

## Project 1: Autonomous Superelasticity Investigation Apparatus

### Motivation:

During week 4 of Michaelmas term in second year, IB materials students investigate the properties of materials that exhibit shape memory and superelasticity when at elevated temperatures. This is done by the progressive discretised loading of springs made from two materials, one steel spring and one nitinol spring. Students place weights one by one on the springs and attempt to measure the new displacement for plotting normalised peak shear stress and peak shear strain at both room temperature and elevated temperatures.

The output of the room temperature curves shows the linear region followed by the plastic deformation of each spring and eventually the linear unloading curve that terminates at a constant plastic strain. The steel has deformed by dislocation motion however the nitinol has deformed by de-twinning from the austenite phase to martensite, this process is reversible by heating. At elevated temperatures, this driving force for re-twinning is constantly present and allows superelastic behaviour to be exhibited which appears as a hysteresis loop on the peak shear stress - peak shear strain graph.

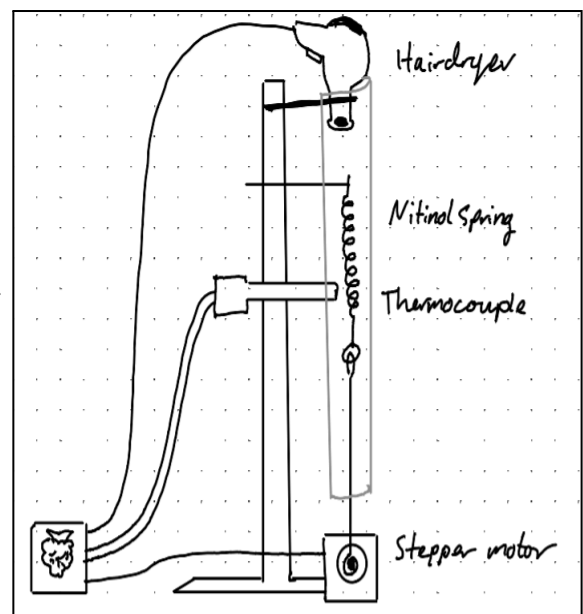
The issue with this experiment is that a significant amount of error is introduced by the human attempt to determine displacement on an unstable mass contained within a plastic tube. Furthermore in the interest of time, students are only able to reach moderate resolution on their hysteresis graphs and all data must be collected, noted and plotted manually.

During 2022-2023, a group of part II students attempted to improve this practical by using a LIDAR sensor to determine the position of the weights stack and hence calculate displacement. This helped to solve the issue of measurement accuracy however the achievable sampling rate remains constant and human intervention throughout was still required. We aim to solve the same challenge and more through a different approach detailed below.

### Concept:

The displacement can be much more accurately determined using a stepper motor which is capable of reaching specific pre-determined displacements and measuring the force required to do so digitally. Note that an alternative, likely more accurate, solution to measure the force is to use a calibrated strain gauge in series with the spring so this is what we expect to incorporate. A motor is also capable of “continuous” measurement at high resolution intervals which would result in a smoother and more accurate loading - unloading curve.

Additional autonomy will be incorporated to the project in the form of a raspberry pi compatible thermocouple that determines at what point the loading process can be



initiated. We also aim to design a mechanical piston-based switch operator that will turn the attached hairdryer on and off to automatically start and end the heating phases.

To make the system more representative of professional equipment used for research, we aim to design a basic GUI application that will plot out real time the loading and unloading curves. The interface will also provide you with a section to input your email address which will simultaneously send you the plotted data and csv files.

### **Workflow:**

The initial part of the project will be concerned with attaching the motor to the clamp stand, spring, strain gauge, hairdryer and tube setup, followed by managing to control and measure the displacement - force output digitally. Then we will find a way to export and visualise the data using the python script GUI, this will ideally involve live animation of the loading - unloading curve being traced out. The next task will be to develop the automatic hairdryer switch and work on incorporating the thermocouple feed to the GUI so that the temperature can be viewed live and used to determine when to kick off the experiment.

### **Expected Challenges and Solutions:**

The key variable to success in this project is the ability to gather accurate data from the motor throughout its operation, without accurate measurements, the project doesn't improve significantly on previous years attempts or the original manual practical. Furthermore there are a number of engineering challenges that we may encounter when practically executing our goals.

Expected Challenges	Explanation and Possible Solutions
Accurate measurement of force experienced.	Initial solution will be to determine the power output from the operational rating and transform that to force by calculating torque using the angular velocity. An alternative solution may be the incorporation of a strain gauge to directly measure the force.
Accurate measurement of displacement.	To calculate displacement we need to measure the angular velocity of the motor, initially we will aim for this to be constant and measurable at the loads we are expecting. If this turns out not to be the case, we may need to attach a spoked wheel to the motor that passes through light gates; the frequency of light gate trigger can then be transformed into the angular velocity and measured over time.
Dexterity for turning on the hairdryer.	The cam switch operator will have to be held against the switch with some force so that the device doesn't just push away from the socket. We plan to overcome this by building a small frame that attaches around the back of the lab power socket blocks to hold the operator in place.
GUI connection to the devices.	We have had practice with operating components connected to the raspberry pi by running code scripts but we are yet to build the GUI and hence there may be issues with attaching preset code scripts to interface buttons or vice versa with presenting the data gathered from an attached component on the interface. This will be an area of research over the Christmas break.

**Aims:**

The initial goal for the project is to be able to conduct a full load and unload cycle at elevated temperature while measuring the force-displacement over time. Additional to the core goal is to achieve visualisation of the data (ideally live) and the ability to export by email. As a stretch challenge we hope to link the heating process to the GUI and also represent the live data feed of the thermocouple digitally.

**Appendix 1: Equipment and budget**

Practical equipment: Clamp stand, Nitinol spring, plastic tube, hairdryer,

Component	Cost /£	In-department?	Notes
<a href="#">Raspberry Pi 4</a>	33.60	Y	
<a href="#">Thermocouple</a>	9.60	N	
<a href="#">Thermocouple breakout</a>	11.40	N	May be able to make from scratch (op-amp circuit)
Frame - <a href="#">wood</a>	1.56/m	N	Need approximately 1 meter for hairdryer switch box
<a href="#">Keyboard</a>	13.67	Y	Could just be borrowed
<a href="#">Simple display</a>	11.60	N	For simple text
<a href="#">Screen</a>	57.60	N	For full GUI (could borrow monitor)
<a href="#">Beam Breaker</a>	2.60	N	May be needed to measure angular frequency of motor
<a href="#">Stepper Motor Driver Pack</a>	6.70	N	Unsure which motors will work best, but they are reasonably priced so we could try a few  Accurate rotation, usually used for 3D printers etc
<a href="#">SC15 17kg High Torque Programmable Serial Bus Servo</a>	17.30	N	Seems like the best option for control of the loading

<a href="#">ESP32 Servo Driver</a>	15.40	N	Necessary driver for servo
<a href="#">Multi-output motor</a>	13.00	N	
<a href="#">Adafruit A4988 Stepper Motor Driver Breakout Board</a>	5.80	N	Similarly, many drivers exist but this is a good option for stepper motors
<a href="#">Adafruit DRV8833 DC/Stepper Motor Driver Breakout Board</a>	5.80	N (but similar drivers are available from edukit3)	
<a href="#">Solenoid</a>	14.40	N	To push hairdryer switch
<a href="#">Strain Gauge Load Cell - 4 Wires - 5Kg</a>	3.80	N	
<a href="#">Adafruit HX711 24-bit ADC for Load Cells / Strain Gauges</a>	9.60	N	

On top of this, some thin, strong string will be needed to transfer the load. 3d printed gears may also be required if the motor is not strong enough (or an upgrade may be required). Wiring will also be needed

Approximate total: £170 - £240 (with screen and keyboard)

## Appendix 2: Safety

Risk	Precaution	Severity
Hairdryer breaks	Prepare a kill switch to turn off the component, leave to cool before handling.	1/5
Spring Snaps	Surround the spring with a plastic cylindrical tube. Have a motor kill switch to prevent unintentional over-extension. Fully unwind motor to release elastic energy before touching the setup.	1/5
Clamp Stand Falls	Ensure mechanical aspects (hairdryer switch operator) are physically separated from the stand. Clamp the stand to the table. Stand back during operation.	2/5

## Project 2: Autonomous 3-point Fracture Testing Robotics

### Motivation:

During week 4 of Lent term, IB Materials Students complete bend testing of concrete slabs that they created the week before.

The bend testing of concrete slabs involves manual addition of 500g weights to a growing stack on top of the concrete. Not only does this pose a potential hazard to students as the slab fails and the weights fall, but the accuracy of the failure strength is determined by the precision with which students can lightly place a metal weight.

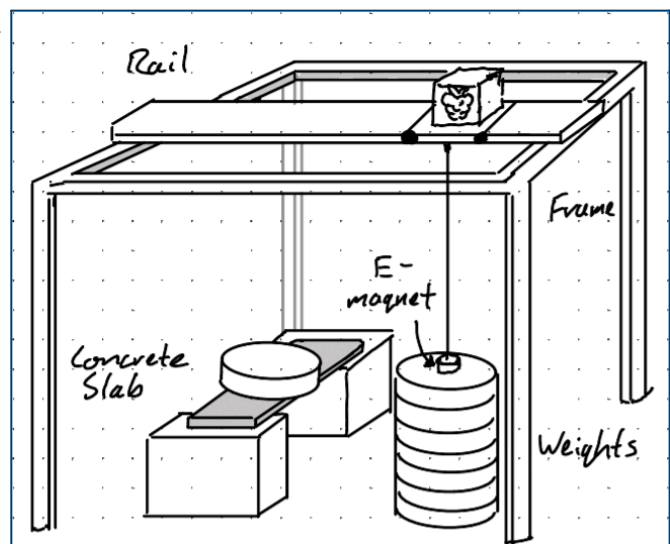
By automating this process, all weights can be loaded without students being close by. This increases the overall safety of the practical and allows for a lower error in the breaking force. Maximum tensile strength can no longer be affected by students dropping weights too quickly and causing a brief period of elevated stress that cannot be accounted for.

### Concept:

We will create a crane system that is capable of picking up weights from a stack and placing them one at a time on the concrete slab. The raspberry pi will both control the motors present on the crane to adjust the x,y & z location of the weights, as well as record and monitor the current force on the slab.

Steel weights will be picked up by an electromagnet, also controlled by the raspberry pi, which can engage and disengage as the weights are placed. The crane itself is a rigid cuboid whose top face contains a 1D rail system. This allows the

horizontal position of the electromagnetic grabber to be adjusted between above the concrete and above the spare weights. If this proves difficult then the project is achievable with only one rail system, but the plan is to include two orthogonal rails such that the grabber can move to any position within the crane's frame.



The crane continues to load weights until the slab breaks, which it will detect via a small decibel monitor that can detect the sound of the weights hitting the floor. At which point the crane ceases operation. The final number of weights the concrete supported could be read visually by any students present, but the system could be fully automated by the students inputting their emails into a small screen at the start of the experiment. If they do this, a small piece of text describing the experiment's results can be emailed to all students in the lab group once the test concludes.

**Workflow:**

The project will begin with building the motor-winch carriage. This carriage needs to be able to move along the rail, with its position controlled by the raspberry pi. After this some of the frame can be built and the winding and unwinding of the electromagnetic grabber can be coded, along with the controlling of when the electromagnet engages. Once this system works we can design the user interface and make the system capable of running one testing cycle by itself. If this can be done quickly, then we can start working on the additional goals discussed below in “Aims”

**Expected Challenges and Solutions:**

The main problem we expect to encounter first is making sure the crane can cycle through many weight loadings in a row while keeping its accuracy. This will require careful calibration of how the coordinates of picking up and placing change as weights are added. If we have time, the method of detecting where the weight stack is will also be challenging. We would like to include a lidar sensor to check where the weights are, but we may have to change to an alternative solution.

**Aims:**

The most basic level of success for this project would be the ability to load weights from a stack at a fixed location onto a concrete slab, also at a fixed location. For this we would only need a rail system that could move in 1 dimension and this would likely require manual intervention at the start and end of the practical.

We would like to add a keyboard and small display, such that students can be given any required instructions for operation as well as the ability to input their email addresses. After the test is completed, the students can be automatically emailed with the test results. This would improve the user experience with the goal that using this system is easier than conducting the test by hand.

We anticipate that requiring an exact placement of the weight stack may be limiting, so if we can get the crane working in good time we would like to add a way to detect the location of the weights at the start of the test. This is unlikely to be as complicated as a full vision system, but some rudimentary way of distinguishing the weights from the surroundings would lower the initial effort to start up the practical. If this is successful, it may be useful to add a second, orthogonal rail, such that the crane can move in 2 dimensions around the entire area of the crane’s frame.

## Appendix 1: Equipment and Budget

Practical equipment: concrete block, 500g weights

Component	Cost	In-department?	Notes
<a href="#">Raspberry Pi 4</a>	33.60	Y	
<a href="#">NEMA 17 Stepper Motor - 42mm x 60mm</a>  3 needed in total	18.00	N	Capable of 6.5Kg-cm holding torque and 280g-cm  It is hard to know what motors will be suitable without testing, but this torque seems feasible for gantry movement
<a href="#">Adafruit TMC2209 Stepper Motor Driver Breakout Board</a> 3 needed in total	8.60	N	To drive NEMA 17 motors
<a href="#">SC15 17kg High Torque Programmable Serial Bus Servo</a>	17.30	N	Capable of torque for lifting 500g
<a href="#">ESP32 Servo Driver</a>	15.40	N	Necessary driver for servo
Frame - <a href="#">wood</a>	1.56/m	N	Expect to use around 6m for the frame
Frame - <a href="#">Al extrusion</a>	10/m	N	Expect to use around 3m for the rail system
<a href="#">Electromagnet</a>  Expect to use 4	9.60	N	Need a driver for power and induction protection. Either custom built or motor drivers can be used
<a href="#">Adafruit DRV8833 DC/Stepper Motor Driver Breakout Board</a> Expect to use 2 (although maybe only 1 needed)	5.80	N	Drivers for electromagnets  Only really used for their H bridges
<a href="#">TF-Luna Lidar Ranging Sensor</a>  3 needed (x,y,z)	24.00	N	
<a href="#">5mm Brass Hex Mounting Hub</a> 4 needed	2.46	N	Only 7mm available from pihut
<a href="#">65mm x 25mm Wheel Pair</a> 2 sets needed	6.00	N	

On top of this, some thin, strong string will be needed to transfer the load. 3d printed gears may also be required if the motor is not strong enough (or an upgrade may be required). A 3d printed pulley is also needed to fit our needs. Extensive testing of these components will be necessary to assess feasibility of the current plan. Powering the motors may be an issue but we are hoping to use batteries.

Approximate total: £335

## Appendix 2: Safety

Risk	Precaution	Severity
Weight Stack Falling - Injury	Experiment operated remotely	2/5
Weight Stack Falling - Damage	Frame construction must be sturdy enough not to break	1/5
Weight Dropping from electromagnet	Electromagnet used has internal permanent magnetic in case of power failure	2/5
Moving Parts Trap Fingers	Frame built to minimise surfaces shearing over each other	3/5