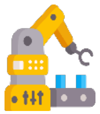
ES3C2 Elcometer 280 – U1915424

- 60% of return is from UAE, possibly indicating the trend of malfunction in hot environment.
- Returns in Russia might suggest product is vulnerable in low temperature as well.



- The Product is manufactured via injection molding of PC – ABS.
- The device is not designed with built-in obsolescence.

Product Briefing:

The Elcometer 280 Pulsed DC Holiday detector is a holiday detector, that allows the user to inspect coating up to 25mm thick, at the same time setting high standards for high voltage measurement safety. Example of what the device detects is **Runs & Sags** where coatings move due to gravity leaving uneven spreading of film, typically caused by overcoating or low paint viscosity. However currently many Elcometer 280s are being returned and most of the returned devices suffer the same issue described below.

Key affect detail part functioning

Currently most returned Elcometer 280s suffer from the same area, which is mainly the plastic paddle shown below:

Figure 1: Paddle head fracture points

The breaking of the spring holes has completely prevented the device from functioning normally, as the users' first indication is the device being unable to output high voltage, which must mean a disruption in current flow, which stems from the breaking of the bottom torsion spring accommodation leading to metal contact. Therefore, the solution for this problem would either to adjust the torsion spring in each device to avoid breaking the paddle, or to strengthen the paddle to accommodate the torsion spring at the fixing points.

Mechanism Clarification

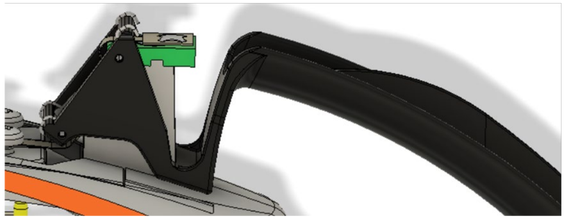
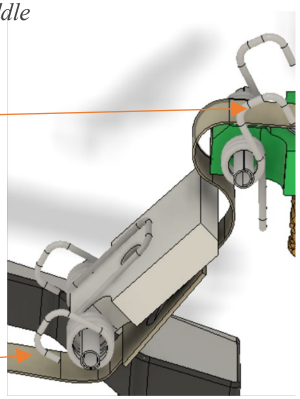


Figure 2: side view of paddle

__Top Torsion Spring__ for keeping the handle down, allowing user to feel the activation force.

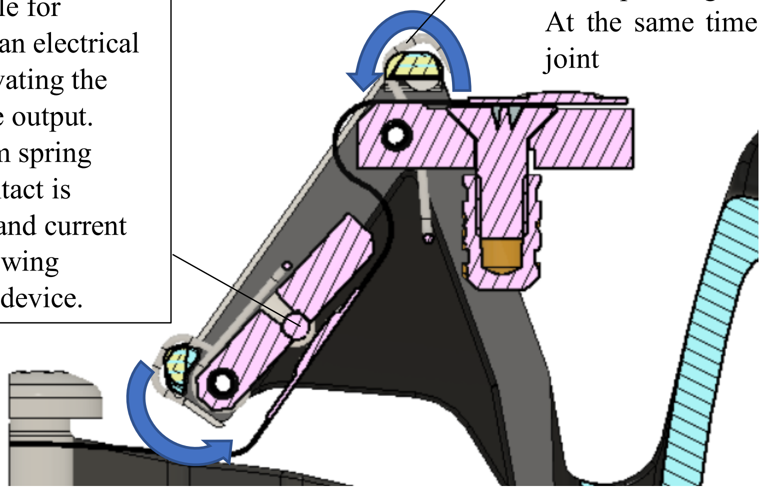


__Bottom Torsion Spring__ for the button

Figure 3: interior view of the button

__*Bottom Torsion spring*__ is responsible for completing an electrical circuit, activating the high voltage output. Once bottom spring retracts, contact is interrupted and current will stop flowing through the device.

__*Top torsion spring*__ is responsible for paddle handle's reaction force exerted against the operator's finger while pressing down on the handle. At the same time acting as a pivot joint



Paddle handle

Figure 4: Section view of the button

Work Conditions

- Outdoors Sun, Wind, Rain,
- Temperature tolerance: 0-50°C
- Users are aware cost of product hence carefully handling products but won't account for accident and designed to be shockproof and water-resistant buttons

Problem Cause

Figure 4 shows the mechanical process causing the deformation. While the machine is working, the handle is being pulled upwards. At that moment, both spring's torsion is acting as a reaction force to the force applied at the handle. As the top and bottom is where the paddle head is housing the torsion springs, it is also where most of the load will be applied to. Once the handle is release, the springs immediately returns the paddle head to its arbitrary position to release the spring tension. Overall, these processes exert forces around the top and bottom of the paddle head. Hence Stresses around those areas will build up, which may lead to material failure, in this case, it occurred near the spring guide rod holes, leading to crack around that area.

Item/Function	Potential Failure Mode (s)	Potential effect of Failure Effects	SEV	Potential Cause(s) / Mechanism (S) of Failure	Occ	Current Design Control	Det	RPN	Recommeneded action
Font Handle	Front handle may break	Causing the whole holiday detector to fall onto the user's feet	7	If the device was just resting on the shoulders without the user's hands on both handles and the hook slot cracks.	3	With Front handle being split into 3 directions, shoulder straps and backhandle to distribute the weight evenly.	2	42	Inspect the handle for cracks before use
Paddle handle Shell	Handle shell plastic may crack / Screws may loosen	Detachment from the elcometer or loosened screws inside of the component may effect wiring	7	Slippage from lack of gripping, causing the device to swing around the shoulder and crash into other objects	3	User should carefully position himself when trying to use the holiday detector, so that even if one of the handles where to slip, the detector woudn't collide with surrounding.	5	105	Design the device with a textured handles to increase grip
Paddle handle Shell	Handle shell plastic may deform	Due to deformation, it may crack hence exposing wires, where the electrical wires may cause electric shock to the user	8	Grip strength is above the yield stress of the handle material / Pointing the detector at directions where only 1 hand can support the device, increasing stress concentrtion on the handle.	3	Inspect before use	6	144	Make sure the user is wearing protective clothing / Design a mechanism that detects breaking of handles, which will immediately stops the holiday detector from functioning
Paddle	Paddle May melt or deform	Plastic may deform, dragging the wire along as it morphs, stopping the holiday detector from functionning properly. May also lead to skin burn on the user.	7	Prolonged period in extreme heat condition, causing thermal exapnsion, leading to internal stresses building up	6	Limit the amount of time exposed in high temperature or allow breaks during long periods in high heat environments	4	168	Choose a material with high heat tolerance, and wear insulating gloves
Paddle	The spring will stop working	Rusting prevents the button from working, stopping the detector from functioning	2	Rain water seeps through the gaps on the handle shell, oxidation occurs, leading to crack	5	Try pressing on the button with safety on, to see if springs are functioning	9	90	Design an extra layer of membrane between the gap to prevent any particles to flow into the interior.

Table 1: DFMEA

Calculations for analysis input:

Load: To simulate the torsion caused by the spring, point forces are used at where the hooks interact with the paddle head. Then using equation below to calculate torque when the spring has compressed (additional 6° rotation from the arbitrary state):

$$Rate\ (k) = \frac{Torque\ (Nmm)}{Angle}$$

Moment is also accounted for from the spring, since the spring force presented in Figure 5 doesn't act on the hooks but the middle of the spring. The calculation results are listed on the next page.

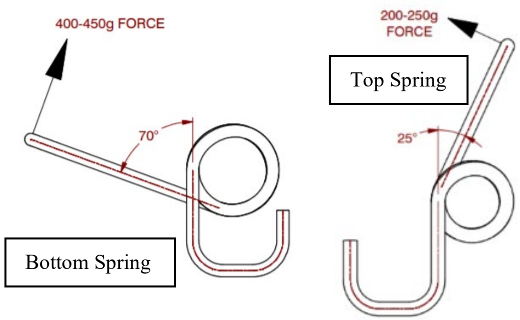


Figure 5: Spring Measurements

Top of the Paddle Head

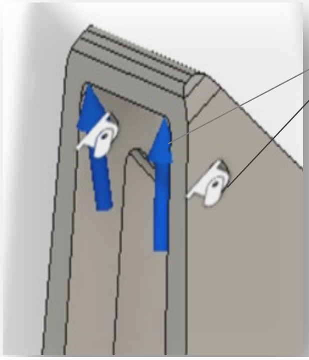


Figure 6: Paddle Head pre-FEA

force is exerted at the top of the paddle, by the hook of the torsion spring. Pin constraints are used on the holes on both sides of the paddle head and are set to have a fix tangential setting

Angled Forces are applied to where the torsion spring's hooks, the magnitudes of the forces are calculated to be 4.5N using above equation.

Figure 7: Paddle pre-FEA

Paddle Handle

Fixed constraint on the handle

Bottom of the Paddle Head

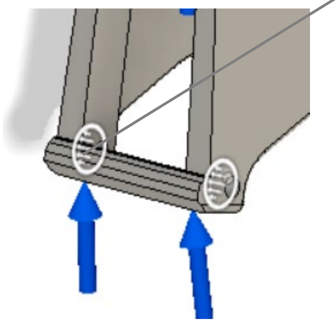


Figure 8: Paddle Head (Bottom) pre-FEA

Angled loads are again applied to the corners of the bottom rod of the paddle head, as these points is where the button torsion spring's hooks are connected to the component. The magnitude would be 9.77N and the forces are angled to replicate the positions of the force from the hooks.

Bearing load is also applied, as there is reaction force from the bottom spring guide trying to bring the paddle head back to its arbitrary position.

Top of the Paddle Head (Post-Simulation)

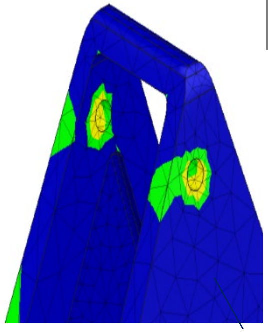


Figure 9: Top Paddle head post-FEA

As expected, the simulation was able to replicate the stress near the fracture area. On the left, the yellow presents a low safety factor of 2 with approximately 30 MPa exerted at that point. The overall model presents a minimum safety factor of 0.35, an extremely low safety score indicating, that design is prone to failure in this load situation.

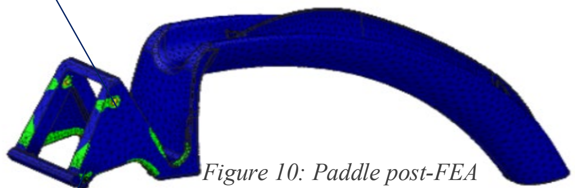


Figure 10: Paddle post-FEA

Bottom of the Paddle Head (Post-Simulation)

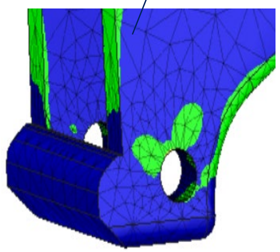


Figure 11: Paddle Head (Bottom) post-FEA

The exact fracture path was not simulated successfully at the bottom spring guide hole as the low safety factor doesn't reach the edge. However realistically, a tiny crack will propagate towards the edge.

<u>Therefore, best option is to either strengthen the weakest area or use a material with a higher yield</u>

Design #1 Stress Concentration Reduction:

Following the FEA analysis results above, stress concentration reduction methods are applied in order to reduce the amplitudes of the stresses around a concentration point

Typically, Geometrical discontinuities, where there is a sudden change in the cross-sectional area in the component will lead to stress concentration in a localized area. Below their glass transition temperature thermoplastics deform principally by elastic deformation and are brittle, and their proportional limit may be at fracture stress, where failure begins at point of stress concentration, essentially a crack begins to from, and propagate through the cross-section, resulting in sudden fracture.

In an object with an internal hole, the sudden redirection of stress lines also builds up stress flux. In this case, removing material may increase load-carrying capacity. This is done by adding smaller holes that are close together, as there is less redirection of stress flux.

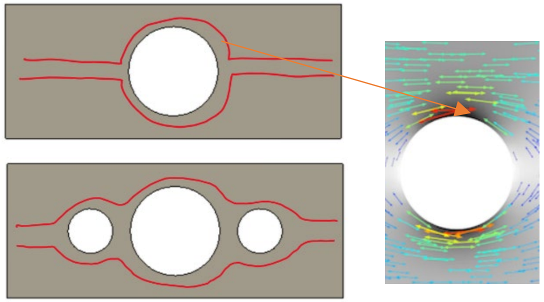


Figure 12: Internal hole stress distribution

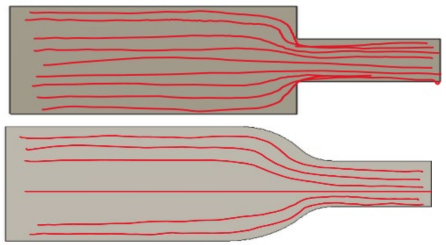


Figure 13: Corner stress comparison

As seen on the left, the top Sharp corner tends to fail due to accumulation of stress in the body from the abrupt change in geometry, seen with the crowded "Stress flow lines" at the sharp corner.

By Providing the fillet radius at the sharp corner, cross section is decreased gradually thus distributing the stress more evenly

Top of Paddle Head in Design #1

Figure 14: Design #1 Top Paddle

Applying the theoretical knowledge on the left, 2 holes (∅= 1mm) with 2mm distance between the center of the circles, located on either side of the original spring guide rod hole are created. This is done to distribute the stress more uniformly around the hole to decrease peak stress, reducing chance of fracture.

Bottom area at the front of the paddle head in Design #1

Stress reduction of corner can be seen on the front edge near the bottom guide rod hole. A 3mm radius fillet is set at the sharp edge where the bottom crack propagated at the paddle head. The fillet again allows for less stress concentrated around the location of the bottom crack.

Figure 15: Design #1

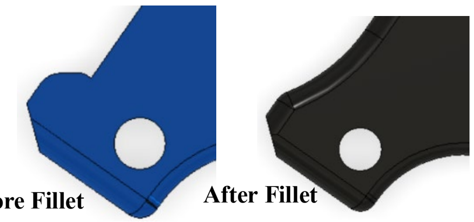


Figure 16: Comparison of edges on Design #1

Design #1 Review:

The design provides a more unifrom stress distribution, reducing the stress concentration at the main fractures points around the guide rod area.

Pro:

- The stress reduction methods allow for small simple yet effective geometric adjustments
- Manufacturing method would be the same, removing the need to reinvest in new equipment
- Removing the need to redesign surrounding components that may be affected by a new shape
- Removed materials instead of adding, resulting in less weight

Con:

- A small change in the design would lead to change in mould change, which may cost a lot
- Reduces stress but doesn't solve other potential problems causing fracture, this may include thermal deformation.

FEA result for Design #1

Actual Minimum Safety Factor increased up to 1.28, and analysis also states that the design is marginal, which is sufficient but outside factors such as heat/cold may produce different result. Around the bottom hole area, the stresses have decreased down to 8-9 MPa from 12-11 MPa. Maximum stress has also come down to 42.67 MPa. A slight improvement just enough to prevent cracking at previous faulty areas.

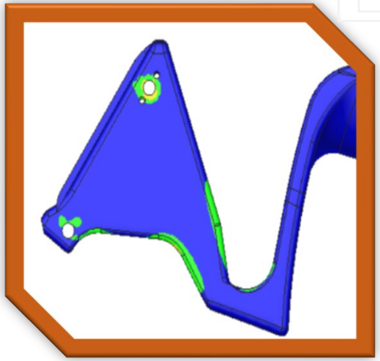


Figure 17: FEA of Design #1

Design #2 inspiration:

Figure 18: PosiTeset Holiday Detector

Through analysing the competitor's button mechanism has also inspired design #2 to focus on the continuity of useful actions. The PosiTeset Holiday Detector from DeFelsko uses just a symbol trigger to activate the voltage output.

Design #2: Complete Redesign of Paddle

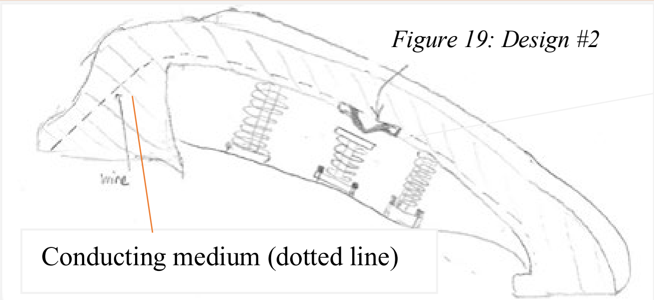


Figure 19: Design #2

Figure 20: Design #2's button

Design #2 extends the conducting medium across the top handle shell. The activation membrane is curved downwards so that when the button is pressed, the button will apply force upwards towards the activation membrane, completing the circuit to output voltage. Which removes the risk of having the paddle head failing as all stress are applied on the handle.

However, this design would mean a completely redesign of the paddle and the interior of the top handle shell to accommodate the conducting medium.

Final Design:

Material Selection

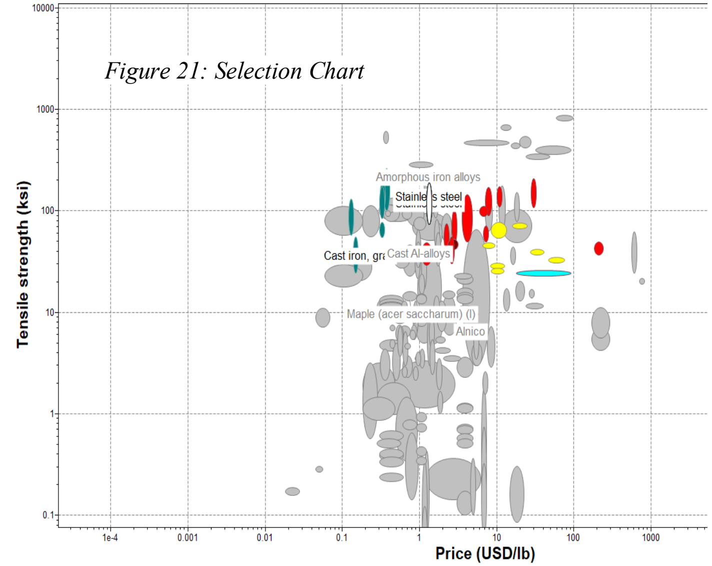


Figure 21: Selection Chart

The Grant EduPack material selector is used to pick a material for the reinforcement bracket. A selection chart plotting Price against Tensile Strengthis activated, moreover a limit tool was used to filter materials, limit tool properties set:

-Minimum 150MPa tensile strength (maximum stress stated from the original FEA.)

-Durability up to 150°C: Excellent

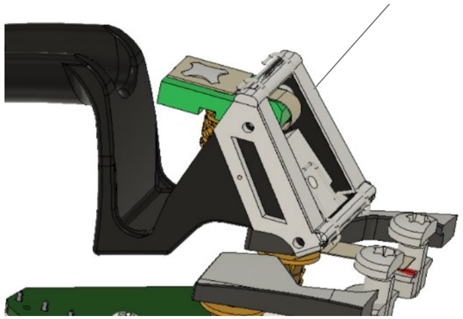
Selected: Stainless Steel due to high tensile strength, high thermal durability, and reasonable price of 1.67 GBP/kg.

Figure 22: Rendered final design

The Stainless Steel will also withstand extreme heat environments, which may reduce thermal deformation, cutting down the number of returns from users in UAE.

The Reinforced Stainless-Steel Bracket can also be easily manufactured through laser cutting stainless steel sheets, programmed from computer CAD files. Finish by welding the corners and filing them down. Additionally, the whole product could be 3D printed.

Figure 23: Reinforcement bracket attached to original body



Final design's suitability

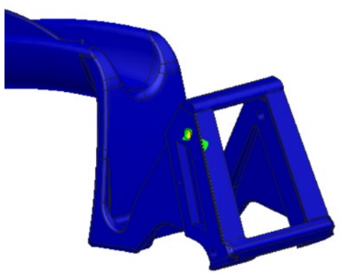
The Reinforcement Bracket easily fits onto the original component, making it the perfect solution as it can prevent future products from suffering the defect, at the same time, it can be sent to current users to fit it on as a protective layer.

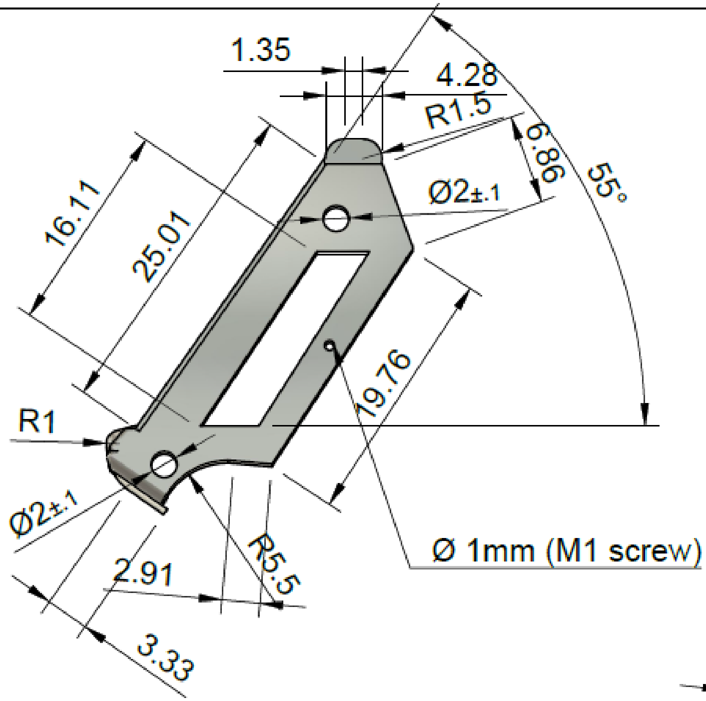
Furthermore, this means that there is no need to redesign the whole paddle handle as well as surroundings components.

Final design FEA

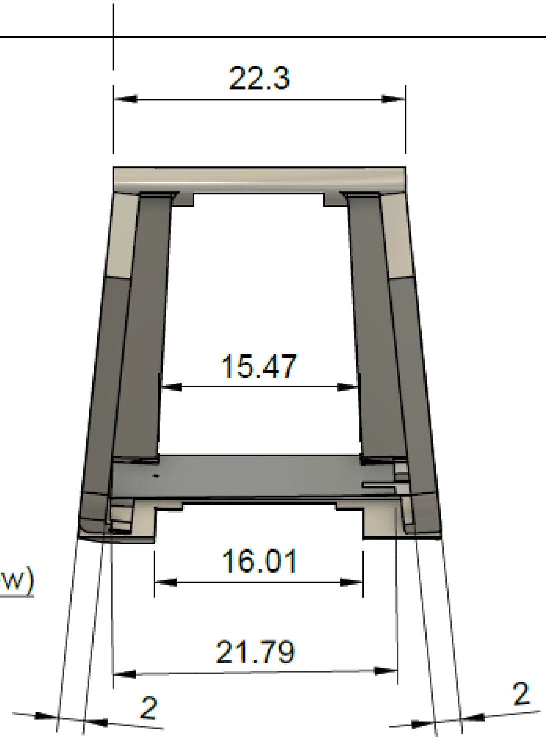
As seen on Figure 24, for most part the safety factors have increased all the way up to 8, with the top spring guide hole having a lower safety rating of 4, which is still acceptable. Overall, the final design completely prevents fracture by providing higher yield.

Figure 24: Final design FEA

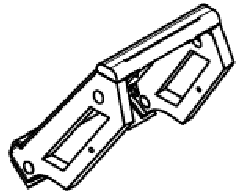


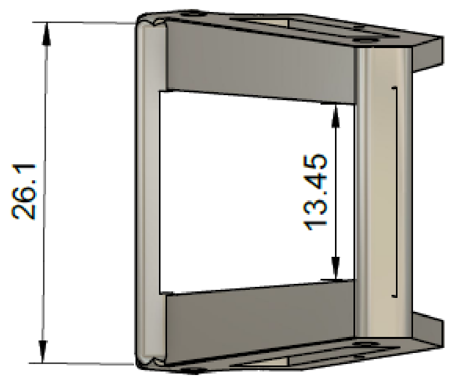


Side View



Front View





Top View

Qty	Item	Part Number	Description	Material
1	2	Component3		Stainless Steel

Parts List

Dept.	Technical reference	Created by	Approved by
Engineering		henry chan 12/9/2021	

Document type	Document status

Title	DWG No.
Bracket Reinforcement	

Rev.	Date of issue	Sheet
	8/12/2021	1/1