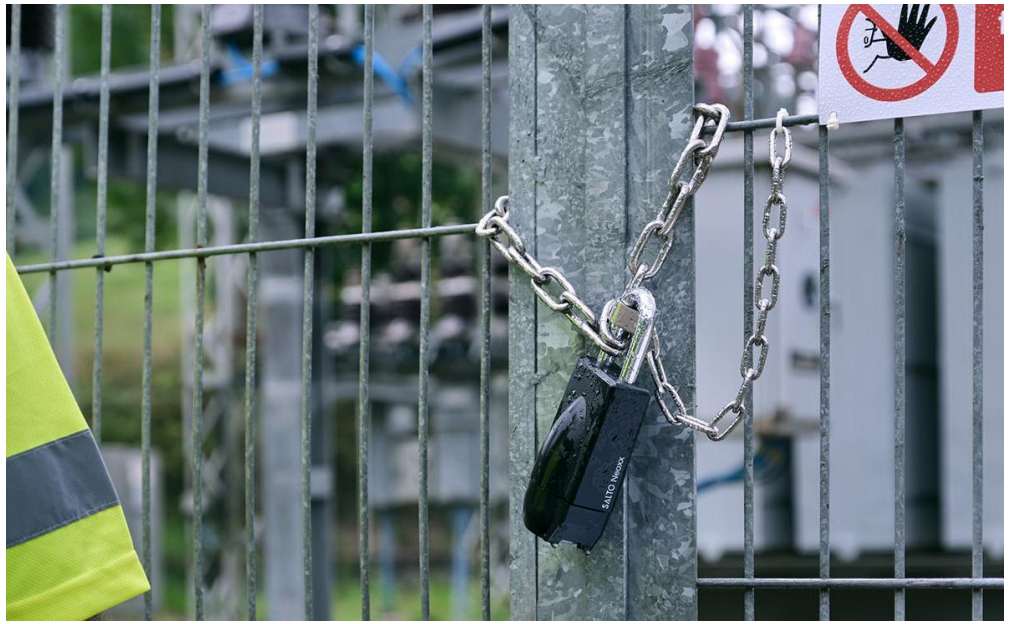
Design Considerations of High Security Padlock

LEUNG Hei Tzit Samuel (21051167)

Motivation

- To make a high security padlock for high security situations, such as for militaries, corporations or advanced home protection)
- For lock-picking hobbyists



Functional Specifications

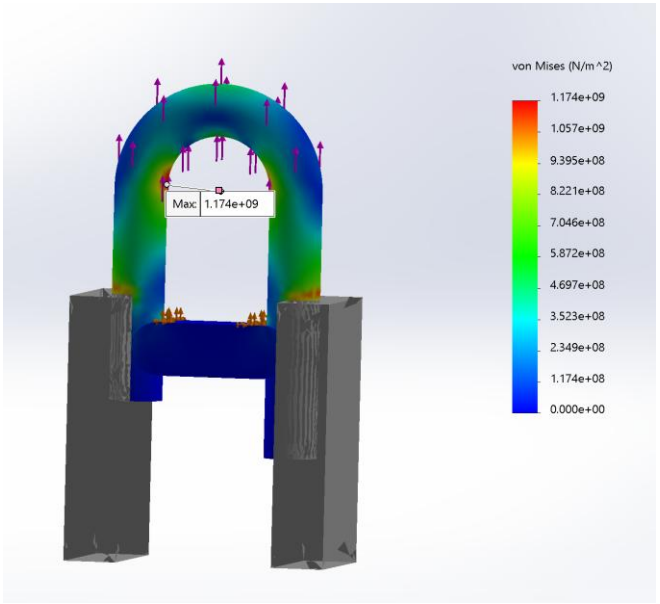
1. The padlock should be able to open and close its shackle.
2. The padlock should be able to be fit onto an object of normal size when locked, such as handles, latches, hoops and chain links.
3. The padlock should only be operable when in ownership of a key/unlocking device.
4. The padlock should be able to withstand unauthorized intrusion, such as: Picking/Decoding, Drilling, Cutting/Sawing, Pulling, Heavy and/or Repeated Impact, etc
5. The padlock should be able to withstand repeated use and environmental-related wear, such as weather, temperature and corrosion.
6. The padlock should be minimized to be affordable enough for consumers more concerned with security, such as corporations or businesses.
7. The padlock should be able to be certified as CEN Grade 5.

Engineering Specifications

1. Minimum Number Of Key Differs: 10000 (from CEN EN12320 Grade 5)
2. Resistance to Pulling Of Shackle: $\geq 70\ \mathrm{kN}$ (from CEN EN12320 Grade 5)
3. Resistance to Twisting Of Shackle: $\geq 1200\ \mathrm{Nm}$ (from CEN EN12320 Grade 5)
4. Resistance to Cutting of Shackle: $\geq 70\ \mathrm{kN}$ (from CEN EN12320 Grade 5)
5. Low Temperature Resistance to Impact on Shackle: $-40℃, 6550\ \mathrm{g}, 1400\ \mathrm{mm} \geq 5\ \mathrm{times}$ (from CEN EN12320 Grade 5)
6. Low Temperature Resistance to Impact on Lock Body: $-40℃, 6550\ \mathrm{g}, 1400\ \mathrm{mm} \geq 5\ \mathrm{times}$ (from CEN EN12320 Grade 5)
7. Resistance to Force on Locking Mechanism: $\geq 10\ \mathrm{kN}$ (from CEN EN12320 Grade 5)
8. Resistance to Torque on Locking Mechanism: $\geq 20\ \mathrm{Nm}$ (from CEN EN12320 Grade 5)
9. Time taken to Drill through Lock: $\geq 4\ \mathrm{Minutes}$ (from CEN EN12320 Grade 5)
10. Time taken to Saw through Lock: $\geq 4\ \mathrm{Minutes}$ (from CEN EN12320 Grade 5)
11. Lifetime: $\geq 10\ \mathrm{Years}$ (Point 5)
12. Cannot insert normal lock pick

Calculations from Engineering Specifications

- Though modelling the key elements of padlock design and using FEA, the key stress zones of the design were found to be on the shackle. Comparing with solutions found in the industry and these calculations, hardened high strength steel was chosen for the shackle. EN 1.5510+H Boron Steel or 17-4 PH Stainless Steel are potential candidates for the shackle as they both have a UTS of above 1.3GPa, which allows for the system to withstand above 70kN of pulling force on the shackle once, as specified in the CEN grading requirements.
- The number of pins was calculated though the assumption of having 4 height settings for each pin.
  Total Combinations $= 4^7 = 16384 \geq 10000$ combinations
  Thus 7 pins will be used.



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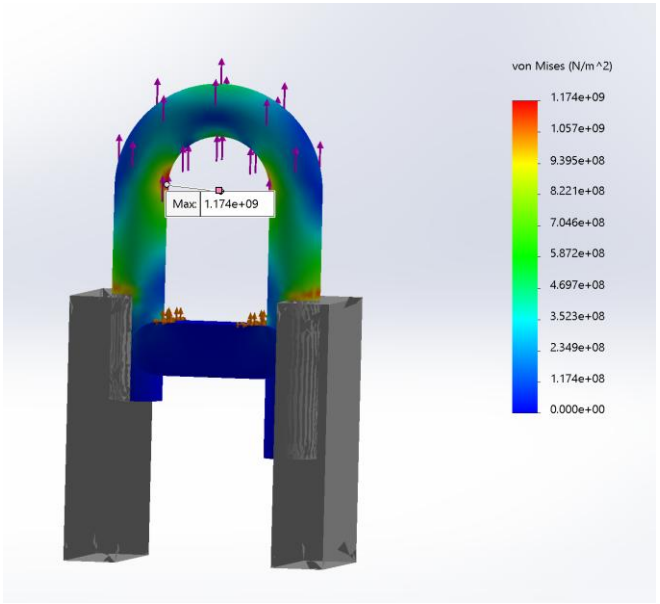

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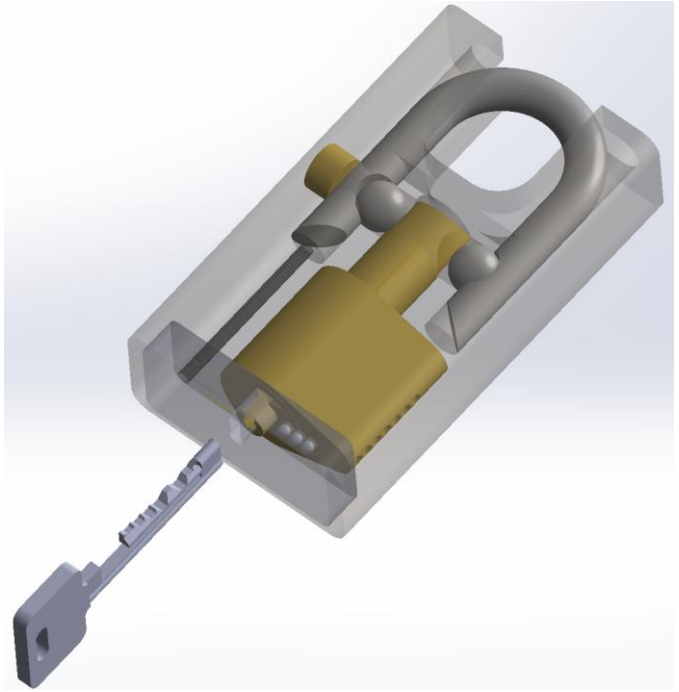
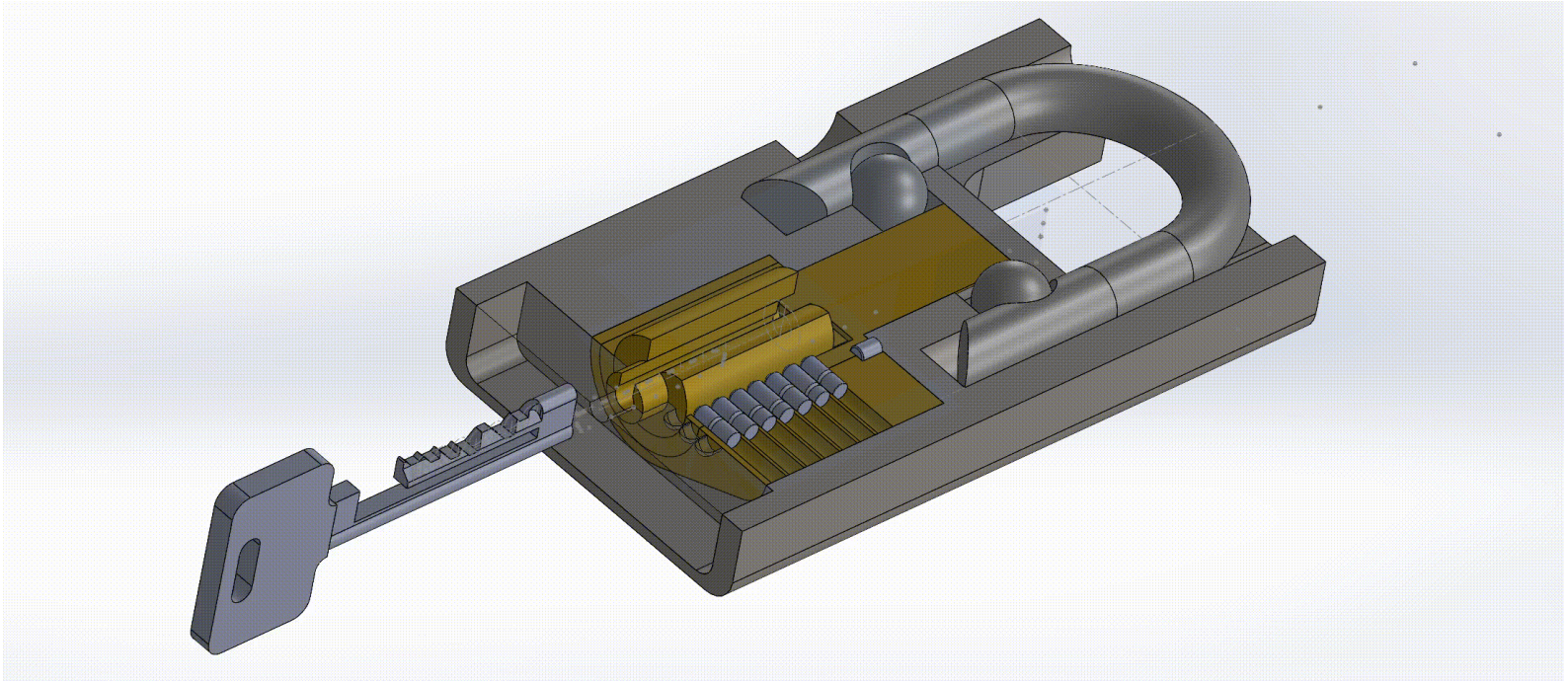
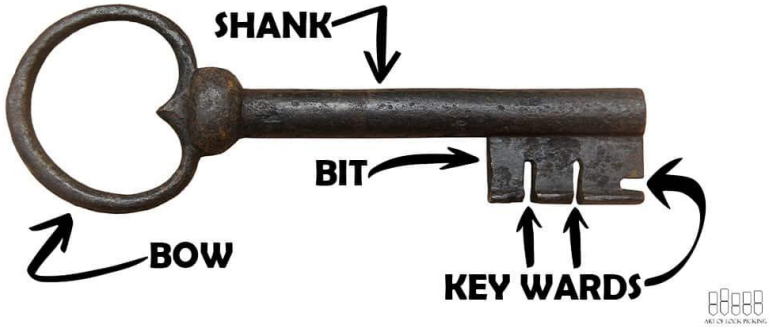
Assembly Drawing

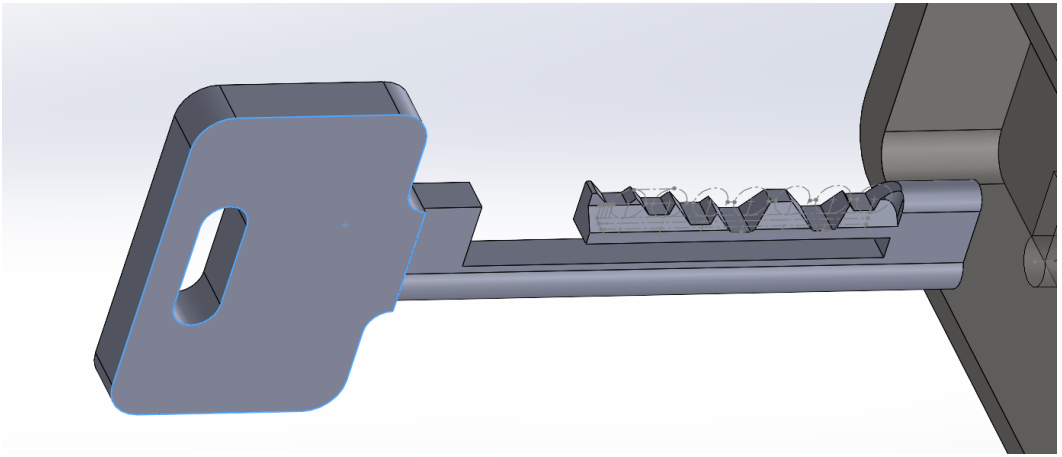


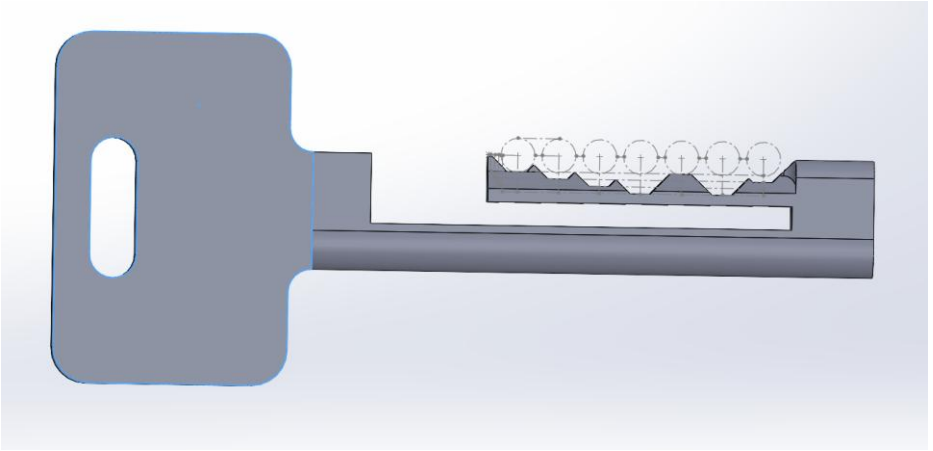


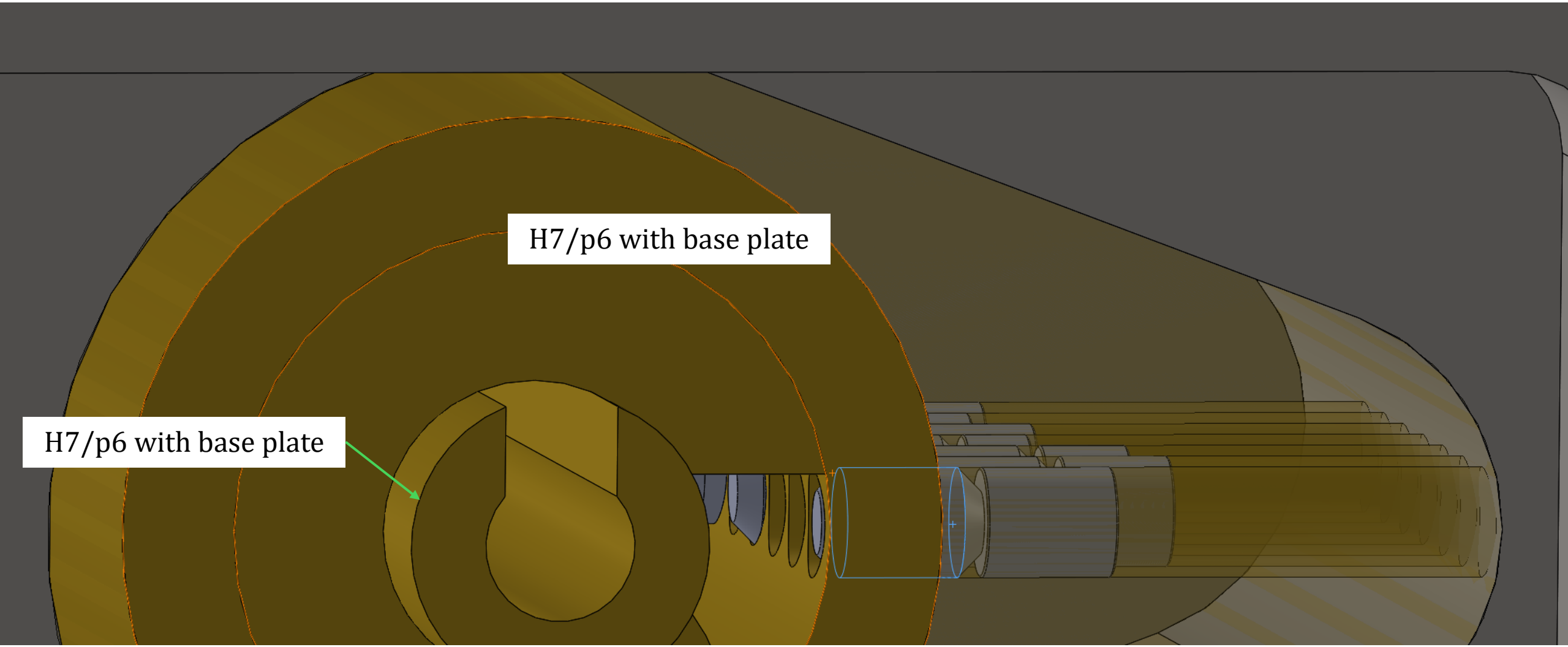
Design Choices

- A unique key design was employed, combining the key design from warded keys and pin tumbler keys.



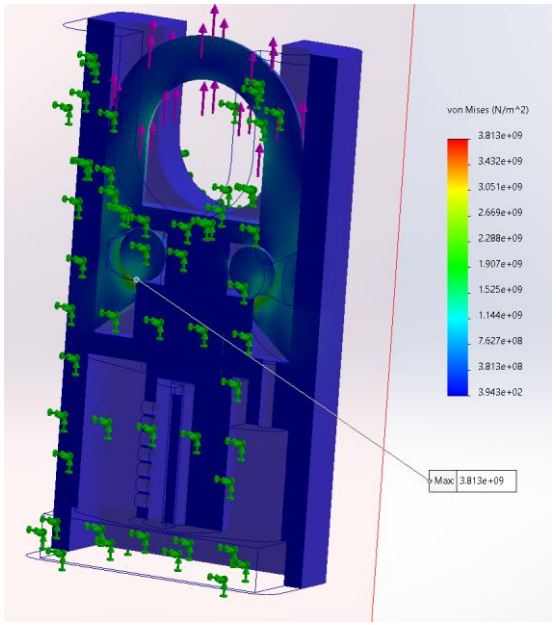




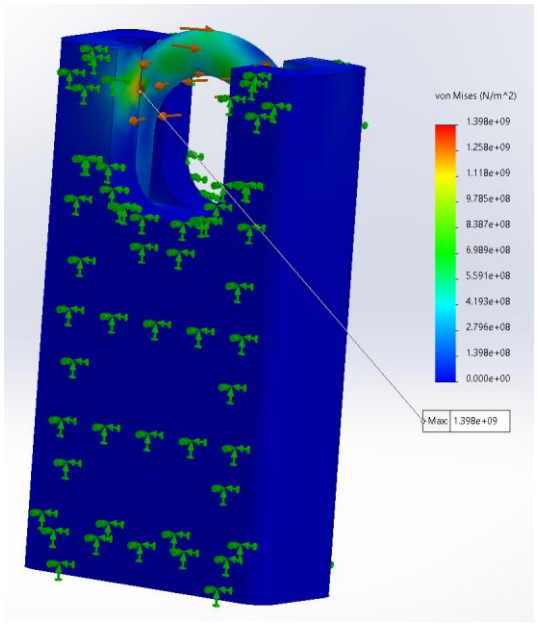

H7/p6 with base plate
H7/p6 with base plate

Verification of design: FEA

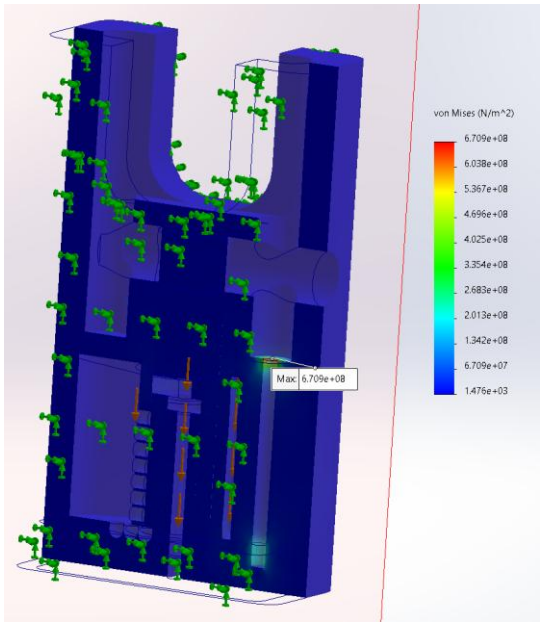
Shackle Pulling Test



Shackle Twisting Test



Plug Pulling Test



Verification of design: Calculation

Shackle Cutting Resistance

Material Properties

- **Steel Grade:** 1.5510 (Chromium-Tungsten Tool Steel)
- **Ultimate Tensile Strength (UTS): 1600 MPa** (from material data)
- **Estimated Shear Strength (**τ\tau**)**:

$$\tau \approx 0.6 * \text{UTS} = 960 \text{ MPa}$$

For **full-section shear** (assuming bolt cutter jaws fully engage the shackle):

$$A = \pi \times d^2 = \pi \times (10 \text{ mm})^2 \approx 314.16 \text{ mm}^2$$

Using the shear equation:

$$F_s = \tau \times A = 960 \text{ MPa} \times 314.16 \text{ mm}^2 \approx 301.6 \text{ kN}$$

Plug Twisting Resistance

Material Properties

- **Steel Grade:** Brass
- **Ultimate Tensile Strength (UTS): 480 MPa** (from material data)
- **Estimated Shear Strength (**τ\tau**)**:

$$\tau \approx 0.6 * \text{UTS} = 288 \text{ MPa}$$

For **full-section shear** (assuming bolt cutter jaws fully engage the shackle):

$$A = \pi \times d^2 \times n = \pi \times (2.921 \text{ mm})^2 \times 7 \approx 187.63 \text{ mm}^2$$

Using the shear equation:

$$F_s = \tau \times A = 288 \text{ MPa} \times 187.63 \text{ mm}^2 \approx 54 \text{ kN}$$

$$\tau_{plug} = F_s \times r_{plug} = 54 \times 11 \text{ mm} = 594 \text{ Nm}$$

Access Prevention Measures

- The pins are shielded away from the keyhole, meaning typical/standard lockpicks and rakes cannot access the pins.
- The design provides little room for bumping due to having no room for the key to shift in and out of the lock when engaging with the pins, enforceable with decent tolerances.
- Hardened steel plates and ball bearings are placed in key locations such as near the shear line, pins and securing bolt, vastly increasing the difficulty of drilling though the padlock.
- The shackle penetrates deep into the lock body, increasing the difficulty of breaking the lock open using the double wrench method.
- A closed shackle design forces intruders to cut 2 times before being able to access the contents

Bill of Materials

ITEM NO.	COMPONENT NAME	DESCRIPTION	QTY.
1	Shackle	Held by #2	1
2	12mm Diameter Bearing Ball	Part of the latching mechanism, Loose fit, Purchased from supplier: https://simplybearings.co.uk/shop/p35948/12mm-Diameter-Grade-100-Hardened-52100-Chrome-Steel-Ball-Bearings/product_info.html	2
3	Lock Plug Body	Engages with the rest of the lock plug and the latching mechanism	1
4	Key Limiter	Blocks unauthorized access to pins, Press fitted onto base plate	1
5	Lock Plug Shell	Holds pins and rest of lock plug in place, Interference fit	1
6	Lock Plug Key Holder	Holds key in plug, Loose fitting	1
7	0.115D Kwikset B1 0.172H	Purchased from supplier: https://www.uhs-hardware.com/products/lab-lmdkwk-mini-dur-x-kwikset-rekeying-kit?variant=39588093329475/?utm_source%3Dsurfaces&utm_medium=freelistings&srsltid=AfmBOorg4zO5F0RCj6K5LhZmbID8cBJCDeKrGQW6kP-Sqc710dRzmEcgdC4 Clearance fit into #6	2
8	0.115D Kwikset B2 0.195H		2
9	0.115D Kwikset B3 0.218H		1
10	0.115D Kwikset B4 0.241H		2
11	0.115D Kwikset M6 0.138H		2
12	0.115D Kwikset M5 0.115H		2
13	0.115D Kwikset M4 0.092H		1
14	0.115D Kwikset M3 0.069H		2
15	0.115D Kwikset T1 0.16H		8
16	0.115D Kwikset Spring		7
17	Base Plate	Steel plate to prevent drilling attacks against the base of the padlock	1
18	Key		1
19	3mm Diameter Bearing Ball	Anti-Drill protection, Purchased from supplier: https://simplybearings.co.uk/shop/p35912/3mm-Diameter-Grade-100-Hardened-52100-Chrome-Steel-Ball-Bearings/product_info.html , Clearance fit into #17	3
20	Lock Body		1
21	Press Fit Plug	Seals hole on #20 from milling out space for latching mechanism, Press fitted onto #20	1
22	M4 45mm Machine screw	Purchased from supplier: https://sg.misumi-ec.com/vona2/mech_screw/M3301000000/M3301050000/M3301050200/ Attaches #17 onto #20	1

Summary

- To conclude, the High Security Padlock provides a strong security package for users to protect their valuables, facilities, homes, etc.
- The specifications are all fulfilled and exceeded, allowing this padlock to be certified as CEN EN12320 Grade 5 or above after lab testing.
- The manufacturability of parts is high and many standards parts are used.
- The padlock should be suitable for those concerned with their security, and should give lockpicking enthusiasts a decent challenge.