BIOE 4950

Design and Manufacture a Murphy Bed Lock for Wood Products Unlimited (WPU)

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Executive Summary

A Murphy bed is a foldable bed frame that can be vertically stored against a wall when not in use to save space. Wood Products Unlimited (WPU) is a Canadian-based manufacturer that makes and sells a Murphy bed product, the Embed. WPU wants a locking mechanism designed for the Embed that customers can choose to purchase with the Embed as an optional add-on. The purpose of the locking mechanism feature is to enhance overall safety and help avoid misuse of the Murphy bed.

A few key features of the locking mechanism include a 12V DC power supply that will power a keypad and two solenoids. Each solenoid and its electrical circuit are protected by a steel case mounted at each corner of the bottom rear bed frame to increase the strength and durability of the attachment of the solenoids to the bed. The locking mechanism works by allowing authorized users of the bed to lock and unlock the Murphy bed using the keypad. When the bed is in the closed position, the extended solenoid pins restrict bed movement and lock it upward. The authorized user can use the keypad to control the solenoids and retract the pins so the Murphy bed can be lowered to the open position. If the authorized user wants the bed to be locked in the open position, they would have to reuse the keypad to re-extend the solenoid pins outward, which would lock the bed in the open position.

Custom modifications will be made to both solenoids, such as a pin extension connected to the pin armature. A prototype testing rig was manufactured to simulate the forces that will be exerted on the locking mechanism and to observe the positioning of components during movement. The testing rig was used to ensure minimal force is experienced by the solenoid and to verify it will not be damaged at the armature or mounting point. The locking mechanism design had to be complete and functional within eight months and cost under $200 CAD to manufacture. The budget constraint was met but the validation results of the application of the locking mechanism onto an Embed were left unresolved due to time constraints. If the locking mechanism is successful, this design would position the Embed as the sole Murphy bed on the market with this unique capability, providing WPU with a competitive advantage over other manufacturers.

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1 Introduction

The objective of this project is to develop a locking mechanism for the Embed, a Murphy bed manufactured by Wood Products Unlimited (WPU). A Murphy bed is a bed hinged at each bottom corner at the rear of the bed frame, allowing it to be stored vertically against the wall to save space. Depending on the Murphy bed's size and additional features, they can weigh between 150 - 450 pounds (Murphy Bed-HQ, 2024). Murphy beds are installed against the wall and secured by bolting the bed to wall studs for safety and stability. Their design makes it a popular choice for small apartments, guest rooms, or any space where optimizing floor space is essential. The proposed locking mechanism aims to secure the Murphy bed in a closed position, and potentially in the open position as well. Therefore, the lock must resist the force of a person trying to open the locked bed. The primary purpose of the lock is to provide bed owners with control over access to the bed and to enhance overall bed safety. The target audience of the locking mechanism includes hotels, short-term rental hosts, and homeowners with limited space. The Embed bed's main components that will be referenced repeatedly throughout the report are listed in Table 1.1 and labelled in Figure 1.1.

Table 1.1: Embed Bed Main Components

Components	Purpose	Location
Mattress Platform	The platform is the surface where the mattress rest and is parallel to the wall when the bed is in use.	1
Bed Frame	The bed frame supports the mattress platform, provides structural stability when the mattress platform is lifted and lowered	2
Support Frame	The support frame anchors the Murphy bed to the wall studs when it is installed	3
Hinges	The hinges incorporate springs that pivot to facilitate the movement of the Murphy bed. When the bed is in the closed position, the hinges allow it to be secured upright and when the bed is lowered to the open position, the hinges ensure that it unfolds smoothly and stays in place.	4
Cover Plate	The cover plate is used to encase the hinge springs to ensure durability and safety by preventing external objects from getting stuck in the bed hinge such as bed sheets and fingers.	5
Side Units	Side units are optional additional features that can be installed as add-ons with the Murphy bed such as shelves, drawers, or cabinets	6
Rim	The rim refers to the edge of the mobile part of the bed frame that connects to the bed hinge	7
Rear of Bed	The side that faces the wall and not visible when the bed is in the closed position	8
Front of Bed	The side that is visible and accessible when the bed is in the closed position	9
Mobile Parts	Mobile parts refer to components that move when the bed if folded up or down, such as the springs, mattress platform and bed frame	1, 2, 4
Immobile Parts	Immobile parts refer to fixed components such as the support frame anchored to the wall and side units, the cover plate and side units	3, 5, 6

[redacted]

Figure 1.1: Components of Embed, (a) Embed Closed (Adapted from Woods Products Unlimited 2024), (b) Embed Opened (Adapted from Woods Products Unlimited 2024)

1.1 Background Information

WPU is looking for two key features of the locking mechanism that allows bed owners to have complete control of bed usage and access. The first key feature of the locking mechanism is to lock the bed in the closed position as shown in Figure 1.1a. The purpose of this feature is to only allow authorized users to open the Embed when necessary. A second key feature that WPU would like is to have the locking mechanism electronically controlled. The purpose of creating an electronically controlled lock as opposed to a mechanical one such as a key lock, is to reduce the risk of bed users losing keys and being unable to use the bed. An advantage of an electronic lock is that bed owners can easily grant access to users by sending password information through a code, eliminating the need to provide a physical key.

It has been acknowledged that an electronic keypad may experience malfunctions during a power outage. Concerns regarding this issue have been raised to WPU's attention, and they have confirmed that solving this problem is not a requirement but rather something to be mindful of when designing the locking mechanism device. Additionally, WPU has requested us to integrate off-the-shelf components into the locking mechanism that are readily available to purchase in North American markets such as Canada. This is aimed to ease the purchasing process and ensuring the integrity of the product.

When designing the locking mechanism, it was important to consider past incidents and accidents related to Murphy beds that have led to recalls and design modifications. Murphy beds incorporate springs and counterbalances that can be hazardous if not adequately maintained (Holden 2022). Natural disasters such as earthquakes and improper usage, such as jumping and playing on it can also cause failures to Murphy beds. Murphy beds may also present a hazard to children given the challenges associated with opening and closing them, potentially resulting in a child becoming trapped inside the closed bed (Holden 2022). Therefore, it is crucial to have correct installation of a Murphy bed by having the bed frame anchored to the wall studs and annual maintenance of the bed to ensure that an adequate locking mechanism is designed to minimize danger.

1.1.1 Other locks

Although some Murphy Beds with locks exist on the market, these beds are relatively uncommon and only lock the bed in the closed position. Some examples include the lock with key shown in Figure 1.2. The lock and key mechanism are installed by drilling a large hole in the bed frame to accommodate a keyway. The keyway is connected to a lever latch located in the inner frame of the Murphy bed. When the key is inserted into the keyway and turned, the latch lifts to unlock the bed. Turning the key in the opposite direction causes the latch to lower, locking the bed. A mechanical problem with this design is that a specific key must be used to open and lock the bed, and if the key is lost, the bed may become permanently locked or open.

Meanwhile, the side latch lock is installed to the bed frame using small screws. This mechanism can be quite delicate since the thin metal loop must bear most of the force if someone were to pull on the bed when it is locked. A potential issue with this design is that repeated use of the lock may lead to the small screws stripping, causing damage to the bed frame due to bearing and shear stresses.

(a) (b)

Figure 1.2: Types of existing locking mechanisms, (a) Lock with key mechanism to secure a Murphy bed in the closed position (Wilding Wallbeds, 2023), (b) Side latch mechanism to secure a Murphy bed in the closed position (eMurphy Bed Store, 2022)

From these lock examples, the lock with key is the only option that effectively restricts movement of the bed to unauthorized users. Additionally, the lock with key and side latch are mounted directly on the side of the bed frame which is an option that is not always available if the Murphy bed has additional side units or is installed in a corner. Neither of these two locks can lock the bed in both open and closed positions to prevent misuse and potential injury.

As WPU requested an electrical lock for their Embed bed, the mechanical locking design examples stated above are not suitable for this project and is why an innovative locking mechanism must be designed as there are no electrical Murphy bed locks on the market. With that in mind, the locking mechanism design explained in Section 2 Design Solution incorporates two electronic pull-type solenoids to help lock the Embed bed. Pull-type solenoids are popular electrical components in the automotive and household appliance industry. The automotive industry commonly uses pull-type solenoids to control vehicle door locks, and the household appliance industry often implement pull-type solenoids into dishwashers and washing machines (Electricity - Magnetism 2023). Other popular electronics such as computers, and printers also tend to incorporate pull-type solenoids. The Embed bed locking mechanism solenoid requires a return spring that will mechanically extend the solenoid pin armature outward when power is not supplied to it. Most pull-type solenoids do not incorporate a return spring because the automotive and household appliance industry rarely require one for their applications. As a result, it was challenging to source a pull-type solenoid that had the return spring feature. More information about the locking mechanism design will be explained in the forthcoming chapters.

1.1.2 Problem Definition

Wood Products Unlimited requires a lock add-on solution for their Murphy bed product, the Embed, to ensure secure locking in both the open and closed positions. The primary goal is to restrict unauthorized access to the bed, mitigating the risk of injuries resulting from improper usage and providing additional security during events such as earthquakes.

1.1.3 Project Constraints

WPU has established an approximate budget of $200 CAD to manufacture the Embed locking mechanism. The project duration is eight months starting from September to complete a prototype of the locking mechanism. Additionally, the majority of the locking mechanism components must be off-the-shelf, as summarized in Table 1.2.

Table 1.2: Constraints

Constraint	Description	Implications of the Constraint	Mitigation Strategies
C1	Manufacturing cost of <$200 CAD.	- The low budget may limit the off-the-shelf parts available for purchase	- Select components from North America manufacturers and websites for low shipping costs and fast delivery. - Review the catalogue list of suppliers from WPU for parts.
C2	Project duration is limited to 8 months to design a prototype.	- May not have time to perform the required tests for verification of the specifications. - A Gantt chart is tracked weekly to ensure the milestones of the project are completed with regular meetings on Tuesdays and Thursdays.	- Select components from Canadian manufacturers and websites for fast shipping and delivery.
C3	Off-the shelf components, besides electrical components, must be sourced from North American companies and websites	- Limits the design solutions of custom-made parts. - It will be easier for WPU to assemble the parts for the locking mechanism. - The parts purchased may be more expensive when sourced solely from North American companies and websites.	- Ask the technicians Daniel Benedet and Minami Maeda for resources. - Review the catalogue list of suppliers from WPU for parts.
C4	Lock must not interfere with the mattress and void mattress warranty.	- The lock design must be small and compact to not interfere with the mattress. - It limits the location of where the lock can be installed.	- Position the lock along the outside of the bed frame to not interfere with the mattress.

1.1.4 Specifications Table

In collaboration with WPU, the team has established a set of specifications outlined in Table 1.4. The specifications list in Table 1.4 are quantifiable and play a crucial role in guaranteeing that the EMBED locking mechanism design meet the project objectives. The specifications are grouped into S1, S2, S3 and S4 categories to distinguish different aspects of the locking mechanism as describe in Table 1.3.

Table 1.3: Specifications Categories

Specification Category	Description
S1	Prototype Function Specifications
S2	Keypad Specifications
S3	Electrical Circuit Specifications
S4	Assembled Embed Specifications

Table 1.4: Specifications

Spec.	Description	Criteria	Verification Method
S1 – Protype Function Specifications			
S1.1	Brass pin extension	Diameter of 0.67 inch	Visual inspection Section 3.1
S1.2	Solenoid protective box	No deformation of box	Visual inspection Section 3.1
S2 – Keypad Specifications			
S2.1	Keypad passcode function	100 % accuracy	Instrumentation test Section 3.2.1
S2.2	Keypad relay timer	20 seconds	Instrumentation test

Spec.	Description	Criteria	Verification Method
			Section 3.2.1
S2.3	Keypad RFID fob function	100 %	Instrumentation test
			Section 3.2.2
S3 – Electrical Circuit Specifications			
S3.1	Locking time	<5 seconds	Instrumentation Test
			Section 3.3.1
S3.2	Diode quality control	0 mA	Instrumentation test
			Section 3.3.2
S3.3	Solenoid quality control	Armature throw 0.5 inch	Instrumentation test
			Section 3.3.3
S4 – Assembled Embed Specifications			
S4.1	Embed locks closed	Bed does not move to open position when locked	Physical test
			Section 3.4
S4.2	Embed locks opened	Bed does not move to closed position when locked	Physical test
			Section 3.4
S4.3	Lock installation	Install time: <45 minutes	WPU's test
			Section 3.4.1

Spec.	Description	Criteria	Verification Method
S4.4	Serviceability	Service time: <15 minutes	Physical test
			Section 3.4.1

1.1.5 Problem summary

The locking mechanism for Wood Products Unlimited Embed is intended to lock the bed in both the closed and potentially open positions. Additionally, the locking mechanism will have an electronic control system to prevent unwanted entry to the bed. Most competitor Murphy bed locking mechanisms only lock beds in the closed position and have drawbacks such as key loss and delicate mechanisms. WPU's request for an electronic lock aligns with the plan of incorporating two pull-type solenoids. Challenges such as sourcing suitable components within a $200 CAD budget and verifying the strength and durability of the locking mechanism have been addressed but not all challenges were overcome due to time constraints. The solutions to these challenges are provided in further chapters in the report. Overall, the main goals for the WPU Embed locking mechanism are to increase safety, security, prevent unauthorized access and to satisfy WPU's requirements and industry standards.

2 Design Solution

The Embed assembly can be divided into two different sections: the support frame and the bed frame, as indicated in Figure 2.1.

[redacted]

(a)

[redacted]

(b)

[redacted]

(c)

Figure 2.1: Model of Embed assembly sections and solenoid location, (a) Opened position (Adapted from Woods Products Unlimited 2024), (b) Closed position (Adapted from Woods Products Unlimited 2024), (c) Expanded view of solenoid location (Adapted from Woods Products Unlimited 2024)

The support frame is attached to the wall of the user's room to allow the bed frame to move up and down to close and open the bed respectively. To lock the bed in the closed and opened positions, two solenoids are mounted at the bottom of the bed frame, as circled in red in Figure 2.1. The Embed is locked when the solenoid pin is extended out towards the metal support frame, which is secured to the wall. This action requires the correct passcode to be pressed on the keypad or correct encoded RFID fob to be tapped. To unlock the Embed and retract the solenoid pin back in, the same passcode and fob must be entered or tapped on the keypad.

2.1 Modification to Support Frame

In the Embed's closed position, a modification was made to the support frame to accommodate the size of the solenoid casings. The solenoid casing is mounted to the bottom of the bed frame as shown in Figure 2.2. Member (1) of the metal support frame needs to be moved downwards to accommodate solenoid casing height of 1.97". Therefore, the height between the top of Member (1) and the ground was modified from 5.23" to 3.50". This allowed a space of 3.24" for the solenoid casing to be mounted. The height of 3.50" was selected for ease in manufacturing and this modification will be required on all Embeds with the locking mechanism add-on.

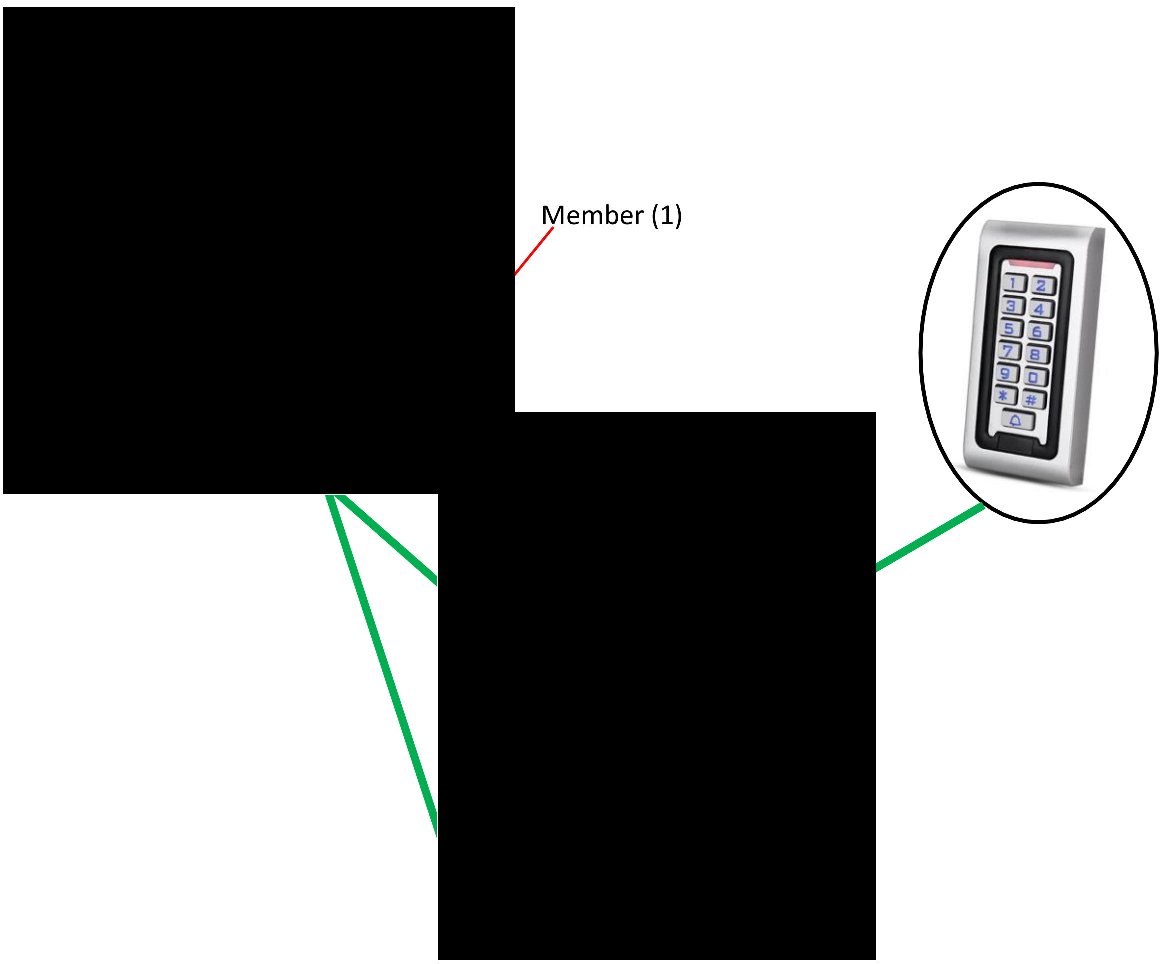


Figure 2.2: Modification to Member (1) of the Embed in the closed position and locations of solenoids and keypad indicated by green arrows (Adapted from Woods Products Unlimited 2024; Hfeng 2023)

2.2 Main Component: Keypad

The electronic keypad serves as a readily available commercial tool widely employed for locking and unlocking mechanisms. Authentication of users occurs through two primary methods: either by employing a preconfigured RFID fob or by inputting a passcode directly into the keypad as shown in Figure 2.3. The functionality of this keypad relies on an integrated relay, which activates upon user authentication. The keypad has an adjustable relay output delay timer between 0 to 99 seconds. Additionally, the specifications and manual for the HFeng keypad are shown in Appendix D Figures D.3 to D.7.

This keypad proves suitable for our implementation as it eliminates the necessity for an additional relay or transistor within the circuitry to control the solenoid. Furthermore, its seamless integration into our design requires minimal modifications. Additionally, it offers valuable features such as waterproofing, resistance to physical tampering, and a user-friendly interface. These attributes enhance its suitability for the project's requirements.

Figure 2.3: HFeng electronic keypad (B07DLP1QNY), HFeng 2023)

2.3 Main Component: Linear Solenoid

One of the major components of the lock design solution includes the use of two solenoids. Solenoids are electronically powered devices that create an electromagnetic field around a metal pin called the solenoid armature. This electromagnetic field moves the armature either a little more in, or a little more out of the solenoid body. The amount the solenoid armature reciprocates is called the throw. The solenoid has a throw of 0.5”, and when powered, will withdraw the armature 0.5” into the solenoid body. When power is cut to the solenoid, a spring returns the armature back into its resting position. The end of the solenoid armature has a female clevis attachment that will be used to hold a solenoid pin extension and discussed in the next subsection.

2.3.1 McMaster-Carr Linear Solenoid (70155K541)

The solenoid chosen is the McMaster-Carr Linear Solenoid (70155K541), shown in Figure 2.4. This model of solenoid was chosen over other solenoids because:

a) Solenoid runs on 12 V, as does the keypad. This allows for a simpler circuit to be used
b) Has a sufficient stroke to cross the gap between cover plate and solenoid casing (0.5”)
c) Comes with return spring and needed armature setup to use the return spring (note the C clip and matching grooves in the armature in Figure 2.4.
d) Has clevis-style attachment for easily attaching pin extension
e) Is within budget
f) Power can be supplied indefinitely without damage to the solenoid (this is called having a continuous duty cycle). This allows for the solenoid to be in the unlocked position for prolonged periods of time

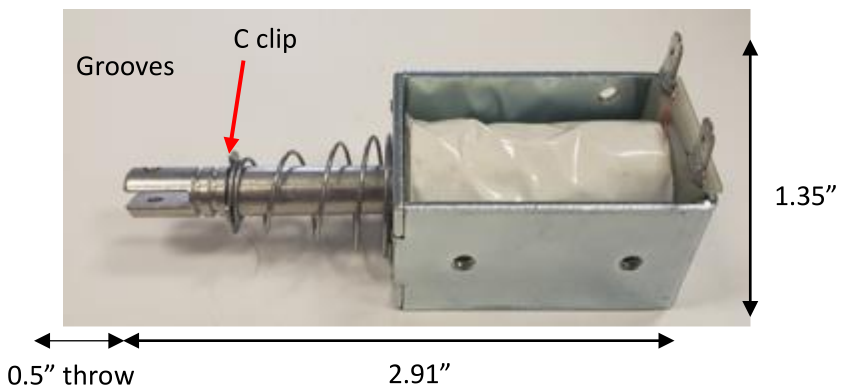


Figure 2.4: McMaster-Carr solenoid (70155K541) with return spring kit installed (McMaster-Carr 2024)

2.4 Solenoid Pin Extension

The McMaster-Carr solenoid has a steel armature with a diameter of 0.31”. A detailed drawing of the pin extension is shown in Figure C.3 of Appendix C. To lock the Embed in the open position, the pin extension must pass through the slotted hole in the cover plate as shown by the red arrow in Figure 2.5.

Figure 2.5: Solenoid pin extended into cover plate interface without solenoid casing (Adapted from Woods Products Unlimited 2024)

The stresses that the cover plate must withstand were calculated by applying 200 lbs (889.6 N) on the prototype testing rig, as listed in Specification S1. To prevent the cover plate from being sheared or damaged by the small and thinner armature, a brass pin extension was designed with a larger diameter of 0.67”. The larger diameter increases the surface area between the pin and cover plate hole and prevents damage to the cover plate by the calculations shown in Appendix Section B.2. Brass was selected as the material to prevent high frictional wear, and binding between similar metals, between the pin extension and the steel pin holes of the solenoid casing, L-bracket, and cover plate. Furthermore, a 3/32” diameter cotter pin is used to attach the pin extension to the solenoid armature clevis hole, as shown with the blue arrow in Figure 2.6.

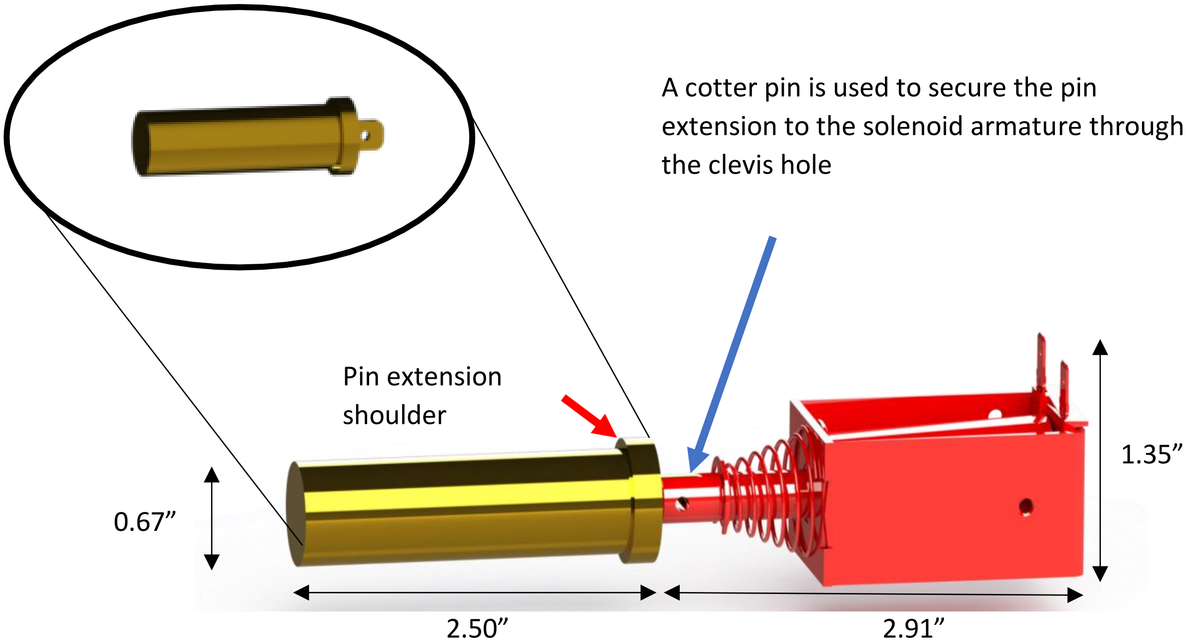


Figure 2.6: Solenoid pin extension assembly with McMaster-Carr solenoid in red (McMaster-Carr 2024) and pin extension in brass

Additionally, a shoulder is added onto the pin extension with a diameter of 0.80”, as shown with the red arrow. The shoulder is designed to be larger than the solenoid pin holes of the solenoid casing to prevent the pin from falling out the case when the power is turned off and the pin is extended.

2.5 Solenoid Casing

A 6.50" X 2.75" steel case has been designed to encapsulate each solenoid and its additional electronic components. A more detailed drawing of the solenoid casing dimensions is shown in Figure C.4 of Appendix C. The purpose of the case as shown in Figure 2.7 and Figure 2.8 is to provide the solenoid with extra protection, support, and to increase safety by not having the solenoid and wires exposed to external elements. The case will be mounted on the bottom left and right side of the bed frame to lock the Embed in the closed and open positions.

Figure 2.7: Solenoid position within solenoid casing

The solenoid armature will pass through two holes that are 0.77" in diameter to help support and guide the pin, as shown in Figure 2.8. One hole is located on the outer surface of the case labelled as Outer Hole and another hole is labelled as Inner Hole and is located inside the case. The purpose of the inner hole is to add extra reinforcement for the solenoid armature and to prevent the pin extension from rotating which would otherwise cause force on the solenoid body. The tolerance for all solenoid case holes is referenced in Appendix B

Table B.**3**.

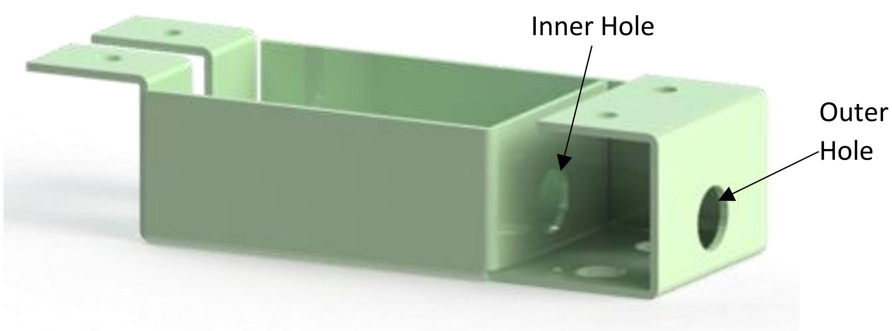


Figure 2.8: Location of two holes labeled as Inner Hole and Outer Hole, which the solenoid pin passes through

The casing is made from 14-gauge galvanized sheet steel. This thickness is equivalent to the thickness of the Embed’s spring cover plate for convenience, as this eliminates the need for WPU to source an additional type of metal. Manufacturing the case will first begin with laser cutting the sheet metal and then bending it with a press break. Once the case is bent and shaped, the solenoid is attached to the case by 6-32” screws and bolts that will be inserted into the 0.19” diameter holes shown by the orange dotted lines in Figure 2.9.

Additionally, the mounting of the solenoid casing onto the bed will be done by using the pre-existing lower bed frame holes, nuts, and bolts of the Embed to mount one side of the case as shown by the purple dotted lines in Figure 2.9. To provide access to these holes, two additional 0.60” access screw holes were made on the surface of the case to create an opening so the screw heads can be easily accessible for attaching and dismantling the solenoid case on the Embed as shown by the red arrow in Figure 2.9.

To mount the other side of the solenoid casing, two 0.31” holes are drilled into Member (2) of the bed frame as shown by the blue dotted lines in Figure 2.9. In total, four 1/4-20 X 5/8" screws and four 5/8" locknuts will be used to mount each solenoid case onto the Embed.

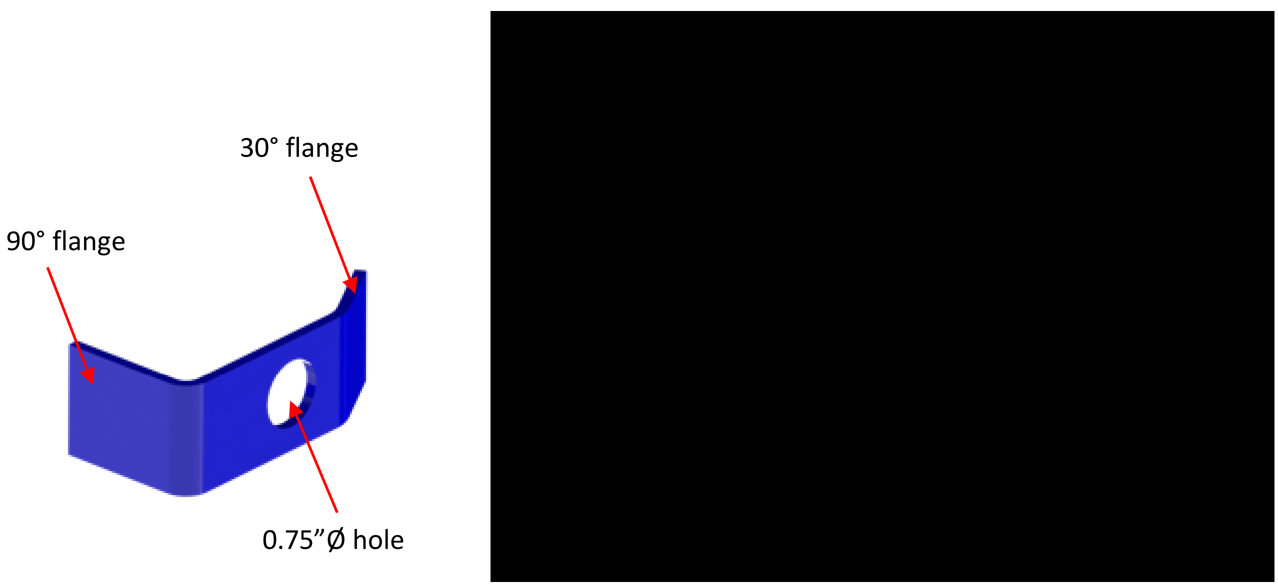
[redacted]

Figure 2.9: Mounting holes alignment between the solenoid casing (green), solenoid (red), and Member (2) of bed frame (Adapted from Wood Products Unlimited 2024)

2.6 The Locking Holes: Cover Plate and L-Bracket

There are two different locking holes for each solenoid pin extension to lock into. One is added in the existing cover plate of the movement assembly to lock the bed in the open position, and the other is in an L-bracket to lock the bed in the closed position. The center position of both holes was determined via measuring the location of the solenoid pin in the open and closed positions in a SolidWorks 3D CAD Model of the assembled Embed.

Figure 2.10 shows the L-bracket and its respective 0.75” locking hole Figure C.1 in Appendix C shows more detailed dimensions. The sizing of the cover plate slotted hole is shown in Figure 2.11 A more detailed drawing is shown in Appendix C Figure C.5 and Figure C.6 for the left and right cover plates respectively. The slotted hole shape accounts for the floor being up to +/- 2.5° off from being perpendicular to the wall the bed is mounted against. Tolerances and the parts that contributed to the tolerances of these holes can be found in Appendix B in Table B.**1** and Table B.**2**.



(a) (b)

Figure 2.10: L-bracket description and location on Embed, (a) L-bracket features, (b) Location of L-bracket in Embed assembly (Adapted from Woods Products Unlimited 2024)

[redacted]

(a)

[redacted]

(b)

Figure 2.11: Right side cover plate description and location, (a) Cover plate features (Adapted from Woods Products Unlimited 2024), (b) Location of right cover plate in Embed assembly (Adapted from Woods Products Unlimited 2024)

There are three different cases where the solenoids of the lock design can enter the locked position. The first two cases are the intended case-scenarios; the code is punched into the keypad, the bed is moved into the open or closed position, the keypad timer runs out, and the solenoids revert to their ‘locked’ position with the pin extensions extending into their intended locking holes. The 3rd case is that the keypad timer runs out while the bed is being moved. This could mean that the solenoids enter their ‘locked’ position (meaning the solenoid has extended its pin) somewhere between the two intended locking holes. When this happens, the pin needs to be slightly pushed back towards the ‘unlocked’ position, just enough so the pin extension can slide up and onto the surface the locking hole is in. The design does this by having small separate ramps made from slightly bent flanges (30°) on the edge of the cover plates and L-brackets. After the pin slides up the ramp and along the surface the locking hole is in, whether the surface is of the cover plate or the L-bracket, the pin will pass over the hole and be pushed into the hole by the return spring.

2.7 Electronic Control System

The complete set of electrical components consist of:

- Keypad
- Diode x2
- Power Supply
- Solenoids x2

All components will be connected to a 12V 5A power supply with 18-AWG wire as shown in Figure 2.12. There will be 4 wires coming out of the keypad:

- **12V (red) and Common (purple):** These wires will be connected to the positive terminal of the power supply. The 12V wire (red) carries the power input, while the common wire (purple) provides the reference ground.
- **Ground (black):** This wire will connect to the negative terminal of the power supply. This wire serves as the ground connection for the system and should be connected to the negative terminals of the solenoids as well.
- **Normally Open (blue):** This wire will connect to the positive terminals of the solenoids. The normally open wire (blue) controls the activation of the solenoids and should be connected to the positive side of the solenoids.

Diodes are placed in parallel with each solenoid to eliminate flyback, which refers to a sudden voltage spike occurring when the system is switched off. This is implemented to safeguard the solenoids against potential damage and ensure their longevity.

To ease in manufacturing, a junction box will be used for multiple wire connections inside, joined by marretes for easy installation. The junction box is a plastic box with a dimension of 5.308" L x 2.942" W X 1.959" H. It will be mounted beside the keypad on the side cabinet, as shown in Figure 2.13.

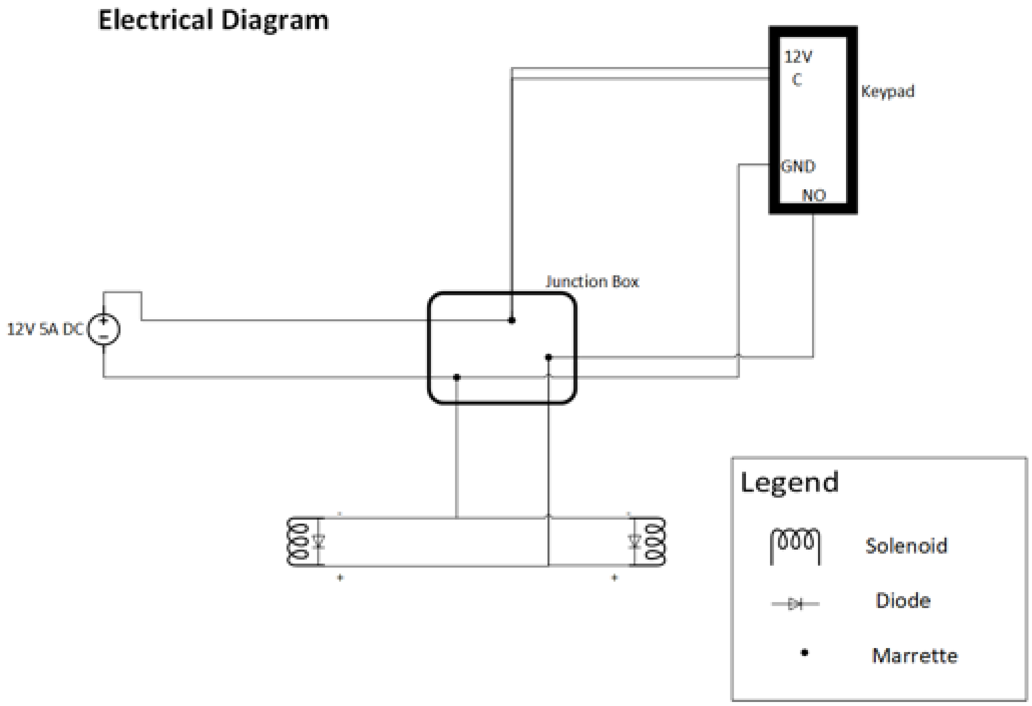


Figure 2.12: Electrical diagram of Embed locking mechanism

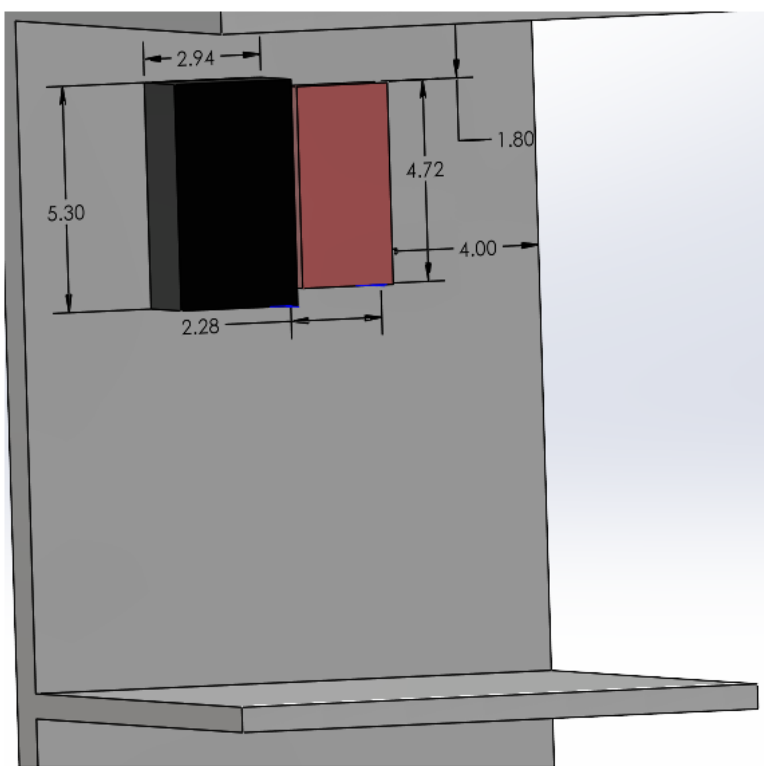


Figure 2.13: Location of keypad and junction box, Junction box black left, keypad red right on Embed side unit

Once all components are securely mounted and set up on the bed, the operational procedure is as follows:

1. The user approaches the keypad and enters a 4-digit passcode to unlock the bed.
2. Upon successful entry of the passcode, the bed immediately unlocks, accompanied by the illumination of a green LED light and a buzzer sound from the keypad.
3. The user can then freely open or close the bed and proceed with their activities.
4. Upon completion of the pre-set timer, the keypad will stop supplying power to the solenoids and the solenoids will return to their ‘locked’ position.

3 Verification

For the locking mechanism, some specifications tested using the verifications methods as shown in Table 3.1. The specifications that were not tested are listed as TBD under the Pass/Fail and Results column.

Table 3.1: Verification Table

Spec.	Description	Criteria	Verification Method	Pass/Fail	Result
S1 – Protype Function Specifications					
S1.1	Brass pin extension	Diameter of 0.67 inch	Visual inspection	Pass	0.67 inch
			Section 3.1		
S1.2	Solenoid protective box	No deformation of box	Visual inspection	TBD	TBD
			Section 3.1		
S2 – Keypad Specifications					
S2.1	Keypad passcode function	100 % accuracy	Instrumentation test	Pass	100% accuracy
			Section 3.2.1		
S2.2	Keypad relay timer	20 seconds	Instrumentation test	Pass	20 seconds
			Section 3.2.1		
S2.3	Keypad RFID fob function	100 %	Instrumentation test	Pass	100%
			Section 3.2.2		
S3 – Electrical Circuit Specifications					
S3.1	Locking time	<5 seconds	Instrumentation Test	Pass	< 1 second

Spec.	Description	Criteria	Verification Method	Pass/Fail	Result
			Section 3.3.1		
S3.2	Diode quality control	0 mA	Instrumentation test Section 3.3.2	Pass	0 mA
S3.3	Solenoid quality control	Armature throw 0.5 inch	Instrumentation test Section 3.3.3	Pass	0.5 inch
S4 – Assembled Embed Specifications					
S4.1	Embed locks closed	Bed does not move to open position when locked	Physical test Section 3.4	TBD	TBD
S4.2	Embed locks opened	Bed does not move to closed position when locked	Physical test Section 3.4	TBD	TBD
S4.3	Lock installation	Install time: <45 minutes	WPU's test Section 3.4.1	TBD	TBD
S4.4	Serviceability	Service time: <15 minutes	Physical test Section 3.4.1	TBD	TBD

3.1 Verification for Prototype Testing Rig

The objective of the testing rig is to verify specifications S1.1, S1.2 and to ensure the cover plate, brass pin extension, solenoid casing, and solenoid mounting screws can resist 200 lbs of force being applied to the locking mechanism without deformation or breaking in a way that inhibits the functionality of the locking mechanism. The testing rig is shown in Figure 3.1 and the direction of the force applied is shown in Figure 3.2. Some small deformation such as rolling of the edge of the locking hole in the cover plate are expected and permissible.

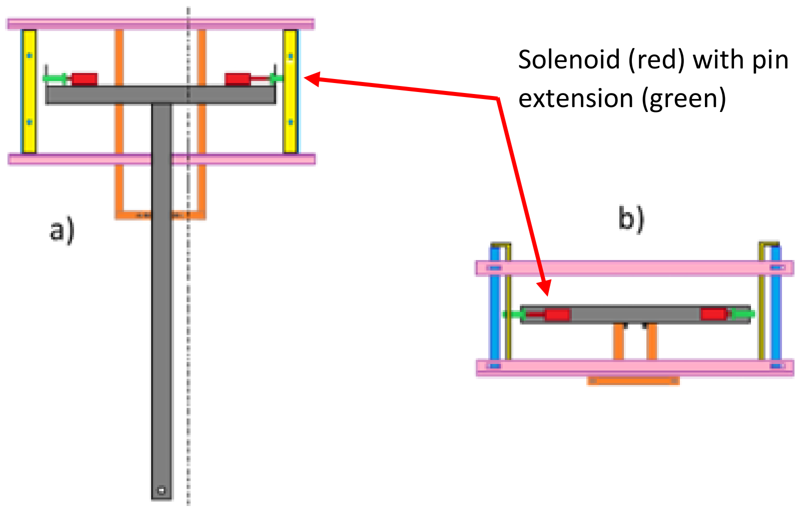


Figure 3.1: Prototype testing rig setup, (a) Top view, (b) Rear view

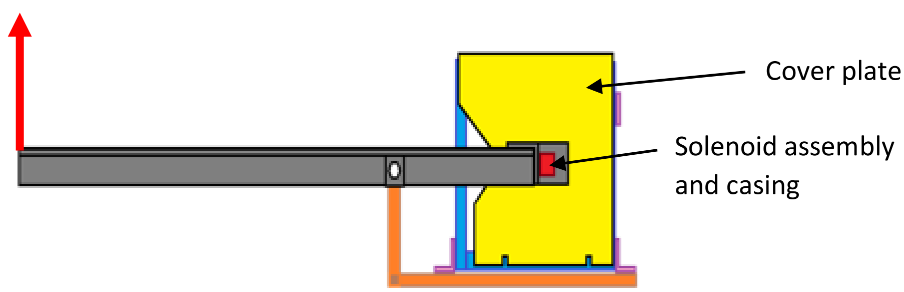


Figure 3.2: Direction of applied force on prototype testing rig indicated by the red arrow

Materials:

- Approximately 10’ of 1.5” angle iron, thickness of 3/16”
- Approximately 16’ of 1” square metal tubing, thickness of 3/32”
- Various ¼” bolts, various sizes
- Eight ¼” wingnuts
- Assorted washers
- 7/16” bolt and nut for pivot point
- 2 cover plates (supplied from WPU)

- Approximately 20” of 1.5” steel flat bar, thickness of 1/8”
- Approximately 18” of ¾” steel flat bar, thickness of 1/8”

The testing rig was built in four main sections. Figure 3.1 shows the main frame in orange. The purpose of the main frame is to provide a clamping point that allows the testing rig to securely attach to the table as shown in Figure 3.3, and to hold the rest of the testing rig together.

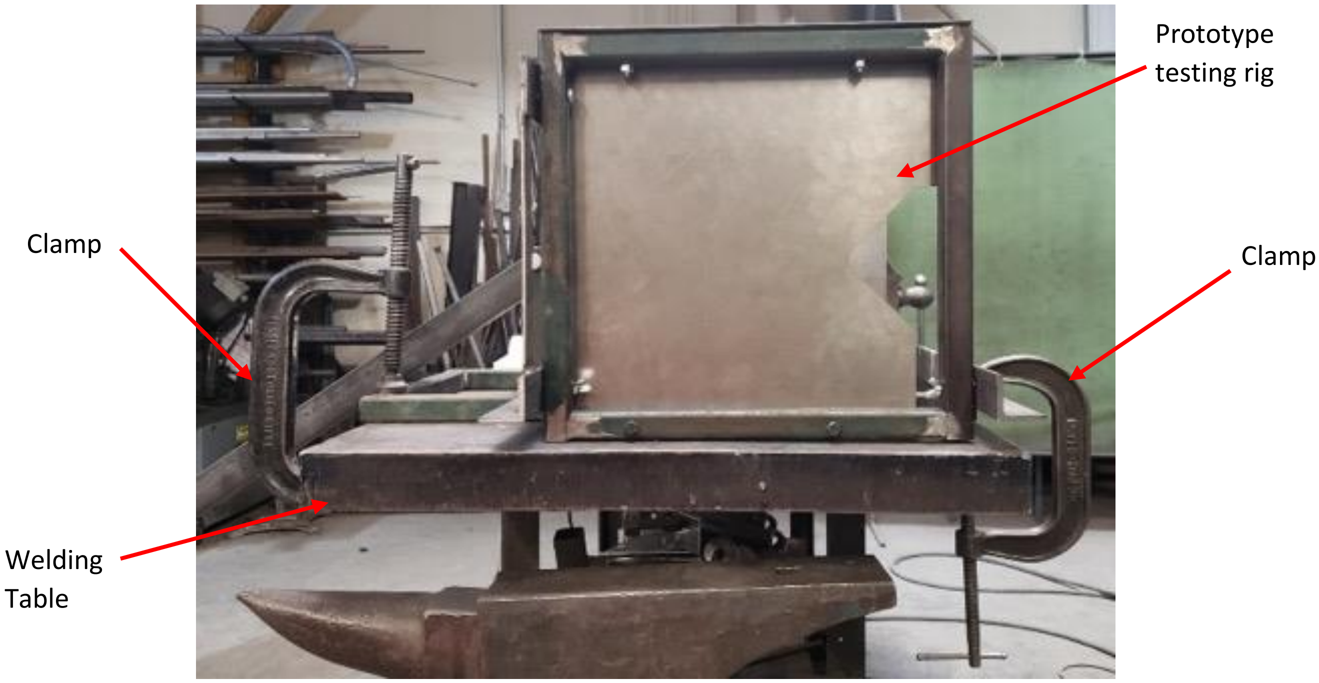


Figure 3.3: Side view of prototype testing rig clamped to welding table

The main frame is made of 1” square metal, tubing welded together. In Figure 3.1, what is seen in yellow is the cover plates supplied by WPU. The cover plates are presumably the most vulnerable part of the locking design as they are made of thin metal and are most likely to deform during testing as they will encounter some of the highest forces the locking mechanism is expected to experience. Effort was made to have the cover plates’ supporting frame (shown in blue in Figure 3.1, comprised of 1” square tubing welded together) to mimic the mounting points the cover plate would have when installed in the Embed. This was done to ensure that the cover plate does not experience any unexpected flexing/bowing that would cause the cover plate’s locking hole to move sideways and away from the pin extension, causing the locking mechanism to fail. The cover plates are attached to their respective supporting frames with ¼” bolts, washers, and lock washers. Washers were used as spacers between each frame and plate to ensure the cover plates remain parallel and vertical. The use of washers and spacers can be seen in Figure 3.4.

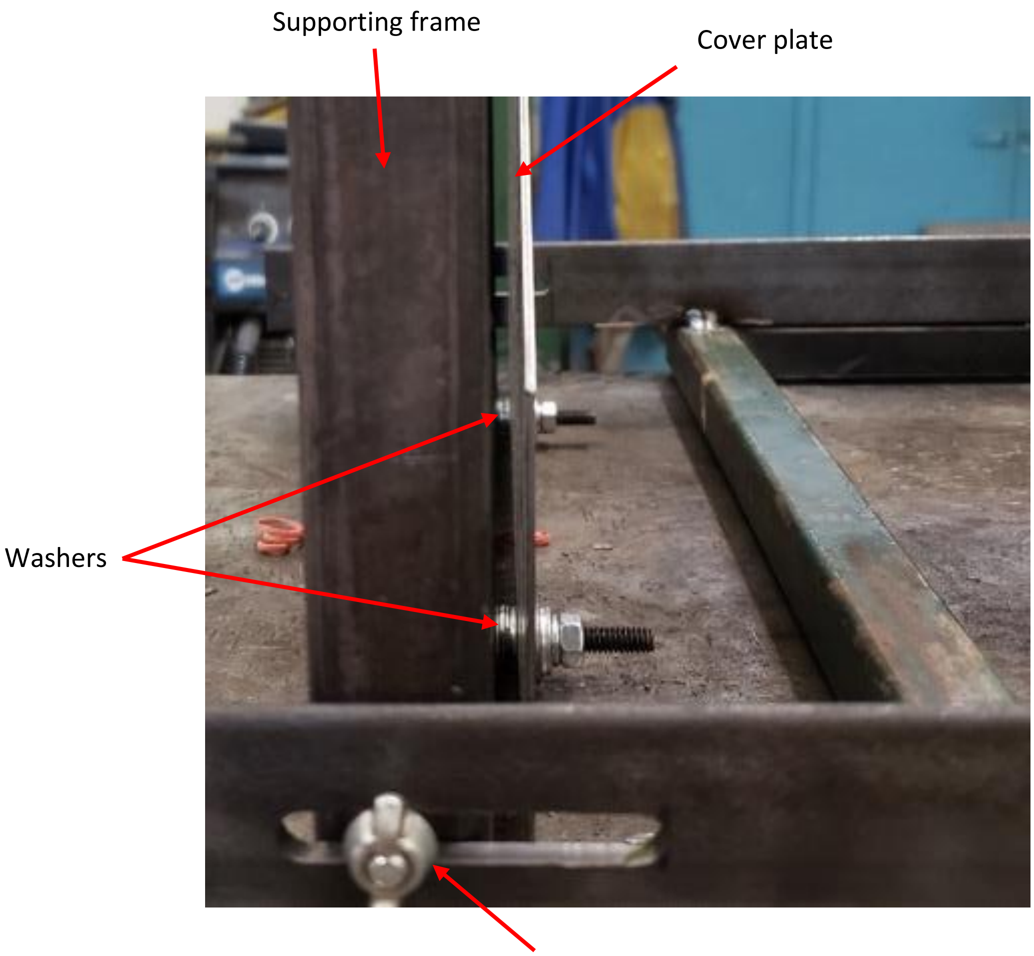


Figure 3.4: View of prototype testing rig with washers between cover plate and supporting frame

The solenoids will be mounted to the bottom corners of the Embed bed frame. The bed frame moves when the rim of the bed frame has force applied to lever it up or down. The length of the bed frame is represented in the testing rig by the grey pieces shown in Figure 3.1a. The width of the grey assembly is much smaller than the width of the Embed, but the length of it closely mimics the Embed in terms of overall length and the pivot point location accurately mimics the forces the locking mechanism is expected to experience. This grey section is comprised of two perpendicular pieces of 1.5” angle iron that are bolted together. Care was taken to ensure that the long length of angle iron is altered as little as possible so this piece can be reused, and the cost of the testing rig can be reduced. Additionally, when a small manufactured piece was required to build the testing rig, scrap metal was used to lower costs. Another important section of the testing rig is shown in pink in Figure 3.1. This pink section has slots that provided positional adjustability for the cover plates so they can move closer to, or further from the solenoids, also shown in Figure 3.4. The slots have ¼” bolts with wingnuts passing through them and into the cover plate’s blue supporting frame, allowing the position of the cover plates to be adjusted and then secured in place when the wingnuts are tightened. This is important because the gap between the solenoid and cover plate varies on the assembled embed; with a larger gap, more tortional force could be applied to the pin extension. This rig will test if the locking mechanism can withstand these larger tortional forces without being negatively affected.

The fully built testing rig shown in Figure 3.5 differs from Figure 3.1 in that additional vertical pieces of flat bar have been welded on to the slotted pieces to better secure the cover plates in position once tightened. It also differs in that the solenoids will be mounted to the solenoid casing and then the casing will be mounted in a very similar position to the one shown in Figure 3.1. The testing rig was originally built with the idea that the solenoid pin extension may not need two guide holes to resist torsional force. However, due to time constraints, testing the strength of one guide hole will not be done. The slotted pieces and the main frame are welded together. Before testing, the solenoid casings will have the hole locations and solenoid pin extension locations traced onto the testing rig, and holes will be drilled. For the hole in the cover plate, a round hole of 0.75” will be drilled to mimic the width of the planned slotted hole.

Figure 3.5: View of test frame with additional supporting flat bar to prevent lateral racking

S1 Procedure:

1. Lock the prototype testing rig in the opened position.
2. Apply 200 lbs of force upwards using the game scale one time.
3. Unlock the locking mechanism.
4. Visually inspect the prototype testing rig after the force is applied for any unexpected tears, deformation, twisting, or damage to the following components:
    a. Cover plate*
    b. Brass pin extension
    c. Solenoid casing
    d. Solenoid mounting screws to solenoid casing

*Some rolling of the edge of the hole in this part is permissible and expected

5. If there is no damage to any components listed in step 3, repeat the test from step 1, two more times. If there is damage, identify which component was damaged and strengthen that component for the next round of testing.

3.2 Verification for Keypad

These verifications are to ensure all S2 specifications related to the electronic keypad are operational and functionality of the electronic keypad.

3.2.1 S2.1 Keypad Passcode Function

The objective of this verification is to ensure that each button is sensitive to user input. The test is considered successful if all numeric buttons (0 to 9) are tested for functionality. Delay between each button press is between 0.5 and 1.
Procedure:

1. Connect the keypad and solenoids to a power supply securely.
2. Verify the keypad's power status by observing the illumination of a bright red light accompanied by a buzzer sound.
3. Input the correct passcode (default: 9999) to initiate the bed unlocking process. Successful operation is indicated by the illumination of a bright green light followed by a buzzer sound.
4. To change the passcode, access programming mode and refer to the keypad's programming guide for instructions.
5. Enter the new passcode and verify its functionality by repeating the unlocking process.
6. Continuously modify the passcode until all numeric buttons (0 to 9) are tested for functionality.

3.2.2 S3.2 Keypad relay timer

The objective of this verification is to ensure the accuracy of the built-in relay timer of the keypad within a tolerance of ±0.5 seconds, as specified in the keypad programming guide.
Procedure:

1. Connect the keypad to a 12V power supply unit.

2. Refer to the keypad programming guide for instructions on adjusting the relay timer.
3. Set the relay timer to 20 seconds.
4. Enter the correct passcode and commence a timer immediately upon the occurrence of a bright green light accompanied by a buzzer sound.
5. Observe whether the relay timer deactivates at the 20-second mark and halt the timer accordingly.

3.2.3 S3.2 Keypad RFID Fob function

The objective of this verification is to ensure the functionality of the built-in RFID fob scanner of the keypad, which involves confirming its capability to recognize and interact with RFID key fobs. This verification is passed if all the included 10 RFID key fobs are read successfully.
Procedure:

1. Connect the keypad and solenoids to a power supply securely.
2. Verify the keypad's power status by observing the illumination of a bright red light accompanied by a buzzer sound.
3. Refer to the keypad programming guide for instructions on how to add RFID users.
4. Scan the RFID key fob on the keypad.
5. Successful operation is indicated by the illumination of a bright green light followed by a buzzer sound.
6. Continuously add RFID key fobs until all are tested for functionality.

3.3 Verification for Electrical Circuit

These verifications are to ensure the electrical circuitry functions properly as it encompasses the operation of the main components of the locking mechanism - the two solenoids and keypad, as specified in Specification S3.

3.3.1 S3.1 Locking Time

Objective: The locking time for the solenoid armature to fully retract or spring back out must be less than 5 seconds. The time will start recording right after the correct passcode is entered.
Procedure:

1. Connect the keypad and solenoids to a power supply securely.
2. Input the correct passcode (default: 9999) to initiate the bed unlocking process.
3. Record the time it needs for the solenoid armature to retract.
4. De-energize the solenoids and record the time it needs to return to its original position.

3.3.2 S3.2 Diode Quality Control

The objective of this test is to verify whether the diodes are effectively suppressing flyback voltage going into the solenoids, thus ensuring their longevity. Procedure:

1. Ensure that the multimeter is set to diode test mode.
2. Connect a multimeter test lead to one end of the diode.

3. Record the measurement.
4. Reverse the orientation of the diode and connect a multimeter test lead to the other end.
5. Record the measurement.
6. One of the readings should read close to 0 volt, indicating proper diode functionality, while the other reading should show some voltage, confirming the diode’s operation.

3.3.3 S3.3 Solenoid Functions

Objective: Ensure the solenoids armature is retracting when energized, and springs back out when power is turned off.

Procedure:

1. Set the power supply unit to 12V before connecting to solenoids.
2. Connect the positive and negative nodes of the solenoids to the power supply accordingly.
3. Turn on the power supply unit.
4. Visually inspect solenoid behavior upon energizing.
5. Turn off the power supply unit and visually confirm if the armature springs back out.

3.4 Assembled Embed Specifications

These verifications are to make sure all specifications that the Embed and entire locking mechanism work together to lock the Embed in the closed and opened positions with the pin extension.

Procedures for S5.1 and S5.2:

1. Assemble the solenoids, keypad, and electrical wiring on the Embed.
2. S5.1: Lock the Embed in the closed position (see Figure 3.6a).
    a. A force of 200 lbs will be applied to attempt to pull the Embed open using a game scale.
    b. The bed frame will be moved side to side to attempt to overcome the locking mechanism.
3. S5.2: Lock the Embed in the opened position (see Figure 3.6b).
    a. A force of 200 lbs will be applied to attempt to pull the Embed closed using a game scale. The individual will use as much force as they can.
    b. The bed frame will be moved side to side to attempt to overcome the locking mechanism. The individual will use as much force as they can.
4. Repeat the closed and opened position tests with three different individuals.

[redacted]

(a) (b)

Figure 3.6: Direction of applied forces indicated by red arrows (a) Embed closed (Modified from WPU 2024), (b) Embed opened (Modified from WPU 2024)

S5.3 Lock Installation

The expertise and opinions of WPU will be provided to ensure the installation of the locking mechanism is feasible and is performed with ease. It is important that the installation is a smooth process to allow a quick installation time for the customer. The locking mechanism should be installed on the Embed within 45 minutes. This includes the installation of:

- Two solenoids and solenoid casings
- Keypad
- Junction box
- Black cable channels
- Wiring

Procedure:

1. First mount the solenoid into the solenoid casing and fit the pin extension through the inner and outer holes of the casing.
2. Install the solenoid casing onto the left and right sides of the bed frame.
3. Mount the keypad and junction box on the side of the Embed. The choice to mount it to the left or right side of the bed will be chosen by the customer.
4. The black cable protectors will be installed on the bed frame to cover the wires as shown in orange in Figure 3.7. The wires that are attached directly onto the bed frame will be threaded through the cable channels and should not be exposed.

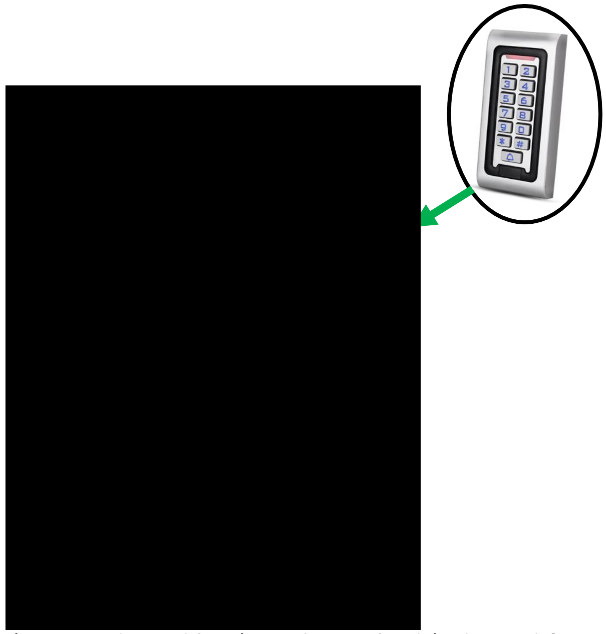


Figure 3.7: Wiring (orange dotted line) on the Embed (Adapted from Wood Products Unlimited 2024; Hfeng 2023)

S5.4 Serviceability

Serviceability is an important aspect for ease of maintenance. A physical test will be conducted to ensure the solenoid casing, solenoids, and keypad are able to be disconnected, dismounted, and replaced. The time to fully disconnect and replace each component is 15 minutes and must be able to be completed in both the closed and opened positions. The following procedures will be the same for the closed and opened positions.

Procedures to replace the solenoid casing and solenoid:

1. To replace the solenoid casing, the four mounting screws of the casing is removed as shown by the purple and blue dotted lines in Figure 3.8. The screw head will fit into the 0.60” access screw holes to remove the screws located along the purple line.
2. To replace the solenoid, the two mounting screws within the solenoid casing is removed as shown by the orange dotted lines in Figure 3.8.

Figure 3.8: Mounting holes alignment between the solenoid casing (green), solenoid (red), and Member (2) of bed frame (Adapted from Wood Products Unlimited 2024)

Procedures to replace the keypad:

1. Remove the back cover of the keypad using the supplied screwdriver. The screws are located at the top and bottom of the keypad, as shown in Figure 3.9a.
2. Remove the mounting screws at the back of the keypad, as shown in Figure 3.9b.
3. The keypad can now be replaced with a new unit.

(a) (b)

Figure 3.9: Location of keypad screws, (a) Back cover screws (Hfeng 2023), (b) Mounting screws (Hfeng 2023)

4 Limitations

Limitations of the proposed design solution occur through various design phases, such as through testing, methodology, and results. The first limitation concerns the modification that must be made to the support frame to fit the solenoid and its case to fit and attach them to the bed. Modifying the support frame of the Embed may introduce design weaknesses, such as alignment issues, which can affect the overall stability of the assembly. Additionally, limitations arise with the electronic keypad, as malfunctions or tampering with the keypad could impact the security of the locking mechanism. The solenoid components also have limitations as the solenoids cannot stay in the 'unlocked' position without consuming electricity. If someone wishes to leave the bed unlocked for a long period of time, the bed will consume power the entire time.

Limitations also arise from other verification procedures conducted such as for the prototype testing rig and the electrical circuit. The purpose of the prototype testing rig was to simulate the dynamics of the Embed. As the testing rig was designed to test for 200 lbs only, it may not fully capture the equivalent stress that can be applied to the actual Embed during usage. This could cause a difference between the prototype testing rig results and its actual performance in the real world. The verification for the entire electrical circuit also has limitations, as the circuit was only tested in a controlled environment. Since the electrical components were never implemented onto an actual Embed, the performance, longevity and environmental factors could not be validated due to time constraints.

Other limitations came from the budget and time constraint of the project. The locking mechanism was restricted to a budget of $200 CAD and an 8-month completion time. These constraints caused limitations in terms of sourcing components, materials, and the scope of the overall design solution. Consequently, some compromises had to be made to the quality and quantity of the materials used, which may affect the performance and longevity of the locking mechanism. Additionally, the time constraint affected the timeline for verification and validation of the design as all desired tests were not able to be completed. Hence, this caused uncertainties about the capabilities of the locking mechanism design.

One significant limitation to the proposed design solution for the Embed locking mechanism stems from external factors beyond the design team's control, such as delays in the manufacturing of crucial components. Despite careful project planning, the solenoid casing and L-bracket, which are essential components for testing the entire design solution on the testing rig, were not laser cut in time for the scheduled testing phase. As a result, mechanical testing could not be carried out as laid out in the verification procedures and only electrical testing was done. This limitation affected the ability to assess the full functionality and durability of the locking mechanism, as mechanical testing is crucial for evaluating its performance. The absence of these components raises doubt about whether or not the locking mechanism can function properly. Because of this, the necessary testing will be performed once the components become available.

Furthermore, the verification results may fail to completely represent the long-term reliability and durability of the locking mechanism. Factors such as wear and tear, environmental conditions, and user behaviour could influence the performance of the locking mechanism system over time. This presents limitations on how well the testing can be used to predict real world scenarios that the Embed may encounter. Although the design solution for the Embed locking mechanism shows promising functionality and security, these limitations should be taken into account to improve and refine the design, testing and implementation processes to ensure the locking mechanism is reliable.

5 Conclusion

In summary, the Embed locking mechanism provides the ability to lock the Embed in the open and closed position. The addition of two pull-type solenoids, a keypad, and modifications to the support frame to accommodate the solenoid and its casing, was necessary for the functionality of the locking mechanism. All components were chosen based on ease of integration, functionality, and pricing to align with the project's constraints and goals.

A recommended improvement to the design solution is introducing a way for the bed to remain in the unlocked position without using power. A latching solenoid is a type of solenoid that only uses power during movement. For a latching solenoid to be incorporated into the locking mechanism, the entire circuitry would have to be modified due to the changes in current directions and the voltage drop the latching solenoid requires. Additionally, a programmed Arduino microcontroller and a circuit board would also need to be installed. This recommendation may be complicated to implement due to the programming but if implemented, electricity is no longer used while the bed is unlocked.

Additionally, constraints such as budget and time affected material selection and testing procedures. External factors such as delays in manufacturing the solenoid casing and L-bracket limited the verification testing that could be performed on the locking mechanism prototype. As mechanical testing and validations of the locking mechanism could not be done within the timeline, there is some uncertainty as to whether the design solution will be functional and durable under real-world conditions. A recommendation is to address these limitations by doing further testing once all prototype components have been manufactured and become available. Another recommendation is to broaden the scope of the durability testing such as testing for more than 200lbs to be exerted on the locking mechanism. This will help further determine if the proposed Embed locking mechanism is a feasible design solution.

In conclusion, the only aspect of the design solution for the Embed locking mechanism that could be tested for, was the electrical circuit which presented efficient retraction and protraction of the solenoid armature. By integrating two pull-type solenoids and a keypad to control them, the solenoids mimic the movement required to lock and unlock the Embed. Every aspect and component implemented into this project from types of solenoids to use, type of material for the pin extensions and solenoid casing and how to create an efficient electronic circuit was carefully considered to enhance serviceability. Prototype testing and verification procedures to testify the effectiveness and safety were limited and further testing shall be undergone to ensure that the locking mechanism is reliable in various circumstances. Although the locking mechanism designed was deemed promising, validations such as ease of use and installation for consumers were not validated due to time constraints. Nevertheless, the positive results from the testing indicate that in theory, the locking mechanism design should translate well to an actual Embed. The locking mechanism's innovative features and unique solution to lock a Murphy bed in the closed and open position is a gateway to enhancing the future of the Murphy bed designs.

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Appendix A – Bill of Materials

Table A.1: Bill of Materials

Description	Manufacturer	Manufacturer Part #	Distributor	Distributor Part #	Quantity	Unit Cost ($CAD)	Total Cost ($CAD)
Linear Continuous Duty Solenoid Open Frame (Pull) Type	McMaster-Carr	70155K541	McMaster-Carr	-	2	44.04	88.08
HFeng Standalone Keypad	HFeng	1	Amazon	B07DLP1QNY	1	49.99	49.99
AC/DC Power Supply	Pro Elec	28-19387	Newark	25AC5054	1	19.63	19.63
L-Bracket [1]	Internal	-	Internal	-	2	-	-
Pin Extension [1]	Internal	-	Internal	-	2	-	-
Crush Nuts	Fastener Warehouse	RRLS420165	Fastener Warehouse	-	4	0.03	0.12
Button Head Screws	Fastener Warehouse	BHSCS0.250-20-0.625	Fastener Warehouse	-	4	0.25	1.00
Cotter Pin	The Home Depot	1000146871	Paulin	165-695	2	2.05	4.10
						SUBTOTAL	**162.92**
Testing Rig Costs [2]	-	-	-	-	-	**-**	**-**
Electronic Box and Components							
Cable Channel Black RAL 9005	Hafele	833.89.033	HomeDecor Hardware	Hafele-833.89.03	TBD	36.7	-
Black ABS Box	Bud Industries	CU-1874-B	Digikey	377-1165-ND	1	5.04	5.04
Power Barrel Connector	Memory Protection Devices	EJ501A	Digikey	EJ501A-ND	1	3.08	3.08

Spade connector	TE Connectivity	2-520193-2	Digikey	A27806TR-ND	4	0.37	1.48
Diode	ONSEMI	1N5400G	Newark	42K2929	2	0.38	0.76
Keypad Mounting Screws	The Home Depot	1000141207	Paulin	197-589	1	6.55	6.55
						SUBTOTAL	**16.91** [3]
						TOTAL	**179.83**

Notes:

[1] The L-bracket and pin extension will be laser cut and manufactured by WPU. Cost will be determined at a later date.

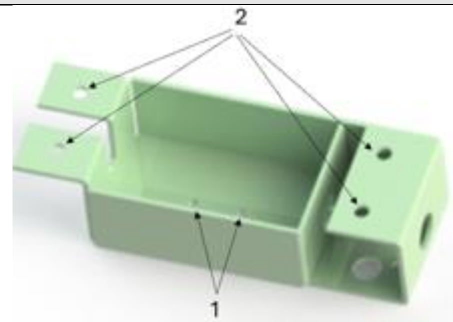
[2] Testing rig price will be determined by Dale once the rig is complete. Cost will be based on what materials can be returned to Dale unchanged once testing rig is disassembled.

[3] Costs does not include the price for the black cable channels as the final quantity is unknown.

Appendix B Tolerance Tables and Calculations

Table B.1: Tolerances and Final Size for Hole in Cover Plate

Description	+/- X Tolerance (inches)	+/- Y Tolerance (inches)	Images of Parts of interest
Holes of cover plate and the heavier plate it's mounted on (1)	0.02		[redacted] Figure B.1: Labelled motion assembly components (Adapted from Wood Products Unlimited 2024)
Top bends of cover plate and the heavier plate it's mounted on (2)		0.02	
Pivot point hole in heavier plate of motion assembly (3)	0.01	0.01	
Motion assembly arm holes and its matching holes on bed frame (4)	0.02	0.02	
Motion assembly arm pivot point hole (5)	0.01	0.01	
Positioning of the slotted hole in cover plate (6)	0.01	0.01	
Holes in solenoid casing that correlate to the solenoid screw holes (1)		0.01	

Description	+/- X Tolerance (inches)	+/- Y Tolerance (inches)	Images of Parts of interest
The four holes in solenoid casing, for mounting the said case to the bed frame rim in addition to their respective mounting holes on the bed frame rim (2)	0.02	0.02	 Figure B.2: Labelled solenoid box mounting holes
Out-of-level floor (+/- 2.5°)	0	0.385	
Rounding down hole center position from CAD model measurements	(only away from pivot)0.01	(only down) 0.01	
Movement of pin extension within solenoid casing guide holes	0.04	0.04	
Final hole dimensions [a]	**0.94**	**1.73**	

Note:

[a] Pin extension diameter is 0.67”

Table B.2: Tolerances and Final Size for Hole in L-Bracket

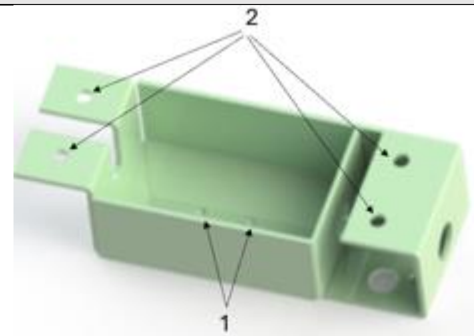
<table>
<tr><th>Description</th><th>+/- X Tolerance (inches)</th><th>+/- Y Tolerance (inches)</th><th>Images of Part of Interest</th></tr>
<tr><td>Holes in solenoid casing that correlate to the solenoid mounting screw holes [a] (1)</td><td>0.01</td><td></td><td rowspan="2">


Figure B.3: Labelled solenoid box mounting holes
</td></tr>
<tr><td>The four holes in solenoid casing for mounting the said case to the bed frame rim in addition to their respective mounting holes on the bed frame rim (2)</td><td>0.02</td><td>0.02</td></tr>
<tr><td>Positioning of L-bracket (allowing for 3/32" off in mounting vertically)</td><td>0.01</td><td>0.1</td><td rowspan="3"></td></tr>
<tr><td>Bend on L-bracket (not the bend for the flange)</td><td>0.01</td><td></td></tr>
<tr><td>Positioning of hole in L-bracket</td><td>0.01</td><td>0.01</td></tr>
<tr><td>Final hole dimensions [b]</td><td>0.79</td><td>0.75</td><td></td></tr>
</table>

Note:

[a] Tolerance of placement of screw holes on solenoid are outside of the project scope

[b] Pin extension diameter is 0.67”

Table B.3: Tolerances for Solenoid Casing

Description	+/- X Tolerance (inches)	+/- Y Tolerance (inches)	Parts Tolerances are Allowing for [d]
Outer guide hole		0.02	2 bends in casing(1)
	0.01	0.01	Placement of outer guide hole (2)
	~0 [a]	~0 [a]	Tolerance of pin extension sizing
Total additional tolerance	0.01	0.03	
Inner guide hole	0.02	0.01	2 bends in casing (3)
	0.01	0.01	Placement of inner guide hole (4)
	~0 [a]	~0 [a]	Tolerance of pin extension sizing
Total additional tolerance	0.03	0.02	
Dimensions of guide holes [c]	0.70	0.70	Note: Took the largest tolerance from both guide holes because the guide holes are successive.
Four casing mounting screw holes [b]	~0	~0	Placement of screw holes and bends
Solenoid mounting screw holes	0.01	0.01	Placement of screw holes (5)

Note:
[a] Dale Bourns said the machining tolerances of the pin extension is +/-0.001”. This is much smaller than the Embed tolerances of +/-0.01” so the pin tolerances are considered negligible.
[b] Tolerances of bends for these holes were not included due to the solenoid casing being able to flex slightly to accommodate any slightly off holes. Additionally, these holes are made to be the same size to match already-existing holes on the Embed, matching company policy.
[c] Pin extension diameter is 0.67”
[d] See the Figure B.4 below for a detailed diagram

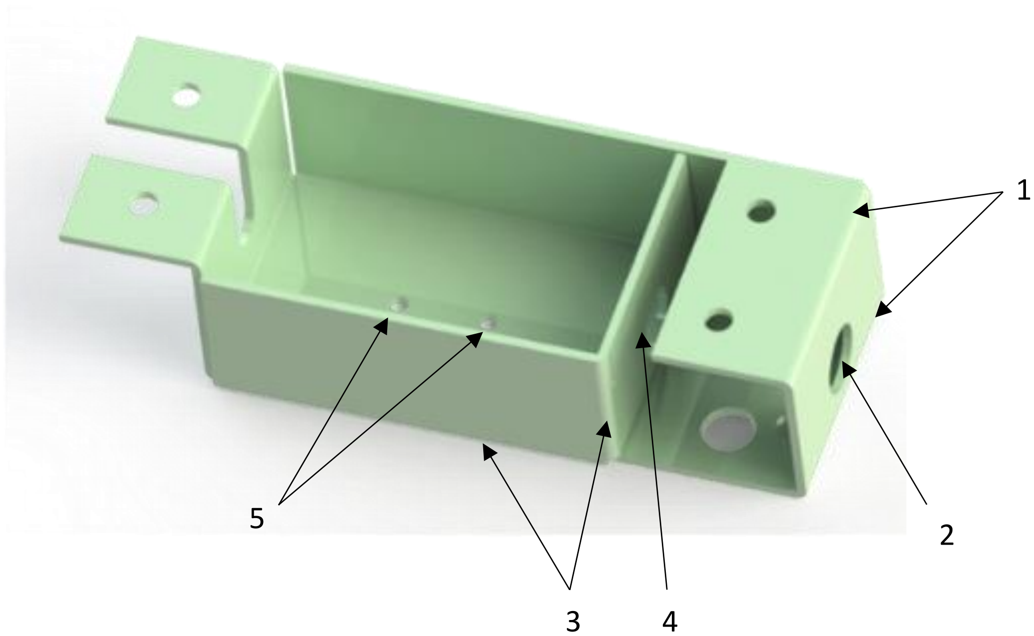


Figure B.4: Tolerances labelled solenoid casing

B.1 Calculations for Out-Of-Level Floor

In older homes it is rare for things to be square. If the Embed is installed in an older home, the floor may be out-of-level and so, the locking mechanism should account for this. Figure B.5 shows a simplified side view of the Embed for when the floor is θ degrees out of level from the wall.

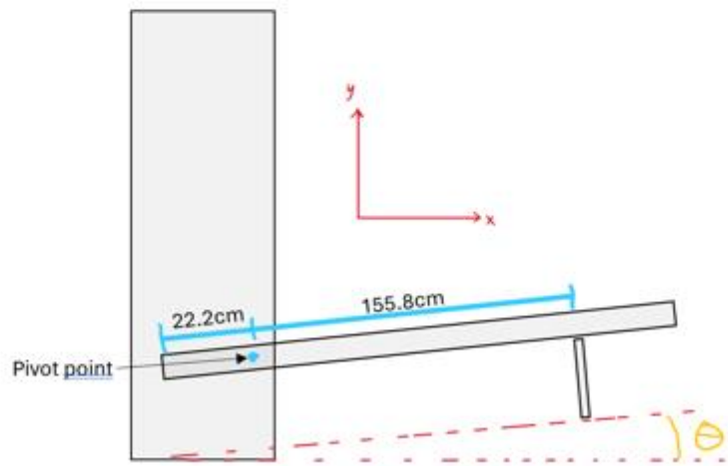


Figure B.5: Out-of-level floor calculations: simplified side view of the embed with dimensions

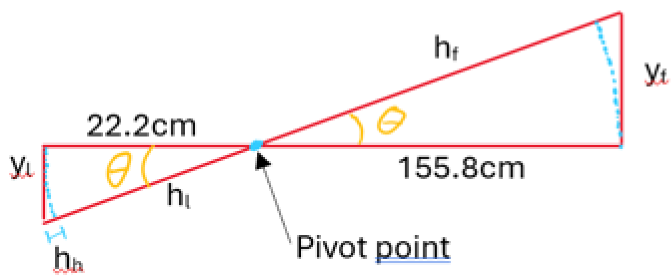


Figure B.6: Out-of-level floor calculations: mathematical diagram of bed

Figure B.6 shows a diagram with an exaggerated θ for clarity. θ =2.5° because it is expected to be higher than any out-of-level house floor would usually be. 2.5° out-of-level means that at the leg of the Embed, the floor would be off by about 2.7”. This value of θ was confirmed with Rob Enns of WPU to be appropriate. The leftmost side diagram in Figure B.6 is the focus of these calculations as this is where the solenoid is mounted and what the dimensions the hole in the cover plate will be affected by. Calculations for the cover plate hole is as follows:

To find the x tolerance caused by the rotation of the bed by 2.5° using trig ratios:

Assuming right-angle triangle gives:

$$h_1 = \frac{22.2}{\cos{(2.5°)}} = 22.221\ cm \qquad \text{Eq. 1}$$

And now we can solve for h_h to determine the x tolerance:

$$h_h = h_1 - 22.2 = 0.01\ cm \cong 0\ cm$$ Eq. 2

So, there is no notable x tolerance needed to account for bed rotation.

To find the y tolerance caused by the rotation of the bed by 2.5° using trig ratios:

$$y_1 = \tan(2.5°) * 22.5 = 0.97\ cm \cong 0.38"$$ Eq. 3

As a result, we will need +/- 0.38” of tolerance to account for bed rotation.

B.2 **Calculations** for allowable pin size

For the maximum allowable bearing force on the cover plate before yielding with a 90% safety factor:

$0.9F_{y_{A36}} = 223.2\ MPa$, where $F_{y\_A36} = 248\ MPa.$

For max allowable brass pin shear force with a safety factor of 40%:

$0.4 * F_{y_{B16}} = 49.6\ MPa$, where $F_{y\_B16} = 124\ MPa$ (Coremark 2024)

An excel spreadsheet was created to determine what the weakest part of the design was and what dimensions the parts needed to be at a minimum. The following **Table B.4** shows the values. Formulas for each column will be explained after.

Table B.4: Force Calculations

			Closed	**Open**	
Pin diameter (mm)	Solenoid pin cross-sectional area (mm^2)	Solenoid Pin bearing area on cover plate (mm^2)	Bearing force on L-bracket (Mpa)	Bearing force on plate cover (Mpa)	Pin shear force (Mpa)
12	113.10	19.05	63.28	304.47	51.28
13	132.73	20.64	58.41	281.05	43.70
14	153.94	22.23	54.24	260.98	37.68
15	176.71	23.81	50.62	243.58	32.82
16	201.06	25.40	47.46	228.35	28.85
17	**226.98**	**26.99**	**44.67**	**214.92**	**25.55**

The pin shear force one pin extension will experience was calculated with: $P_{sf} = \frac{F}{A}$,

where F is half the force the locking system will experience from a 200lb lift on an open bed, and A is the contact area between the cover plate hole and the pin extension.

Bearing force one cover plate will experience cover plate was calculated with: $B_C = \frac{F_{opened}}{A_{bc}}$,

where F_{opened} is half the force locking system will experience from a 200lb lift on an open bed, and A is the contact area between the cover plate hole and the pin extension.

A_{bc} was calculated with: $A_{bc} = D_p * t_c$,

where D_p is the pin extension diameter, and t_c is the thickness of the cover plate.

F_{opened} was calculated with: $F_{opened} = F_y * \frac{2.8937}{0.222*2}$,

where F_y is the vertical force (in N) applied at the foot of the bed to try forcing the bed closed while locked. Our team decided with WPU that 200lbs of lift was enough.

Bearing force that one L-bracket will experience was calculated similarly with: $B_L = \frac{F_{closed}}{A_{bL}}$,

where F_{closed} is half the force the locking system will experience from a 200lb lift on an open bed, and A is the contact area between the cover plate hole and the pin extension.

A_{bL} was calculated with: $A_{bL} = D_p * t_L$,

where t_L is the thickness of the L-bracket.

F_{closed} was calculated with: $F_{closed} = \frac{F_y*2.8937}{0.222*2}$,

where F_x is the horizontal force (in N) applied at the leg of the bed to try forcing the bed opened while locked. Our team experimentally determined this force to be 344 N.

Appendix C – Technical Drawings

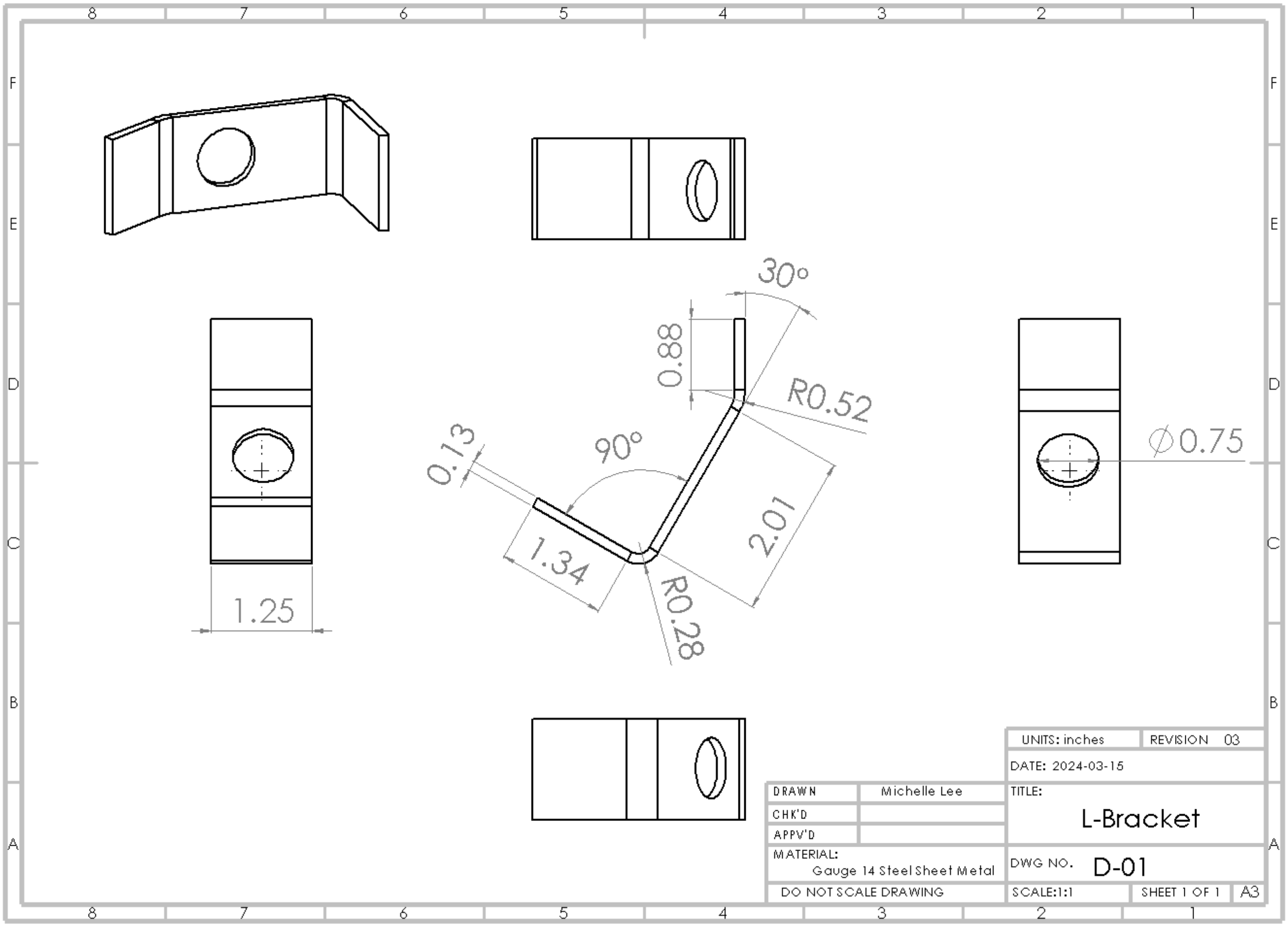


Figure C.1: Dimensions of L-bracket in inches

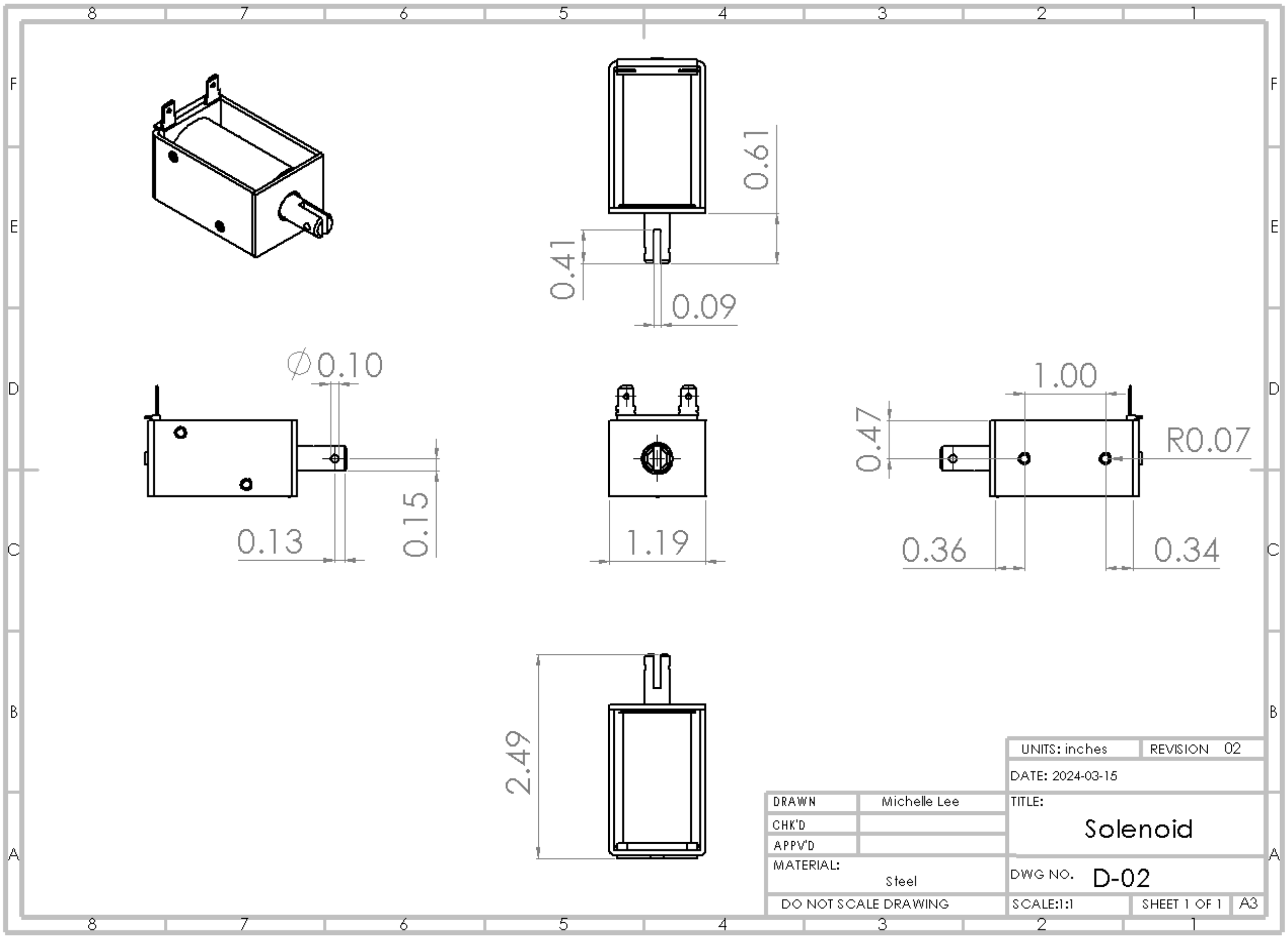


Figure C.2: Dimensions of McMaster-Carr solenoid in inches

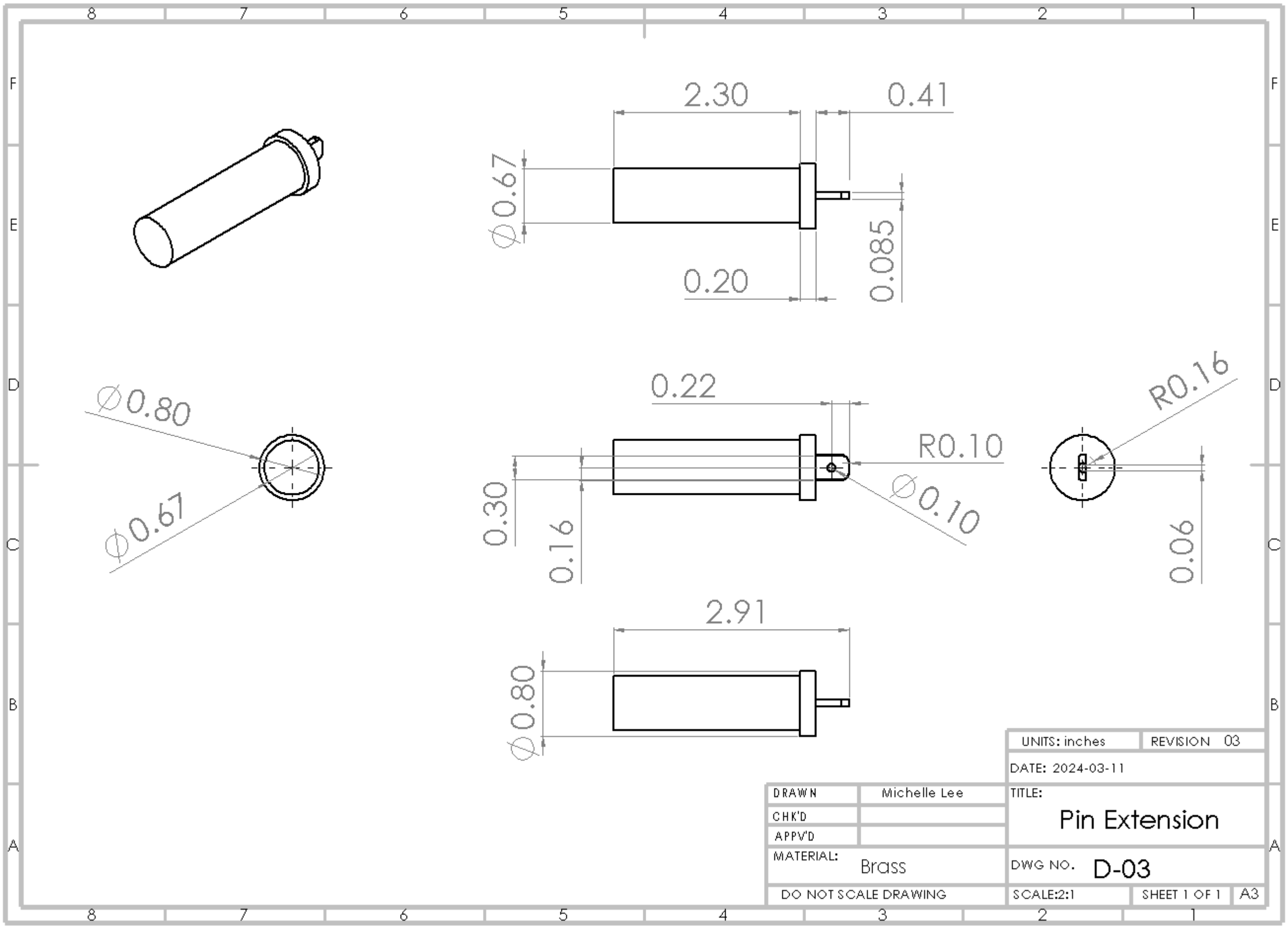


Figure C.3: Dimensions of pin extension in inches

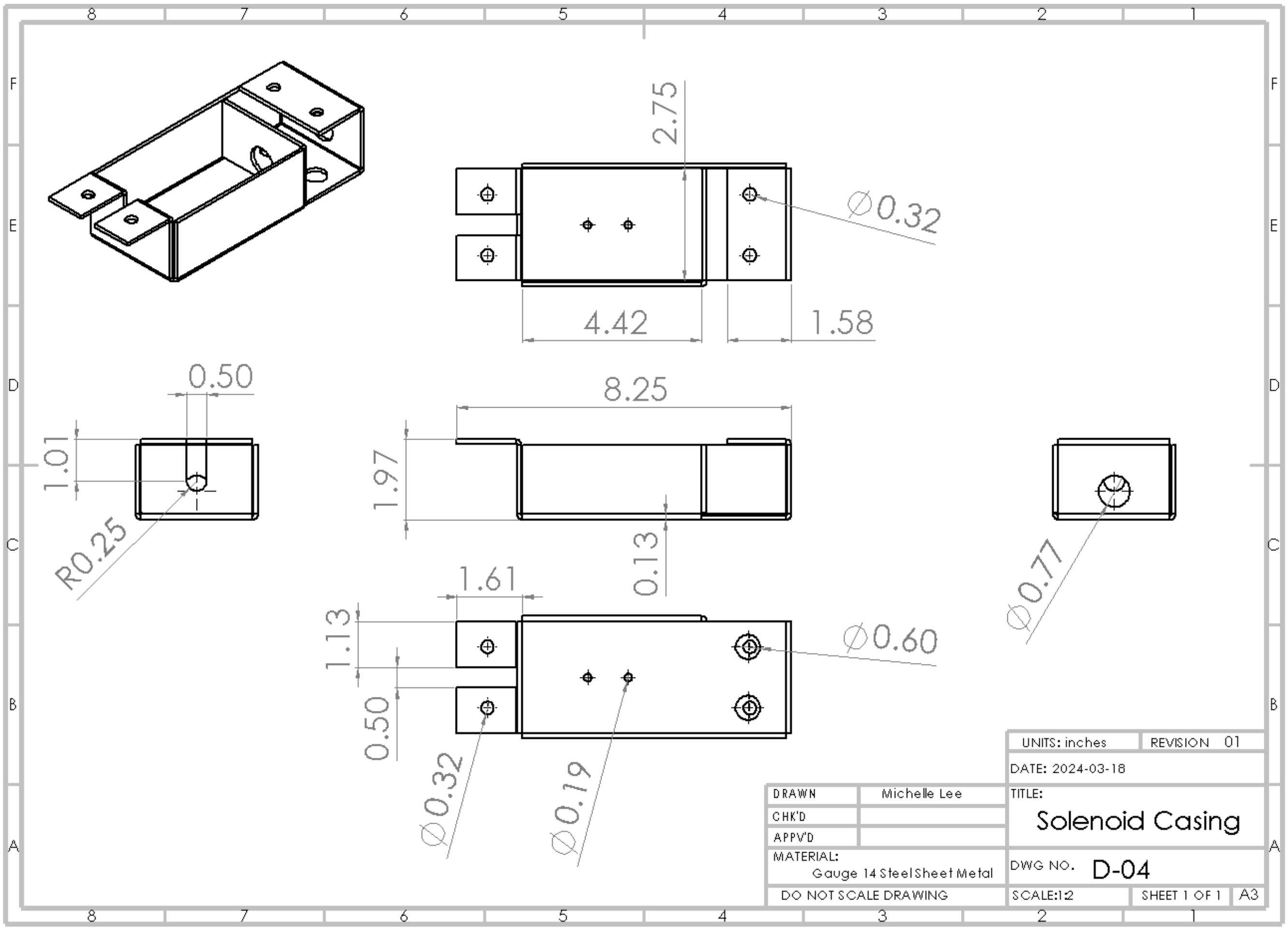


Figure C.4: Dimensions of solenoid casing in inches

Figure C.5: Dimensions of slotted hole and flange for left cover plate in inches

Figure C.6: Dimensions of slotted hole and flange for right cover plate in inches

Appendix D – Datasheets

Direction of Motion	Linear
Frame Type	Open
Direction of Force	Pull
Maximum Stroke Length	1/2"
Length	
Retracted	2.5"
Extended	3"
Overall	3"
Force @ 10% Stroke Length	50 oz.
Force @ 20% Stroke Length	35 oz.
Force @ 50% Stroke Length	15 oz.
Force @ 100% Stroke Length	4 oz.
Voltage	12V DC
For Voltage Type	DC
Electrical Connection	Quick-Disconnect Terminals
Current @ Retracted Stroke	0.67A
Power Draw	8 watts
Duty Cycle	Continuous
Terminal Width	3/16"
Overall	
Width	1 1/4"
Height	1 1/4"
Rod Diameter (R)	0.31"
Rod Return Style	Returns with Included Spring
Rod Type	Clevis
Body Material	Steel

Insulation	
Class	B
Maximum Temperature	266° F
Mounting Orientation	Any Angle, Horizontal, Inverted, Vertical
Mounting Hole Thread Size	6-32
Specifications Met	UL Recognized Component
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/10/2022, 224 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States
USMCA Qualifying	No
Schedule B	850511.9000
ECCN	EAR99

Create linear motion economically with one of these open-frame solenoids.

Pull solenoids exert force when the rod retracts.

Figure D.1: Datasheet for McMaster-Carr Solenoid (70155K41)(McMaster-Carr 2024)

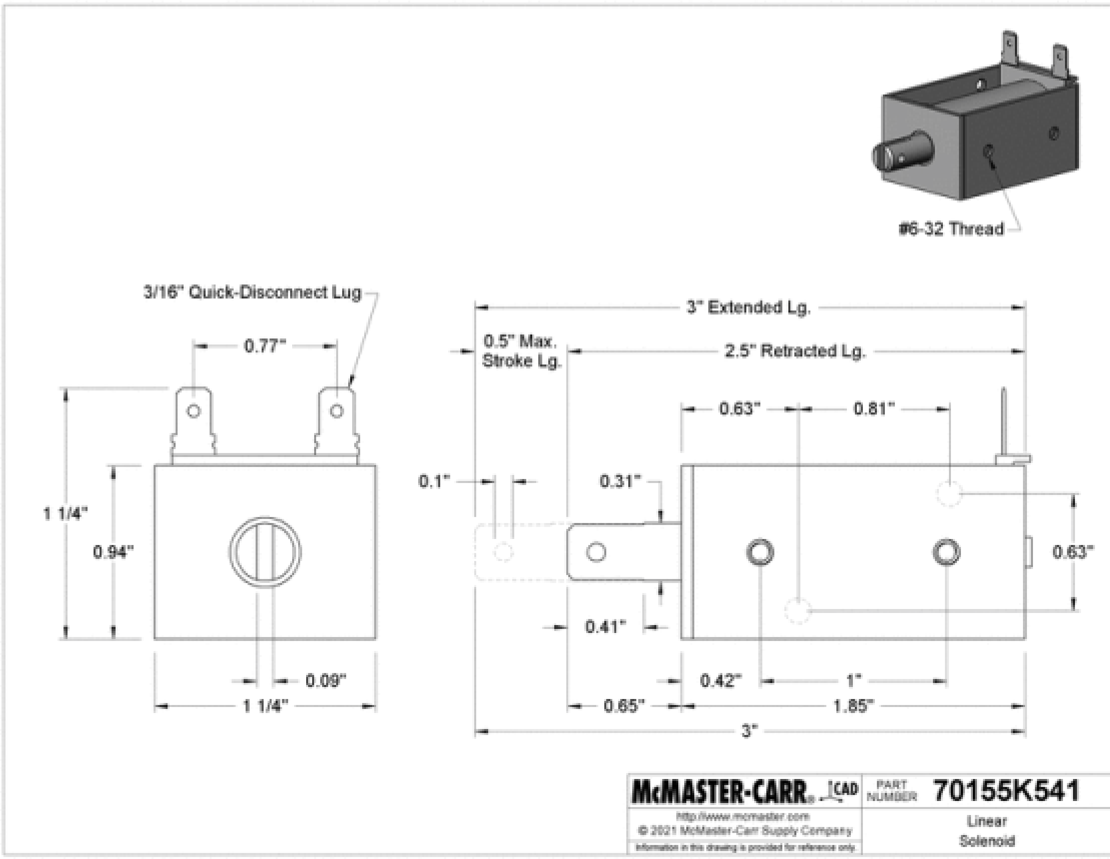


Figure D.2: 2D Drawing of McMaster-Carr Solenoid (70155K541) (McMaster-Carr 2024)

1. Packing List

Name	Quantity	Remarks
Keypad	1	
User manual	1	
Rubber plug	2	Φ6mm×30 mm, used for fixing
Self tapping screws	2	Φ4mm×28 mm, used for fixing
Diode	1	1N4007

Please ensure all the above contents are correct. If any missing, please notify the supplier of the unit.

2. Quick Reference Programming Guide

Enter the programming mode	* Master code # 999999 is the default factory master code
Exit from the programming mode	*
Note that to undertake the following programming, the master user must be logged in	
Change the master code	0 New code # New code # The master code can be 6 to 8 digits
Add a PIN user	1 User ID number # PIN # The ID number is any number between 1 & 2000. The PIN is any four digits between 0000 & 9999 with the exception of 1234 which is reserved. Users can be added continuously without exiting programming mode
Add a card user	1 Read Card # Cards can be added continuously without exiting programming mode
Delete a PIN or a card user	2 User ID number # for a PIN user or 2 Read Card # for a card user Users can be deleted continuously without exiting programming mode
Unlock the door for a PIN user	Enter the PIN #
Unlock the door for a card user	Present the card

1

3. Description

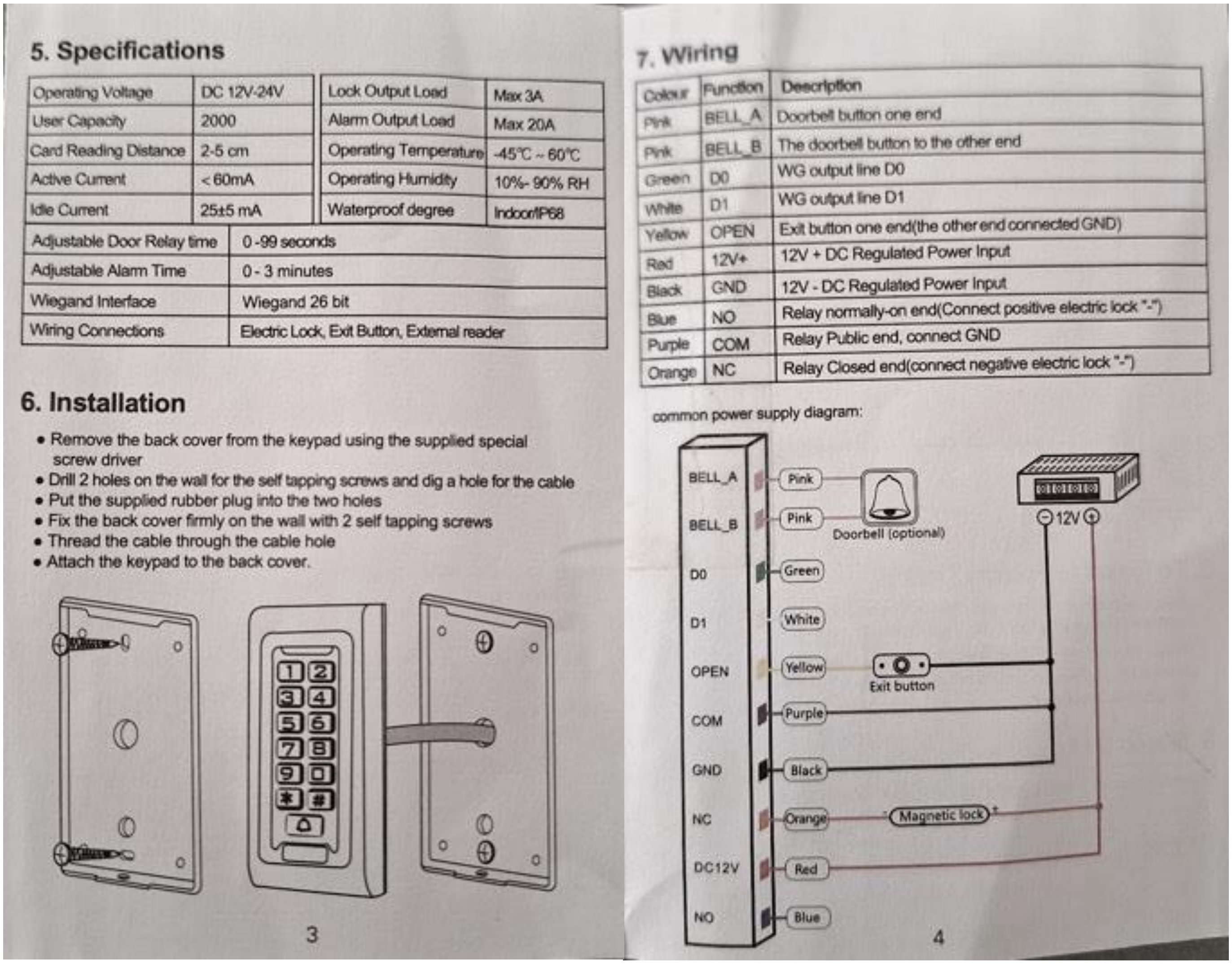
The unit is single door multifunction standalone access controller or a Wiegand output keypad card reader. It is suitable for mounting either indoor or outdoor in harsh environments.
This unit supports up to 2000 users in either a Card, 4 digit PIN, or a Card + PIN option.The inbuilt card reader supports 125KHZ EM cards,13.56MHz Mifare cards. The unit has many extra features including lock output current short circuit protection, Wiegand output , and a backlit keypad. These features make the unit an ideal choice for door access not only for small shops and domestic households but also for commercial and industrial applications such as factories, warehouses, laboratories, banks and prisons.

4. Features

- Waterproof degree,Indoor/IP68
- Full programming from the keypad
- 2000 users, supports Card, PIN, Card + PIN
- Can be used as a standalone keypad
- Backlight keys
- Wiegand 26 input for connection to external reader
- Wiegand 26 output for connection to a controller
- Adjustable Alarm time and Door Open time
- Very low power consumption (30mA)
- Fast operating speed, <20ms with 2000 users
- Lock output current short circuit protection
- Easy to install and program
- Built in buzzer
- Red, Yellow and Green LEDS display the working status

2

Figure D.3: Photos of Hfeng Keypad Manual: Pages 1 & 2



5. Specifications

Operating Voltage	DC 12V-24V	Lock Output Load	Max 3A
User Capacity	2000	Alarm Output Load	Max 20A
Card Reading Distance	2-5 cm	Operating Temperature	-45℃ ~ 60℃
Active Current	< 60mA	Operating Humidity	10%- 90% RH
Idle Current	25±5 mA	Waterproof degree	Indoor/IP68

Adjustable Door Relay time	0 -99 seconds
Adjustable Alarm Time	0 - 3 minutes
Wiegand Interface	Wiegand 26 bit
Wiring Connections	Electric Lock, Exit Button, External reader

6. Installation

- Remove the back cover from the keypad using the supplied special screw driver
- Drill 2 holes on the wall for the self tapping screws and dig a hole for the cable
- Put the supplied rubber plug into the two holes
- Fix the back cover firmly on the wall with 2 self tapping screws
- Thread the cable through the cable hole
- Attach the keypad to the back cover.

3

7. Wiring

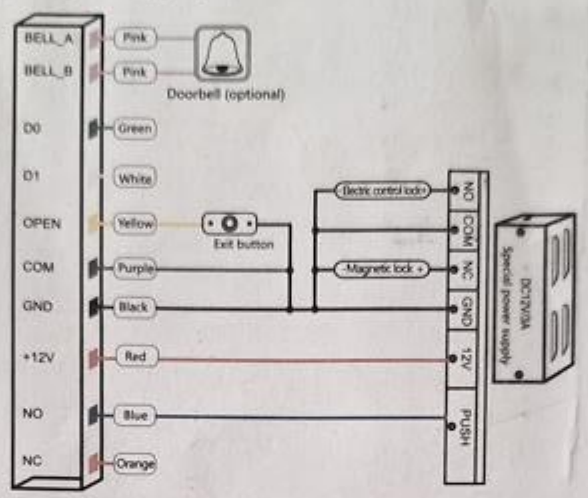
Colour	Function	Description
Pink	BELL_A	Doorbell button one end
Pink	BELL_B	The doorbell button to the other end
Green	D0	WG output line D0
White	D1	WG output line D1
Yellow	OPEN	Exit button one end(the other end connected GND)
Red	12V+	12V + DC Regulated Power Input
Black	GND	12V - DC Regulated Power Input
Blue	NO	Relay normally-on end(Connect positive electric lock "-")
Purple	COM	Relay Public end, connect GND
Orange	NC	Relay Closed end(connect negative electric lock "-")

common power supply diagram:

4

Figure D.4: Photos of Hfeng Keypad Manual: Pages 3 & 4

special power supply diagram:



8. To Reset to Factory Default

Power off,press # continuously ,then power on ,release it after sounds tick or thrice , it means factory default settings is successful.

Power off,press exit button continuously then power on, release it after sounds tick or thrice , it means factory default settings is successful.

***Registered users won't be deleted when reset to factory default**

9. Sound and Light indication

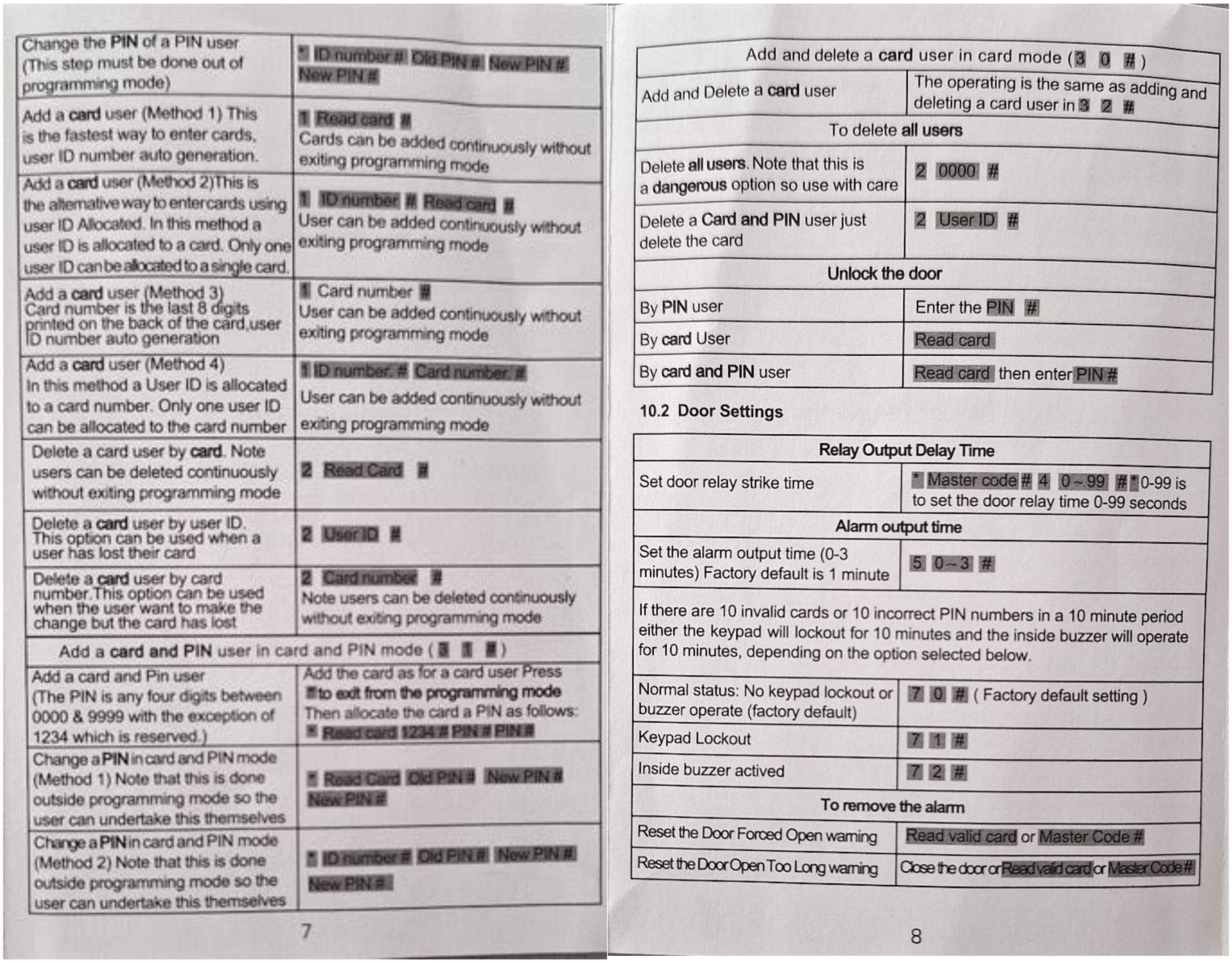
Operation Status	Red Light	Green Light	Yellow Light	Buzzer
Power on	Bright			Di
Stand by	Slow Flash			
Press keypad				Di
Operation successful		Bright		Di
Operation failed				DiDiDi
Enter into programming mode	Bright			
In the programming mode			Bright	Di
Exit from the programming mode	Slow Flash			Di
Open the door		Bright		Di
Alarm	Quick Flash			Alarm

10. Detailed Programming Guide

10.1 User Settings

Enter the programming mode	* Master code # 999999 is the default factory master code
Exit from the programming mode	*
Note that to undertake the following programming the master user must be logged in	
Change the master code	0 New code # New code # The master code can be 6 to 8 digits
Setting the working mode: Set valid card users only Set valid card and PIN users Set valid card or PIN users	3 0 # Entry by card only 3 1 # Entry by card and PIN together 3 2 # Entry by either card or PIN (default)
Add a user in either card or PIN mode, i.e. in the 3 2 # mode. (Default setting)	
Add a **PIN** user	1 User ID number # PIN # The ID number is any number between 1 & 2000. The PIN is any four digits between 0000 & 9999 with the exception of 1234 which is reserved. Users can be added continuously without exiting programming mode as follows: 1 User ID no 1 # PIN # User ID no 2 # PIN #
Delete a **PIN** user	2 User ID number # Users can be deleted continuously without exiting programming mode

Figure D.5: Photos of Hfeng Keypad Manual: Pages 5 & 6



Change the **PIN** of a PIN user (This step must be done out of programming mode)	* ID number # Old PIN # New PIN # New PIN #
Add a **card** user (Method 1) This is the fastest way to enter cards, user ID number auto generation.	1 Read card # Cards can be added continuously without exiting programming mode
Add a **card** user (Method 2)This is the alternative way to entercards using user ID Allocated. In this method a user ID is allocated to a card. Only one user ID canbe allocated to a single card.	1 ID number # Read card # User can be added continuously without exiting programming mode
Add a **card** user (Method 3) Card number is the last 8 digits printed on the back of the card,user ID number auto generation	1 Card number # User can be added continuously without exiting programming mode
Add a **card** user (Method 4) In this method a User ID is allocated to a card number. Only one user ID can be allocated to the card number	1 ID number. # Card number. # User can be added continuously without exiting programming mode
Delete a card user by **card**. Note users can be deleted continuously without exiting programming mode	2 Read Card #
Delete a **card** user by user ID. This option can be used when a user has lost their card	2 User ID #
Delete a **card** user by card number.This option can be used when the user want to make the change but the card has lost	2 Card number # Note users can be deleted continuously without exiting programming mode
Add a **card and PIN** user in card and PIN mode (3 1 #)	
Add a card and Pin user (The PIN is any four digits between 0000 & 9999 with the exception of 1234 which is reserved.)	Add the card as for a card user Press * **to exit from the programming mode** Then allocate the card a PIN as follows: * Read card 1234 # PIN # PIN #
Change a **PIN** in card and PIN mode (Method 1) Note that this is done outside programming mode so the user can undertake this themselves	* Read Card Old PIN # New PIN # New PIN #
Change a **PIN** in card and PIN mode (Method 2) Note that this is done outside programming mode so the user can undertake this themselves	* ID number # Old PIN # New PIN # New PIN #

7

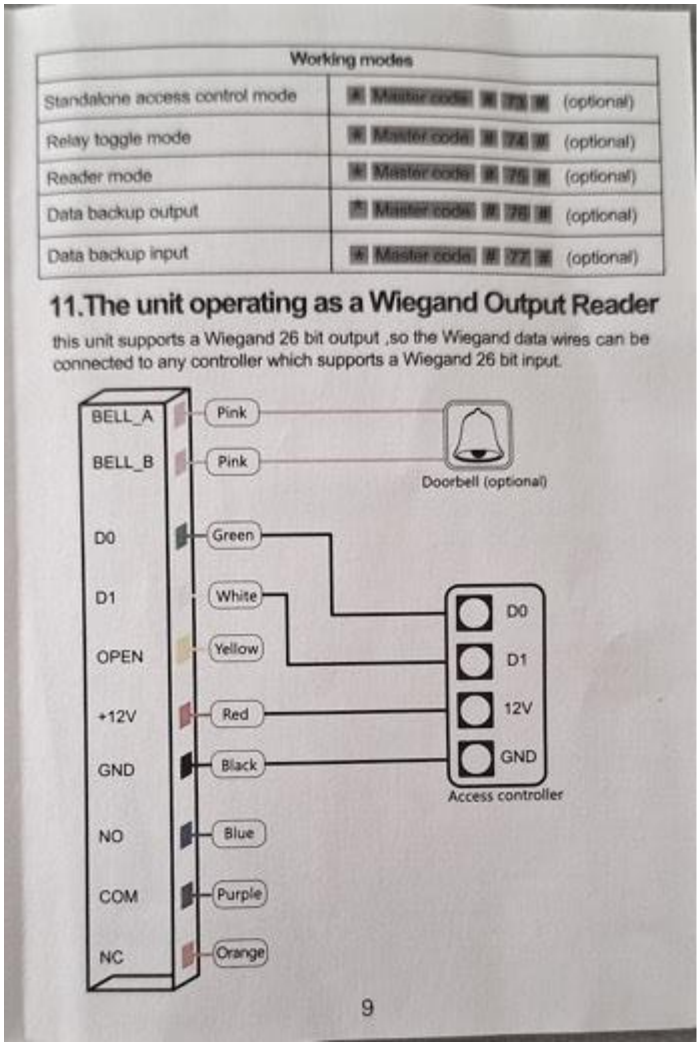
Add and delete a **card** user in card mode (3 0 #)	
Add and Delete a **card** user	The operating is the same as adding and deleting a card user in 3 2 #
To delete **all users**	
Delete **all users**. Note that this is a **dangerous** option so use with care	2 0000 #
Delete a **Card and PIN** user just delete the card	2 User ID #
Unlock the door	
By **PIN** user	Enter the PIN #
By **card** User	Read card
By **card and PIN** user	Read card then enter PIN #

10.2 Door Settings

Relay Output Delay Time	
Set door relay strike time	* Master code # 4 0 ~ 99 # *0-99 is to set the door relay time 0-99 seconds
Alarm output time	
Set the alarm output time (0-3 minutes) Factory default is 1 minute	5 0 ~ 3 #
If there are 10 invalid cards or 10 incorrect PIN numbers in a 10 minute period either the keypad will lockout for 10 minutes and the inside buzzer will operate for 10 minutes, depending on the option selected below.	
Normal status: No keypad lockout or buzzer operate (factory default)	7 0 # (Factory default setting)
Keypad Lockout	7 1 #
Inside buzzer actived	7 2 #
To remove the alarm	
Reset the Door Forced Open warning	Read valid card or Master Code #
Reset the Door Open Too Long warning	Close the door or Read valid card or Master Code #

8

Figure D.6: Photos of Hfeng Keypad Manual: Pages 7 & 8



Working modes	
Standalone access control mode	* Master code # 73 # (optional)
Relay toggle mode	* Master code # 74 # (optional)
Reader mode	* Master code # 75 # (optional)
Data backup output	* Master code # 76 # (optional)
Data backup input	* Master code # 77 # (optional)

11.The unit operating as a Wiegand Output Reader

this unit supports a Wiegand 26 bit output ,so the Wiegand data wires can be connected to any controller which supports a Wiegand 26 bit input.

9

Figure D.7: Photo of Hfeng Keypad Manual: Page 9

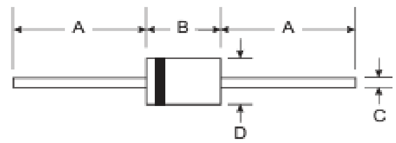
DIODES INCORPORATED

1N5400 - 1N5408

3.0A RECTIFIER

Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 200A Peak
- Low Reverse Leakage Current
- **Lead Free Finish, RoHS Compliant (Note 3)**



Mechanical Data

- Case: DO-201AD
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0
- Moisture Sensitivity: Level 1 per J-STD-020C
- Terminals: Finish — Tin. Plated Leads Solderable per MIL-STD-202, Method 208 (e3)
- Polarity: Cathode Band
- Marking: Type Number
- Weight: 1.1 grams (approximate)

DO-201AD		
Dim	**Min**	**Max**
A	25.40	—
B	7.20	9.50
C	1.20	1.30
D	4.80	5.30
All Dimensions in mm		

Maximum Ratings and Electrical Characteristics

@ T_A = 25°C unless otherwise specified

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

Characteristic	Symbol	1N 5400	1N 5401	1N 5402	1N 5404	1N 5406	1N 5407	1N 5408	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
Average Rectified Output Current @ T_A = 105°C (Note 1)	I_O	3.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms Single half sine-wave superimposed on rated load	I_{FSM}	200							A
Forward Voltage @ I_F = 3.0A	V_{FM}	1.0							V
Peak Reverse Current at Rated DC Blocking Voltage @ T_A = 25°C @ T_A = 150°C	I_{RM}	10 100							μA
Typical Total Capacitance (Note 2)	C_T	50				25			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	15							°C/W
Operating and Storage Temperature Range	T_j, T_{STG}	-65 to +150							°C

Notes:
1. Valid provided that leads are kept at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0MHz and applied reverse voltage of 4.0V DC.
3. RoHS revision 13.2.2003. Glass and High Temperature Solder Exemptions Applied, see *EU Directive Annex Notes 5 and 7.*

Figure D.8: Datasheet for Jameco diode (1N5400) (Jameco Electronics 2024)

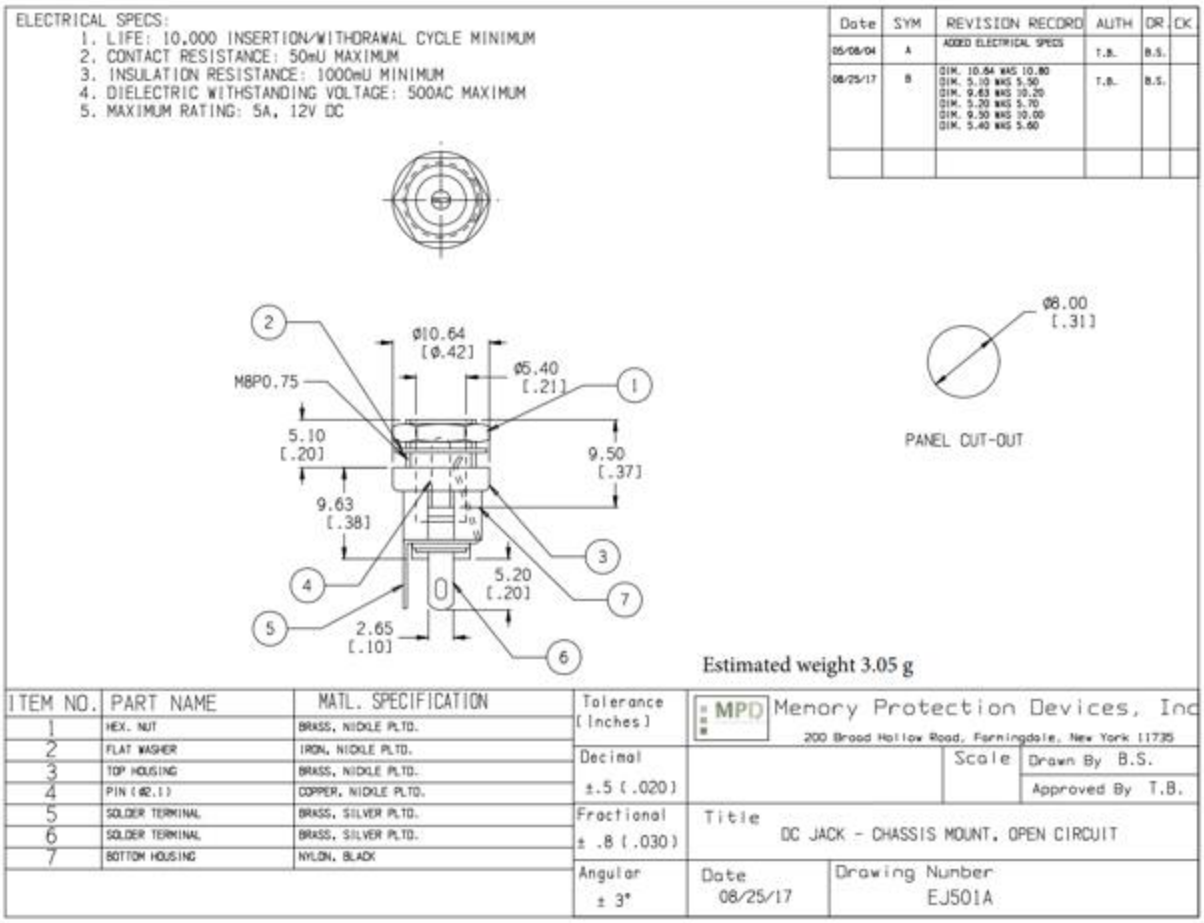


Figure D.9: 2D Drawing and datasheet for barrel connector (EJ501A) (Digikey 2024)