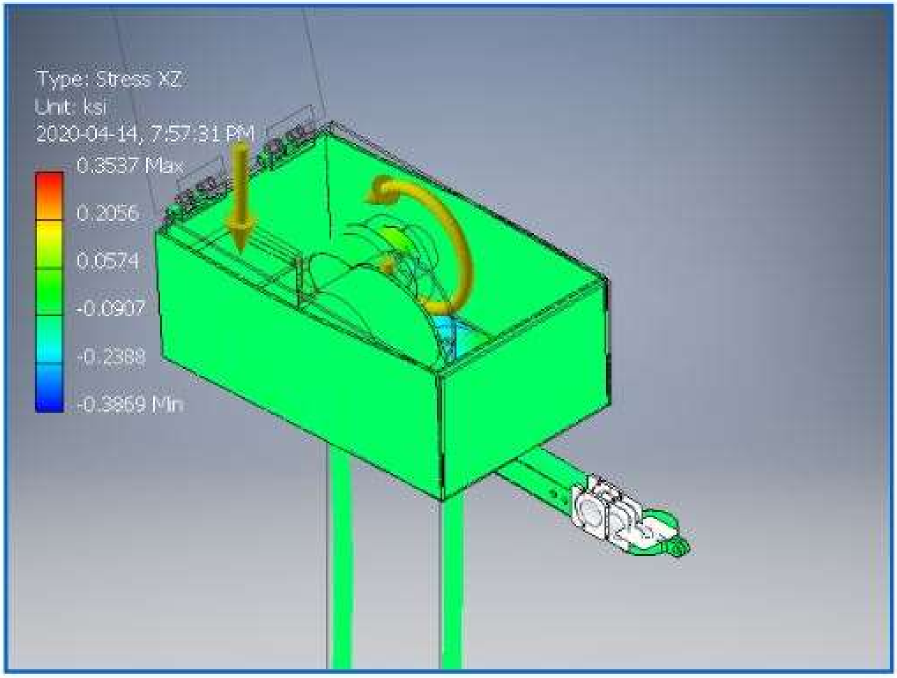
Normal stress in the Z-direction:



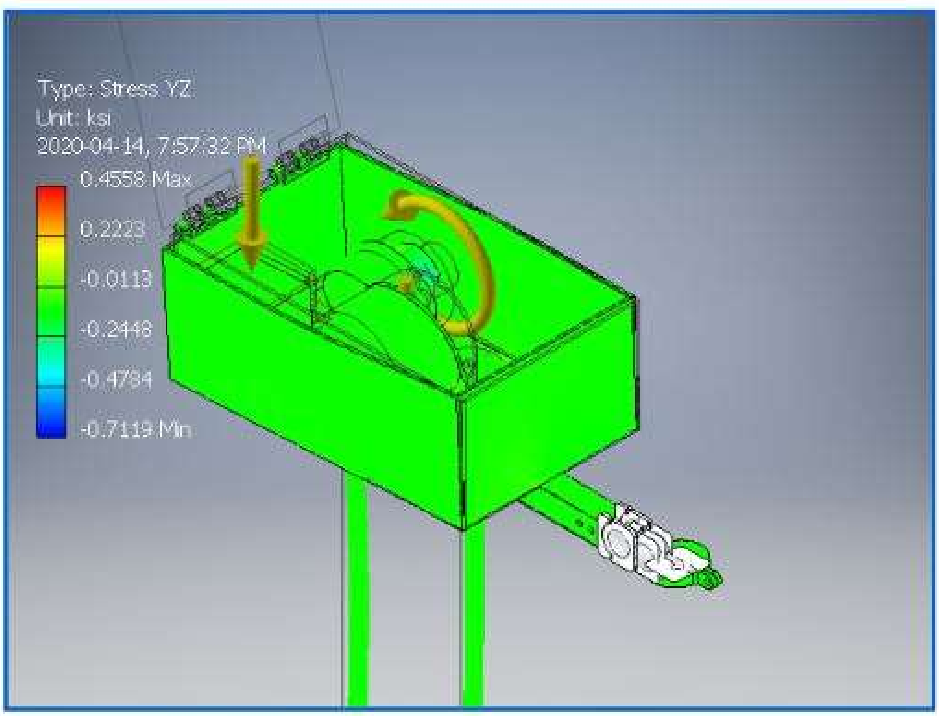
Shear stress in the XY plane:



Shear stress in the XZ plane:



Shear stress in the YZ plane:



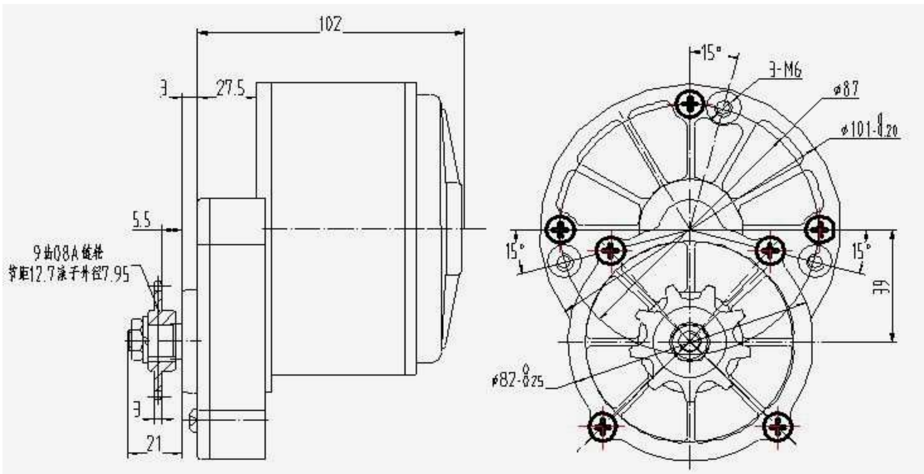
Appendix III – Datasheets

MY1016Z2-250W (250W Brushed DC Motor):

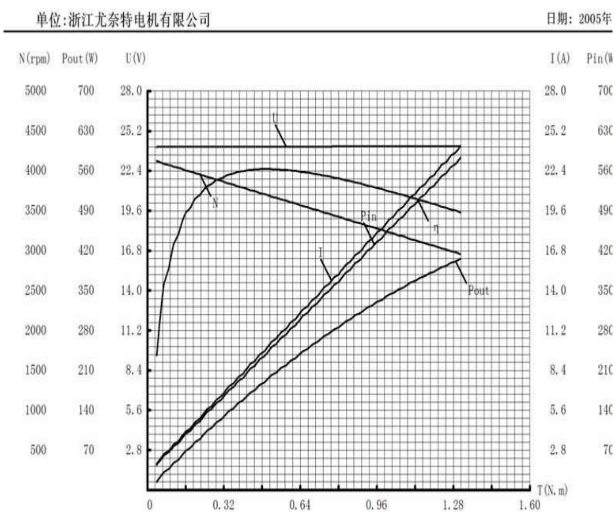
MY1016Z2-250W

1. PHOTO:

2. DIMENSIONS:



3. PERFORMANCE:



	Torque/N.m	Speed/rpm	P-out/W	Volt/V	Current/A	P-in /W	Efficient/%
No Load	0.39	421	15.12	24.09	1.86	44.71	33.81
Max. Efficient	4.79	379	188.97	24.11	9.74	234.87	80.46
Rated Load	6.65	361	251.54	24.12	13.12	316.47	79.48
Max.Torque	11.5	315	380.74	24.14	21.91	528.92	71.98

4. SPECIFICATIONS:

MODEL	SPECS	V	NO LOAD		RATED LOAD				
			SPEED RPM	CURRENT A	TORQUE N.M.	SPEED RPM	CURRENT A	P-OUT W	EFFICIENT η
1016Z2	250W24V	24	434± 5%	≤1.8	6.65± 5%	357±5%	≤13.7	250	≥76%
1016Z2	250W36V	36	434± 5%	≤1.8	6.65± 5%	357±5%	≤9.1	250	≥76%
GEARBOX RATIO i = 88 9 =9.778									

5. PACKAGE:

MODEL	WEIGHT Kg/PC	QTY. PC/CTN	CTN G.W. Kg	DIMENSION CM	PACKING MATERIAL
MY1016Z2-250W24V	2.115	12	26.2	37x32x26	CARTON BOX
MY1016Z2-250W36V	2.115	12	26.2	37x32x26	CARTON BOX

LG 18650 HE4 2500mAh (Lithium Ion Battery):

LG Chem

PRODUCT SPECIFICATION

Description	*Document No.*	*Date*	*Rev*
Lithium Ion LG 18650HE4 2500mAh	BCY-PS-HE4-Rev0	2013-05-30	0

PRODUCT SPECIFICATION

Rechargeable Lithium Ion Battery

Model : 18650HE4 2500mAh

LG Chem

LG Twin Towers 128, Yeoui-daero, Yeongdeungpo-gu,
Seoul, Republic of Korea, 150-721

http://www.lgchem.com

Revision History

Revision	Date	Originator	Description
0	2013-05-30	Kim Hyoungkwon	- Original Release

Contents

1. General Information

1.1 Scope

This product specification defines the requirements of the rechargeable lithium ion battery to be supplied to the customer by LG Chem.

1.2 Application: Power Tools

1.3 Product classification: Cylindrical rechargeable lithium ion battery

1.4 Model name: 18650 HE4

2. Nominal Specification

Item	Condition / Note	Specification
2.1 Capacity	Std. charge / discharge	Nominal 2500 mAh (C_{nom})
2.2 Nominal Voltage	Average for Std. discharge	3.60V
2.3.1 Standard Charge (Refer to 4.1.1)	Constant current Constant voltage End condition(Cut off)	1250mA 4.2V 50mA
2.3.2 Fast charge (Refer to 4.1.3)	Constant current Constant voltage End condition(Cut off)	4000mA 4.2V 100mA
2.4 Max. Charge Voltage	-	4.20±0.05V
2.5 Max. Charge Current	-	4000mA
2.6.1 Standard Discharge (Refer to 4.1.2)	Constant current End voltage(Cut off)	500mA 2.5V
2.6.2 Fast Discharge (Refer to 4.1.3)	Constant current End voltage(Cut off)	10000mA, 20000mA 2.5V
2.7 Max. Discharge Current	For continuous discharge	20000mA
2.8 Weight	Max.	47.0 g
2.9 Operating Temperature (Cell Surface Temperature)	Charge Discharge	0 ~ 50℃ -20 ~ 75℃
2.10 Storage Temperature (for shipping state[i])	1 month 3 month 1 year	-20 ~ 60℃ -20 ~ 45℃ -20 ~ 20℃

* Shipping state : About 40% capacity of fully charged state

3. Appearance and Dimension

3.1 Appearance

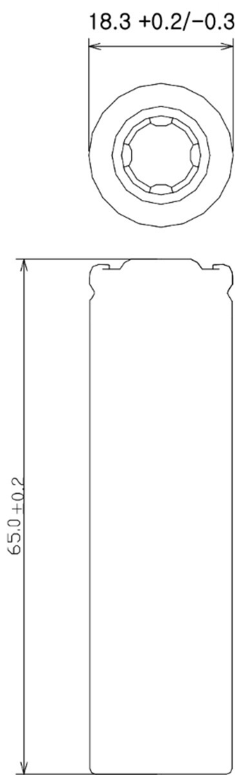
There shall be no such defects as deep scratch, crack, rust, discoloration or leakage, which may affect the commercial value of the cell.

3.2 Dimension

Diameter : 18.3 + 0.2/-0.3 mm (Max. 18.5 mm)

Diameter is defined as the largest data value measured on the “A” area of a cylindrical cell.

Height : 65.0 ± 0.2 mm (Max. 65.2 mm)



4. Performance Specification

4.1 Standard test condition

4.1.1 Standard Charge

Unless otherwise specified, “Standard Charge” shall consist of charging at constant current of 1250mA. The cell shall then be charged at constant voltage of 4.2V while tapering the charge current. Charging shall be terminated when the charging current has tapered to 50mA. For test purposes, charging shall be performed at 23ºC ± 2ºC.

4.1.2 Standard Discharge

“Standard Discharge” shall consist of discharging at a constant current of 500mA to 2.5V. Discharging is to be performed at 23 ºC ± 2 ºC unless otherwise noted (such as capacity versus temperature).

4.1.3 Fast Charge / Discharge condition

Cells shall be charged at constant current of 4000mA to 4.2V with end current of 100mA. Cells shall be discharged at constant current of 10000mA and 20000mA to 2.5V. Cells are to rest 10 minutes after charge and 30 minutes after discharge.

4.2 Electrical Specification

Item	Condition	Specification
4.2.1 Initial AC Impedance	Cell shall be measured at 1kHz after charge per 4.1.1.	≤ 20 mΩ, without PTC
4.2.2 Initial Capacity	Cell shall be charged per 4.1.1 and discharged per 4.1.2 within 1h after full charge.	2500 mAh (C_{nom})
4.2.3 Cycle Life	Cells shall be charged and discharged per 4.1.3, 300 cycles(10A) and 200 cycles(20A) .A cycle is defined as one charge and one discharge. 301st (10A) and 201st (20A) discharge capacity shall be measured per 4.1.1 and 4.1.2	≥ 60 % (of C_{nom} in 2.1)

4.3 Environmental specification.

Item	Condition	Specification
4.3.1 Storage Characteristics	Cells shall be charged per 4.1.1 and stored in a temperature-controlled environment at 23ºC ± 2ºC for 30 days. After storage, cells shall be discharged per 4.1.2 to obtain the remaining capacity□.	Capacity remaining rate ≥ 90% (of C_{nom} in 2.1)
4.3.2 High Temperature Storage Test	Cells shall be charged per 4.1.1 and stored in a temperature-controlled environment at 60ºC for 1 week. After storage, cells shall be discharged per 4.1.2 and cycled per 4.1.1 and 4.1.2 for 3 cycles to obtain recovered capacity□.	No leakage, Capacity recovery rate ≥ 80% (of C_{nom} in 2.1)

* Remaining Capacity : After storage, cells shall be discharged with standard condition(4.1.2) to measure the remaining capacity.
** Recovery Capacity : After storage, cells shall be discharged with standard discharge condition(4.1.2), and then cells shall be charged with standard charge condition(4.1.1), and then discharged with standard discharge condition(4.1.2). This charge / discharge cycle shall be repeated three times to measure the recovery capacity.

4.3.3 Thermal Shock Test	65ºC (8h) ← 3hrs → -20ºC (8h) for 8 cycles with cells charged per 4.1.1 After test, cells are discharged per 4.1.2 and cycled per 4.1.1 and 4.1.2 for 3 cycles to obtain recovered capacity.		No leakage Capacity recovery rate ≥ 80% (of C_{nom} in 2.1)
4.3.4 Temperature Dependency of Capacity	Cells shall be charged per 4.1.1 at 23ºC ± 2ºC and discharged per 4.1.2 at the following temperatures.		
	Charge	Discharge	Capacity
	23℃	-10℃	60% (of C_{nom} in 2.1)
		0℃	80% (of C_{nom} in 2.1)
		23℃	100% (of C_{nom} in 2.1)
		60℃	95% (of C_{nom} in 2.1)

4.4 Mechanical Specification

Item	Condition	Specification
4.4.1 Drop Test	Cells charged per 4.1.1 are dropped onto an oak board from 1 meter height for 1 cycle, 2 drops from each cell terminal and 1 drop from side of cell. (Total number of drops =3).	No leakage No temperature rising
4.4.2 Vibration Test	Cells charged per 4.1.1 are vibrated for 90 minutes per each of the three mutually perpendicular axes (x, y, z) with total excursion of 0.8mm, frequency of 10Hz to 55Hz and sweep of 1Hz change per minute.	No leakage

4.5 Safety Specification

Item	Condition	Specification
4.5.1 Overcharge Test	Cells are discharged per 4.1.2, then charged at constant current of 3 times the max. charge condition and constant voltage of 4.2V while tapering the charge current. Charging is continued for 7 hours (Per UL1642).	No explosion, No fire
4.5.2 External Short - Circuiting Test	Cells are charged per 4.1.1, and the positive and negative terminal is connected by a 100 mΩ-wire for 1 hour (Per UL1642).	No explosion, No fire
4,5.3 Overdischarge Test	Cells are discharged at constant current of 0.2C to 250% of the minimum capacity.	No explosion, No fire
4.5.4 Heating Test	Cells are charged per 4.1.1 and heated in a circulating air oven at a rate of 5ºC per minute to 130ºC. At 130ºC, oven is to remain for 10 minutes before test is discontinued (Per UL1642).	No explosion, No fire
4.5.5 Impact Test	Cells charged per 4.1.1 are impacted with their longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8mm diameter bar (Per UL1642).	No explosion, No fire
4.5.6 Crush Test	Cells charged per 4.1.1 are crushed with their longitudinal axis parallel to the flat surface of the crushing apparatus (Per UL1642).	No explosion, No fire

5. Caution

Warning for using the lithium ion rechargeable battery. Mishandling of the battery may cause heat, fire and deterioration in performance. Be sure to observe the following.

5.1 Cautions for Use and Handling

- When using the application equipped with the battery, refer to the user's manual before usage. • Please read the specific charger manual before charging.
- Charge time should not be longer than specified in the manual.
- When the cell is not charged after long exposure to the charger, discontinue charging.
- Battery must be charged at operating temperature range 0 ~ 45℃.
- Battery must be discharged at operating temperature range -20 ~ 60℃.
- Please check the positive (+) and negative(-) direction before packing.
- When a lead plate or wire is connected to the cell for packing, check out insulation not to short-circuit.
- Battery must be stored separately.
- Battery must be stored in a dry area with low temperature for long-term storage.
- Do not place the battery in direct sunlight or heat.
- Do not use the battery in high static energy environment where the protection device can be damaged.
- When rust or smell is detected on first use, please return the product to the seller immediately.
- The battery must be away from children or pets
- When cell life span shortens after long usage, please exchange to new cells.

5.2 Prohibitions

- Do not use different charger. Do not use cigarette jacks (in cars) for charging.
- Do not charge with constant current more than maximum charge current.
- Do not disassemble or reconstruct the battery.
- Do not throw or cause impact.
- Do not pierce a hole in the battery with sharp things. (such as nail, knife, pencil, drill) • Do not use with other batteries or cells.
- Do not solder on battery directly.

- Do not press the battery with overload in manufacturing process, especially ultrasonic welding.
- Do not use old and new cells together for packing.
- Do not expose the battery to high heat. (such as fire)
- Do not put the battery into a microwave or high pressure container.
- Do not use the battery reversed.
- Do not connect positive(+) and negative(-) with conductive materials (such as metal, wire)
- Do not allow the battery to be immerged in or wetted with water or sea-water.

5.3 Caution for the battery and the pack

Pack shall meet under condition to maintain battery safety and last long performance of the lithium rechargeable cells.

5.3.1 Installing the battery into the pack

-. The cell should be inspected visually before battery assembly into the pack.
-. Damaged cell should not be used. (damaged surface, can-distortion, electrolyte-smell) -. Different Lot Number cells should not be packaged into the same pack.

-. Different types of cells, or same types but different cell maker's should not be used together.

5.3.2 Design of battery pack

-. The battery pack should not be connected easily to any charger other than the dedicated charger.
-. The battery pack has function not to cause external short cut easily.

5.3.3 Charge

-. Charging method is Constant Current-Constant Voltage (CC/CV).
-. Charging should be operating under maximum charge voltage and current which is specified in the product specification. (Article. 2.4, 2.5)

-. The battery should be charged under operating temperature specified in product specification. (Article. 2.9)

5.3.4 Discharge

-. Discharging method is Constant Current (CC).

-. Discharging should be operating under maximum discharge current which is specified in the product specification. (Article. 2.7)

-. Discharging should be done by cut off voltage which is specified in the product specification. (Article. 2.6)

-. The battery should be discharged under operating temperature specified in product specification. (Article. 2.9)

5.3.5 Protection Circuit

-. The protection circuit should be installed in the battery pack, charger.

-. Charger or pack should have voltage sensing system to control over charge or discharge in order to maintain the battery's normal operating mode and protect cell imbalance.

-. Charger or pack should have warning system for over temperature, over voltage and over current.

24V 20A 7Series BMS Protection Board, Lithium BMS Battery Protection Board with Balancing for Lithium Li-ion LiFePO4 Battery Pack (Battery Management System):

This product is a battery protection BMS board which is designed for 7series lithium batteries. It can be used for ternary lithium batteries, manganese acid lithium batteries, cobalt acid lithium batteries and LiFePO4 batteries. And the board is equipped with multiple protective functions including overcharge protection, over discharge protection, overcurrent protection and short circuit protection, so you can use it safely.

Specifications:
Protection: Polymer/Terpolymer/Lithium Manganate
LiFePO4
Overcharge Protection Delay: 1000ms±l00ms
Over-discharge Protection Delay: 100ms±10ms
Discharge Over-current Protection: 60A±5A
Discharge Over-current Delay: 200ms±20ms
Short Circuit Protection: Yes
Short Circuit Delay: 200uS±20uS
Short Circuit Protection Recovery: Disconnect Load Release
Charge Current: 5A(adjustable)
Equilibrium Function: Yes
Equilibrium Current: 50~60mA
Equilibrium Accuracy: ±25mV

Polymer/Terpolymer/Lithium Manganate:
Single Battery Overcharge Protection Voltage: 4.25V±0.025V
Single Battery Overcharge Protection Recovery Voltage: 4.050V±0.025V
Single Battery Over-discharge Protection Voltage: 2.75±0.025V
Single Battery Over-discharge Protection Recovery Voltage: 3.00V±0.025V

LiFePO4:
Single Battery Overcharge Protection Voltage: 3.75V±0.025V
Single Battery Overcharge Protection Recovery Voltage: 3.60V±0.025V
Single Battery Over-discharge Protection Voltage: 2.10V±0.025V
Single Battery Over-discharge Protection Recovery Voltage: 2.30V±0.025V
Size: 65×33×7mm / 2.56×1.3×0.27"
Wire Length: 350mm / 13.77"

Littelfuse KLKR015 (Overload Protection):

POWR-GARD® Fuse Datasheet

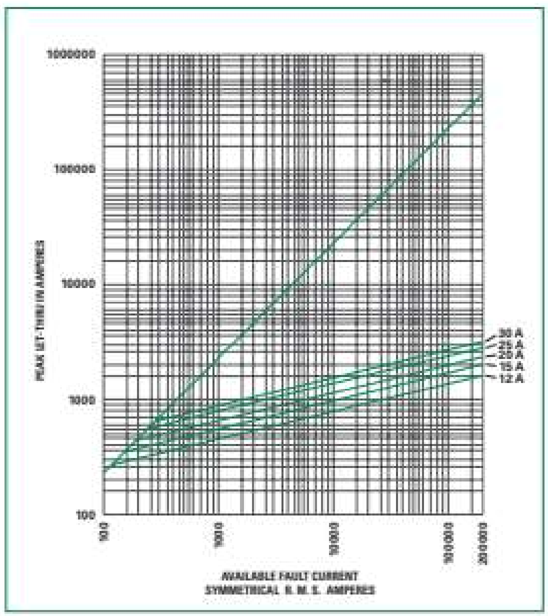
Littelfuse
Expertise Applied | Answers Delivered

CLASS CC KLKR SERIES FUSES

Electrical Specifications

ORDERING NUMBER	AMPERAGE RATING	VOLTAGE RATING		INTERRUPTING RATING		WATTS LOSS AT 100% RATED CURRENT (W)	WATTS LOSS AT 80% RATED CURRENT (W)	TOTAL CLEARING I²T (A² SEC) 200 kA	AGENCY APPROVALS		RoHS
		AC	DC	AC	DC				UL	CSA	
KLKR001.T	1	600	300	200 kA	20 kA	0.38	0.20	80	•	•	•
KLKR006.T	6	600	300	200 kA	20 kA	1.36	0.77	210	•	•	•
KLKR012.T	12	600	300	200 kA	20 kA	1.58	0.83	350	•	•	•
KLKR015.T	15	600	300	200 kA	20 kA	2.3	1.37	314	•	•	•
KLKR020.T	20	600	300	200 kA	20 kA	2.3	1.39	900	•	•	•
KLKR030.T	30	600	300	200 kA	20 kA	3.75	2.10	1720	•	•	•

Peak Let-Thru Curve



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Rev: 062218

Littelfuse L60030C1C (Fuse Holder):

POWR-GARD® Blocks and Holders Datasheet

Littelfuse
Expertise Applied | Answers Delivered

LF SERIES CLASS CC/CD AND MIDGET (10x38) FUSE BLOCKS

600 V

RoHS

Description

The Littelfuse Class CC, CD and midget blocks offer generous space savings and enhanced value. DIN-rail mounting and universal mounting holes are available as well as an indication feature on all Class CD fuse blocks.

Features/Benefits

- Space-saving design
- Universal mounting holes for easy replacement
- Indication offered on CD blocks
- One hand release from DIN rail optional
- Rejection feature that prevents the insertion of fuses with lower interrupting rating or voltage ratings
- Clip design reduces resistance and heat
- Non DIN-rail fuse blocks have interlocking feature allowing ganging for any number of poles
- Covers available for all amperages to enhance safety

Specifications

Voltage Rating	600 Vac/dc
Ampere Ratings	L600M Midget (10x38): 30 A L600C Class CC: 30 A LFC Class CD: 60 A L600CM Class CC & Midget: 30 A
Dielectric strength	1200 V minimum
Materials	Clip/terminals: Tin-plated copper alloy Box lug: Copper Screw & captive pressure plate: Zinc-plated steel Base: Thermoplastic UL94 V-0 flammability rating
Withstand Rating (SCCR)	L60030C: 200kA L60030M: 10kA, 20kA or 100kA based on the Midget fuse used LFC600: 200kA
Approvals	L600M: UL Recognized (File: E14721) CSA Certified (File: LR7316) L600C: UL Listed (File: E14721) CSA Certified (File: LR7316) LFC: UL Listed (File: E14721) CSA Certified (File: LR7316) L600CM: UL Recognized (File: E14721) CSA Certified (File: LR7316)
Environmental	RoHS Compliant, Lead (Pb) Free

Recommended Fuses

Class CC Blocks: CCMR, KLDR, KLKR
Class CM Block: Fuses same as CC & Midget Blocks
Class CD Blocks: CCMR
Midget Blocks: BLF, BLN, BLS, FLA, FLM, FLQ, FLU, KLK, KLKD, KLQ

Web Resources

Sample requests and technical downloads:
littelfuse.com/fuseblocks

Ordering Information (L600C Class CC and L600M Midget 30 A)

AMP RATING	POLES	CLASS CC ORDERING NUMBER NON-DIN*	CLASS CC ORDERING NUMBER DINR	MIDGET ORDERING NUMBER NON-DIN*	MIDGET ORDERING NUMBER DINR	CONNECTOR TYPE	TORQUE	WIRE RANGE	WIRE TYPE		BASE TEMP	COVER ORDERING NUMBER'
30	1	L60030C1C	L60030C1CDINR	L60030M1C	L60030M1CDINR	Box Lug	4.0 N-m (35 in-lbs)	6-14 AWG	CU Only	Solid / Stranded	125°C	SPL001
	2	L60030C2C	L60030C2CDINR	L60030M2C	L60030M2CDINR							
	3	L60030C3C	L60030C3CDINR	L60030M3C	L60030M3CDINR							
30	1	L60030C1PQ	L60030C1PQDINR	L60030M1PQ	L60030M1PQDINR	Pressure Plate w/Q.C. Terminal	2.3 N-m (20 in-lbs)	10-14 AWG			125°C	SPL001
	2	L60030C2PQ	L60030C2PQDINR	L60030M2PQ	L60030M2PQDINR							
	3	L60030C3PQ	L60030C3PQDINR	L60030M3PQ	L60030M3PQDINR							
30	1	L60030C1SQ	L60030C1SQDINR	L60030M1SQ	L60030M1SQDINR	Screw w/Q.C. Terminal	2.3 N-m (20 in-lbs)	10-14 AWG			125°C	SPL001
	2	L60030C2SQ	L60030C2SQDINR	L60030M2SQ	L60030M2SQDINR							
	3	L60030C3SQ	L60030C3SQDINR	L60030M3SQ	L60030M3SQDINR							

Ordering Information (L600CM Class CC and Midget Combination 30 A)

AMP RATING	POLES CLASS CC	POLES MIDGET	COMBINATION 2 CLASS CC / 1 MIDGET ORDERING NUMBER NON-DIN	COMBINATION 2 CLASS CC / 1 MIDGET ORDERING NUMBER DINR	CONNECTOR TYPE	TORQUE	WIRE RANGE	WIRE TYPE	BASE TEMP	COVER ORDERING NUMBER'
30	2	1	L60030CM3PQ	—	Pressure Plate w/Q.C. Terminal	2.3 N-m (20 in-lbs)	10-14 AWG	CU Only Solid / Stranded	125°C	SPL001

littelfuse.com 1 of 3 Rev: 052517

LF SERIES CLASS CC/CD AND MIDGET (10X38) FUSE BLOCKS

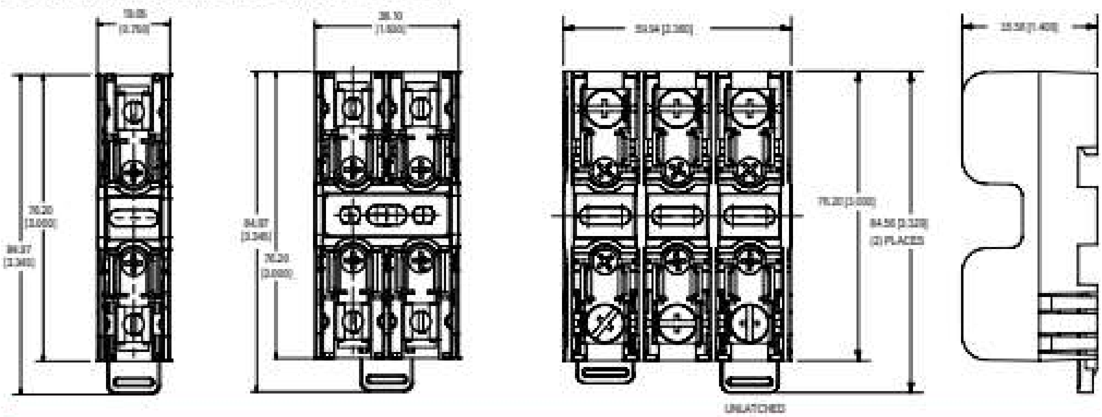
Ordering Information (LFC Class CD 60 A)

AMP RATING	POLES	ORDERING NUMBER	CONNECTOR TYPE	TORQUE	WIRE RANGE	WIRE TYPE		BASE TEMP RATING	DIN RAIL MOUNT	INDICATION	COVER ORDERING NUMBER†
60	1	LFC600601CID	Box Lug	5.6 N-m (50 in-lbs)	2-4 AWG	CU-AL	Solid / Stranded	125°C	•	•	LFC60060FBC
	2	LFC600602CID									
	3	LFC600603CID		2.8 N-m (25 in-lbs)	6-14 AWG						

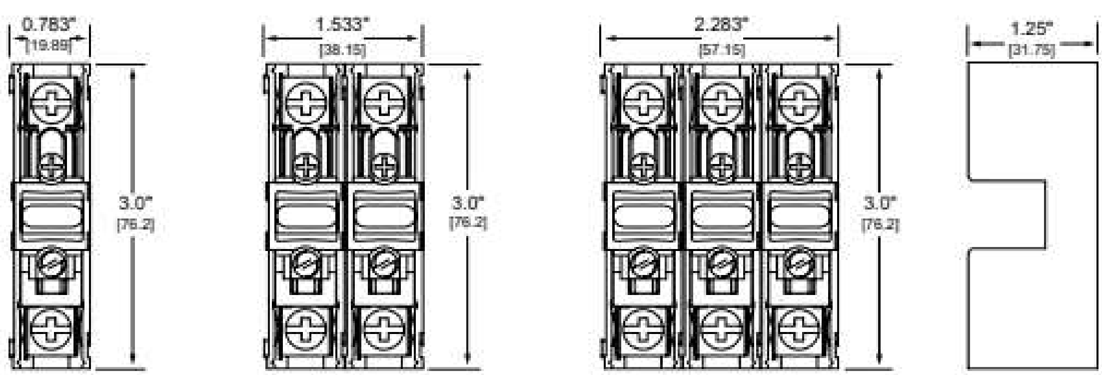
* Gangable – † Covers sold individually. One cover needed for each pole.

Dimensions mm (inches)

L600M-DINR Midget and L600C-DINR Class CC 30 A



L600M Midget, L600C Class CC and L600CM Combination 30 A



LF SERIES CLASS CC/CD AND MIDGET (10X38) FUSE BLOCKS

Dimensions mm (inches)

LFC CLASS CD 60 A