RMMECH24 Project Team 2

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May 2024

1 Group Member Contributions

The contributions of each group member can be seen in Table 1.

Name	Contribution
Jeppe	bending, 3D printing, assembly
Pol	electronics, UI
Theodor	CAD, bending, assembly, 3D printing, testing
Isabella	bending, assembly
Nikolas	CAD, assembly, 3D printing, testing, turning
Milosz	bending, assembly

Table 1: Table of Team Contributions

2 Problem Description

This project aims to design and manufacture a multipurpose exercise machine.

Deliverables

- *Conceptual Designs*: Initial CAD models outlining the proposed design.
- *Prototyping*: Development of a working prototype.
- *Finalize the Design*: Remaking parts that needed changing.
- *Testing and Validation*: Testing to ensure the machine meets safety, durability, and performance standards.

3 Training Concept

The training concept of the machine is that the user sits on a small chair on the ground, with a pull bar above them. This bar is meant to be pulled down with a straightened back to right below the chin. Then the arms should be raised again to repeat the pulling. The machine will be dual-functional, and can also be used as a biceps extension machine. For this exercise, the user needs to be standing with the front towards the machine and grab onto the pull bar. The user must stand so the hands, grabbing the pull bar, are right in front of the shoulders. From here the user can move the hands downward, straightening the arms down. This movement can be repeated to train the triceps muscles.

In the end the machine resembles a standard cable machine with the last pulley fixed at the top of the machine. It was later discovered that the machine could then be used for multiple other exercises without changing the configuration of the machine.This includes exercises like triceps push-down, face pull and high row.

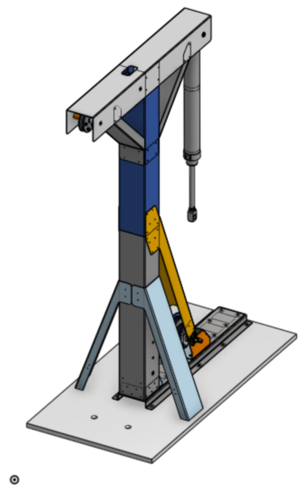


Figure 1: ISO_CAD_View

4 Critical Component Dimensions

The whole design process had one crucial idea in mind, and that was manufacturability. Due to the bending machine being not optimal for industrial grade bending accuracy's, everything was designed around the bending machine. The design utilized simple U-profiles that had a greater width than height, to keep the sheet metal from colliding with the bending machine. Two U-profiles that would intersect had 1 mm of clearance added to the width of one of them, to give a greater tolerance for bending inaccuracies. All of the holes for the shafts in the U-profiles were oversized due to the same reason, with the only precision fits in the entire system were made for the shaft to ball-bearing, shaft to pulley and bracket to ball bearing connections.

The steel details were connected using 3.2 mm diameter rivets. Each connection had over 3 rivets. The distance between rivets in one connection was made to be reasonably large to reduce the lever effect that one detail may apply to the other.

The other design consideration was the stroke length of the piston. In order to achieve the desired range of motion for the exercise, it was necessary to extend the stroke of the piston. The easiest solution to this problem was getting a different piston but that was not possible due to the constraints of the project. The other way to solve this was through some form of reduction.

This was done using two pulleys/drums of different diameter on the same axle. The smaller drum was directly attached to the piston and the larger drum ran to the output of the machine. The diameter ratio being 1:1.5. This resulted in a smaller linear relation to the range of motion applied by the user effectively extending the stroke of the piston. For example the desired range of motion for the machine was 450mm and with the ratio this results in a need of 300mm stroke from the piston. Careful consideration went into choosing the diameters of the pulley drums to get 300 degrees of rotation for the whole stroke of the piston. This was done due to the potentiometer having only 300 degrees of free rotation. The final effective diameters that were chosen were 174 and 116 millimetres. To make this pulley withstand the forces from the piston and to keep it easy to manufacture, a lot of consideration went into the design. Making all the fits for the shaft close enough for it to not wobble, but still keeping the assembly process have minimal friction. The need to connect the potentiometer to the shaft made the pool of possible designs even smaller. The final design utilized 3D printed brackets to lock the rotation of the pulley drums to the shaft with screws that connect to flat spots filed into the shaft, as depicted on page 12.

The main load would still be transferred from pulley walls to the shaft by steel to steel contact. The pulley was connected to the system by ball bearing pillow blocks that would press and hold the ball bearing into the steel bracket, so the loads would be transferred from the shaft to the ball bearing to the steel bracket. See the cut away drawing on page 13. Lastly the potentiometer was connected to the pillow block with a custom 3D printed bracket connecting the frame of the potentiometer to the frame of the exercise machine. The shafts of the pulley and the potentiometer were connected using a tube that was thermoformed around both shafts during installation. This was made possible by the bracket having two open slots on the top and bottom, giving access to the shaft even after installation.

The last component of the machine necessary was the cable routing. With the issue of stroke length out of the way there just needed to be a way to transfer the resistance of the piston to the bar. This was done with a series of idler pulleys. Due to manufacturing constraints it would have been much harder and more time consuming to make custom all metal pulleys, and the goal was not to spend any money on the project so buying of the shelf parts was out of the question. The solution to these problems was designing homemade pulleys that use a combination of laser cut steel plates and 3D printed drums. The pulleys could have been made entirely using 3D printing but then there's the risk of the pulleys not being able to handle the weight, and manufacturing using only laser cutting would be too complicated. The combination design utilized the ability of 3D printing ability to make complex 3D shapes to make the pulley profile with the groove for the rope. The laser cutter was used to make reinforcement face plates to mount on either side of the pulley with a series of bolts. These work as pulley races to help keep the rope contained and use the bolts to transfer the forces from the 3D printed part to the steel races on the outside of the pulley. The ball bearings are also press fitted into the steel plates to allow a straight path for the forces to the steel shaft. Making only a small part of the 3D printed part to be under load. The design for this can be seen in figure 2.

Figure 2: Idler Pulley Design

5 Equipment Force Characteristics

Due to the system relying on rope and pulleys the force of the piston is directly connected to the bar. Thus the force applied to the handle bar by the machine is constant in any configuration. Considering that the pressure in the piston would be constant through out the exercise. This is evident when looking at the angle between rope and the piston rod. The angle is constant and does not change during the full stroke of the piston.

6 Measurement Data and Analysis

One of the tasks in this project is to design and program a data acquisition system, which can provide live metrics to the user. An Arduino Uno has been utilized to gather and process the data. Alongside it, two sensors have been installed in the setup: a 10k Ohm potentiometer located in the main pulley and a pressure sensor that measures the current pressure in the air tank.

Both sensors will be connected to Vcc (5V) and GND, and they produce an analog signal which is proportional to the sensed metric in each case. The analog signals require digital conversion through the Arduino 10-bit ADC. Hence, the data cable coming out of the two sensors is connected to an analog input in the micro-controller board. Going into more detail, the potentiometer has been placed in the main pulley allowing a 1:1 ratio between the rotation of the pulley and the linear movement of the cylinder. Meaning for each degree on the potentiometer the piston travels 1 mm. The angle reading can also be used to count workout repetitions. On the other hand, the pressure sensor has been calibrated according to the data sheet of the pressure sensor. Additionally, a button has been installed near the Arduino to function as a "Reset UI" button.

By using the Arduino serial port, we can output key measurements from the micro-controller to use it in a python script. Specifically, the following metrics are tracked by the arduino:

- Output voltage of potentiometer
- Output voltage of pressure sensor
- Session timer that increments every second
- conversion from voltage to angle
- conversion from voltage to pressure
- Rep counter that adds +1 every time an angle threshold is met

The analog signals from the sensors are converted into digital by using the ADC conversion rule:

$$Potentiometer\_voltage = \frac{Sensor\_reading \cdot 5.0}{1023.0} \tag{1}$$

$$Pressure\_voltage = \frac{Sensor\_reading \cdot 4.0}{1023.0} \tag{2}$$

In case of the ADC conversion for the pressure sensor it has been taken into account that the sensor will only output a signal between 0.5V and 4.5V, as per the datasheet.

Finally, the pressure metric is used to compute the equivalent weight that the user is pulling by means of the following equation:

$$Weight(Kg) = \frac{Pressure(Pa) \cdot Area(m^2)}{9.81(m/s^2)} \tag{3}$$

6.1 Power Metric Calculation

In order to get a power value we will use the next equation derived from force:

$$Power = Velocity \cdot Area \cdot Pressure \tag{4}$$

The area parameter refers to the cylinder piston area. Due to setup, the retraction stroke of the piston was used. The piston's retraction stroke has the effective area of 0.0010556 m^2. The pressure will be given by the pressure sensor present in the setup.

The velocity parameter requires additional steps in order to get the final value. Specifically, we are comparing two angle reading values in order to get it. To do so, we are storing an angle value until a new one is obtained, and then subtracting current minus last reading value. This is then divided by a fixed time step of 0.1s, which happens to be the refresh interval of the UI too. The next equation summarizes the velocity calculations:

$$Velocity = \frac{current_{angle} - previous_{angle}}{0.1} \tag{5}$$

Notice that we are using angular values for the increment in distance. But, as explained before, due to our machine design the angular difference translates 1:1 to the linear distance difference.

Equation 4 in combination with equation 5 will calculate a power value for a small angular increment based on the 0.1 time step. In order for us to get a total power metric, we have to append each individual computed power value to a list. Adding all the values from the list together will result in the final value that we show to the user when it reaches the final threshold of 300 degrees.

This power metric can be seen as the "Mechanical Power", i.e. the power exerted by the user to perform the pulling movement.

7 User Interface

In order to show a live view of the measured data, we have used a Python script that reads the data from the serial port and runs a User Interface. PyQt5 has been used as the Python library that allows the display of text and numeric values. The UI has been divided into two sections: User Interface (this would be the data showed to the user) and Developer View (which shows internal metrics and sensor values). The data showed to the user is the more usefull while doing a workout. The user can reset the UI (the workout timer and the rep counter) by pressing the arduino button.

The design of this UI is simple and readable, with a colour palette that is somewhat similar to current workout machines UI. It updates every 0.1 seconds.

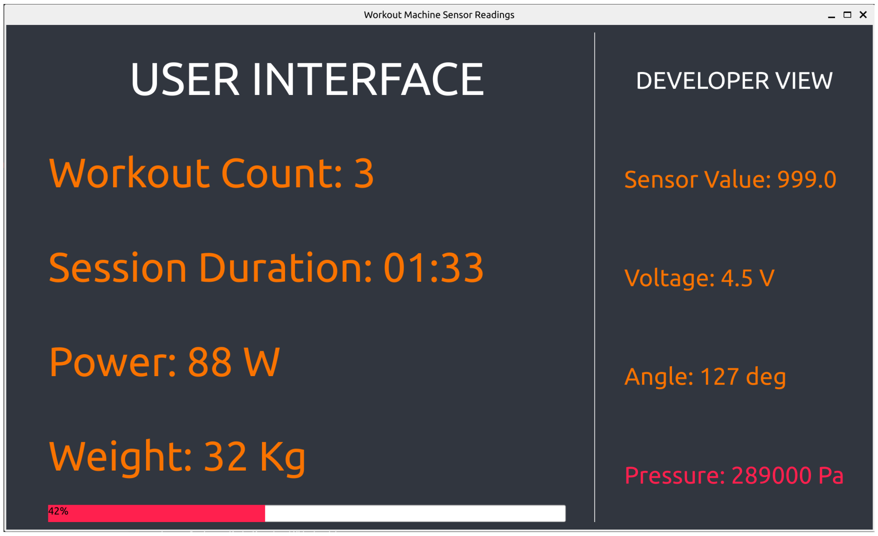
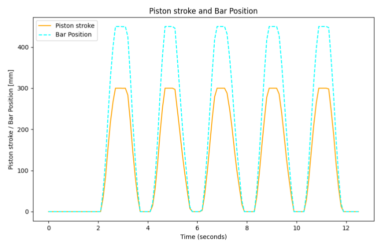


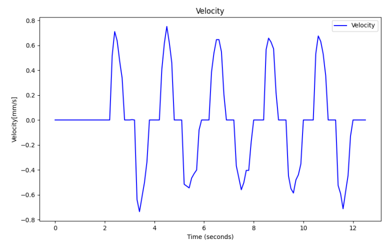
Figure 3: Final design of the User Interface

8 Tests and Results

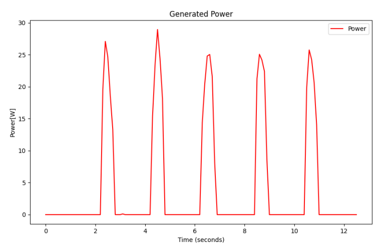
To test the machine an experiment was preformed. It consisted of a user performing 5 pulls of the bar utilizing the full range of its motion, with the pneumatic piston pressurized at 3 bar. The data from the experiment can be seen in the figures below.



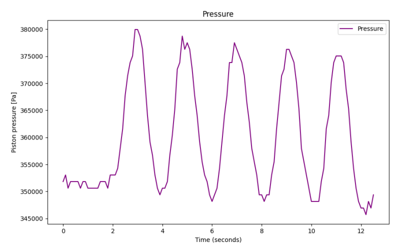
(a) Range of motion of the piston and the bar



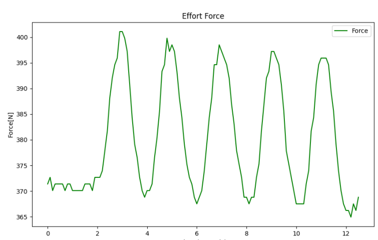
(b) Velocity



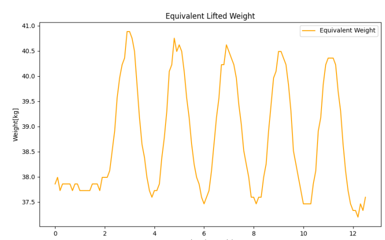
(c) Generated Power



(d) Piston Pressure



(e) Effort Force



(f) Equivalent lifted weight

Figure 4: Data gathered from 5 repetitions

The figure 4a displays the full range of motion of both the piston and bar. The range of motion of the bar is 1.5 times larger than the one of the piston thanks to the use of two pulleys/drums of different diameter on the same axle, mentioned before. The force and lifted weight values are directly correlated with the pressure value. Changing the pressure value would result in a harder exercise, requiring more force from the user to perform.

9 Conclusion

The project successfully achieved the goal of designing and manufacturing a multi-functional exercise machine designed for back, triceps, biceps, and ab exercises. The design prioritized manufacturability by utilizing simple U-profiles and custom-made pulleys to accommodate the available manufacturing tools and materials.

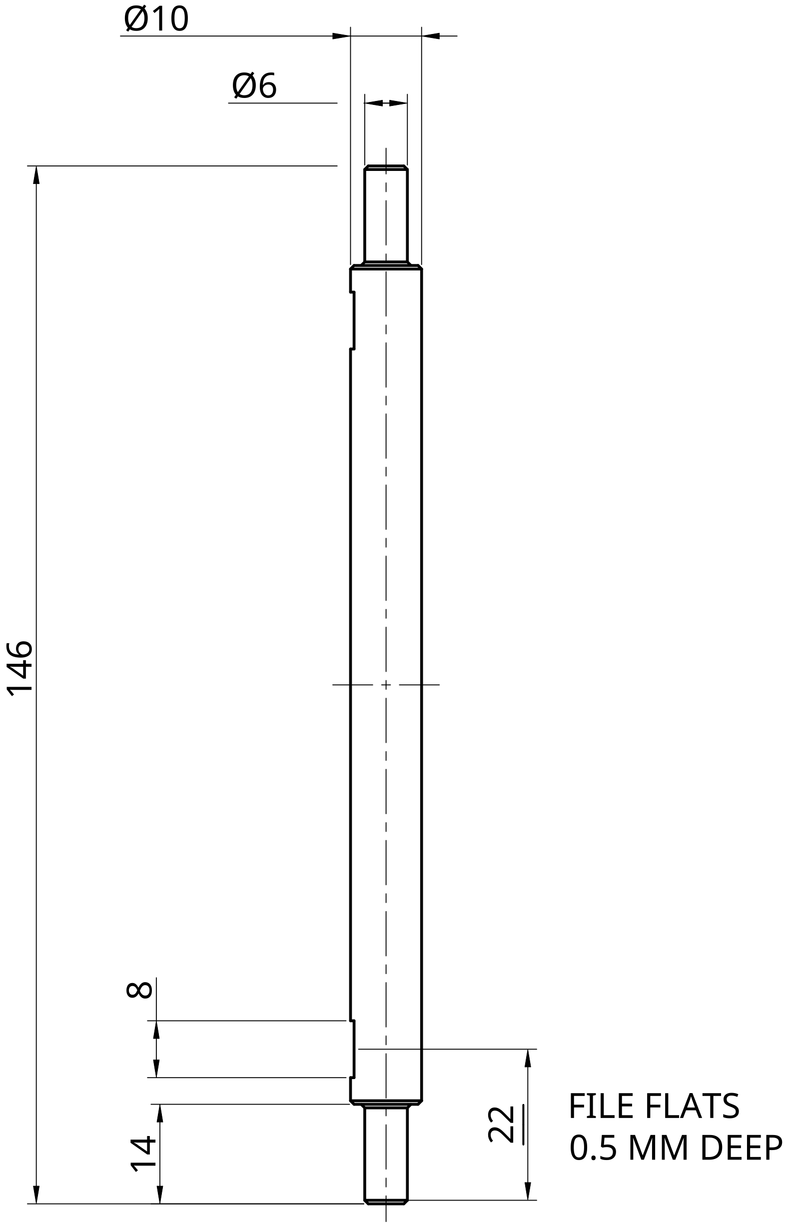
A key part of the final mechanical design was the pulley system, which was designed to extend the stroke length of the piston. This system used two pulleys/drums of different diameters on the same axle, effectively extending the piston's stroke length to achieve the desired range of motion.

The design of the pulleys took into account the material strength of the 3D printed parts by adding laser-cut steel reinforcement plates on both sides. This provided sufficient reinforcement for the pulleys to withstand the considerable load exerted on them.

A data acquisition system was also successfully integrated. This system consisted of an Arduino that measured data from a potentiometer and a pressure sensor. The potentiometer measured the rotation of the pulley, and together with the pressure measurements allowed for live tracking and display of workout performance.

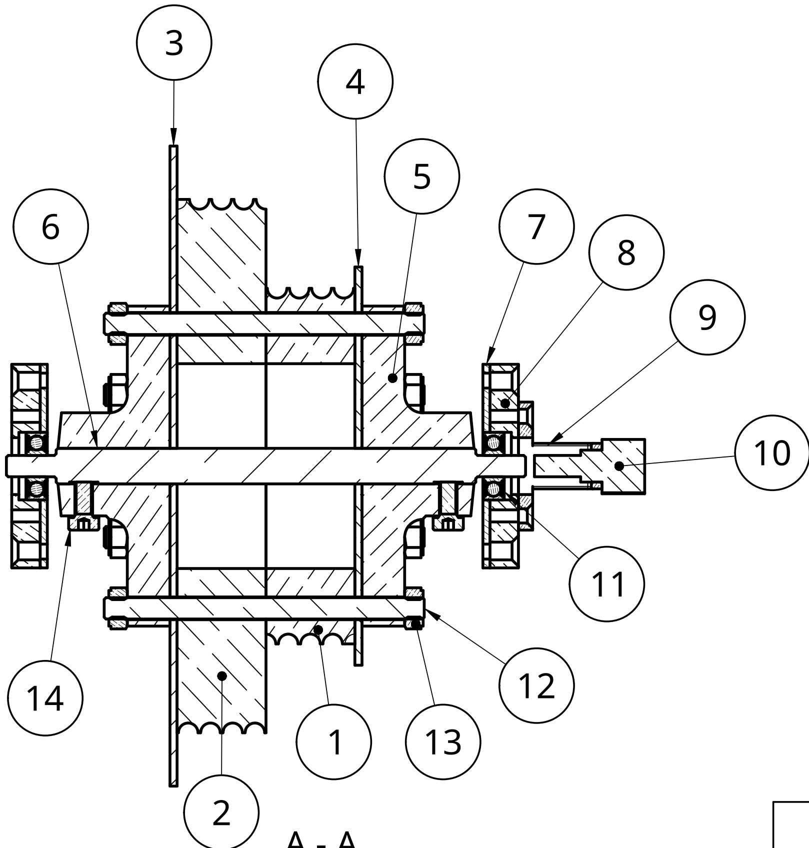
Testing confirmed the machine's functionality and versatility, demonstrating its ability to support multiple exercise types without configuration changes.

10 Technical Drawings

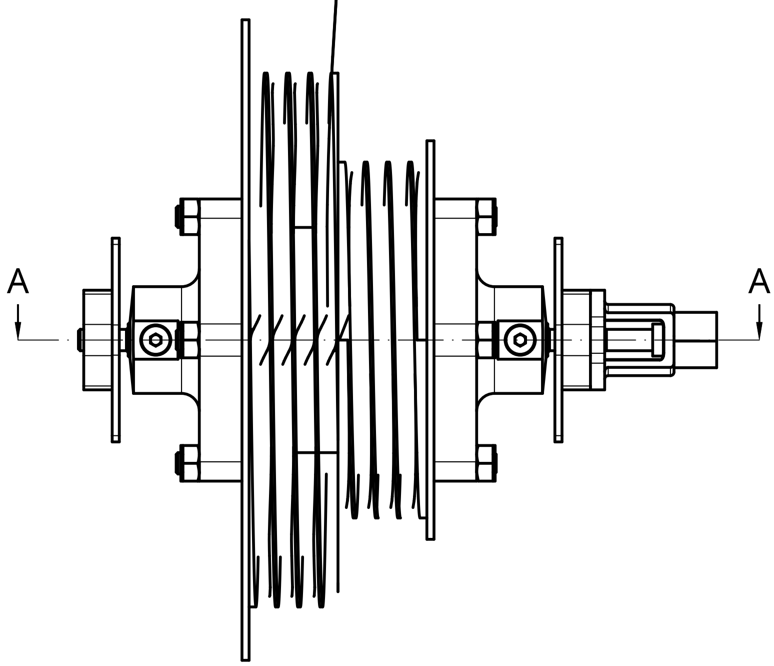


NOTE: BREAK ALL EDGES

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE	
	DRAWN	THEODOR PAAL POLLUSTE		2024-05-21	
	CHECKED	THEODOR PAAL PÕLLUSTE		2024-05-21	TITLE MAIN SHAFT PROFILE VIEW
	APPROVED	THEODOR PAAL PÕLLUSTE		2024-05-21	
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 / DWG NO. MAIN_SHAFT / REV. 01
FIRST ANGLE PROJECTION	MATERIAL S235		FINISH		SCALE 1:1 / WEIGHT / SHEET 1 of 1



A - A



Item	Quantity	Description
1	1	Pulley_S
2	1	Pulley_L
3	1	Pulley_Wall_L
4	1	Pulley_Wall_S
5	2	Pulley_Shaft_Connector
6	1	Main_Shaft
7	2	Pillow_Block_Bracket
8	2	Bearing_Pillow_Block
9	1	Potentiometer_Bracket
10	1	Potentiometer
11	2	608_Z Ball bearing
12	6	M6 threaded rod
13	12	Hex nut style 1 grade A & B M6x1 Steel
14	2	Hex socket head cap screw M5x0.80 x 10 Steel

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS

ANGULAR = ± °

SURFACE FINISH

DO NOT SCALE DRAWING

BREAK ALL SHARP EDGES AND REMOVE BURRS

FIRST ANGLE PROJECTION

	NAME	SIGNATURE	DATE
DRAWN	THEODOR PAAL POLLUSTE		2024-05-30
CHECKED	THEODOR PAAL POLLUSTE		2024-05-30
APPROVED	THEODOR PAAL POLLUSTE		2024-05-30

MATERIAL

FINISH

TITLE

COMBINATION PULLEY ASSEMBLY

SIZE	DWG NO.	REV.
A4	COMBI_PULLEY	01

SCALE	WEIGHT	SHEET
1:2		1 of 1