ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

A Device for Evaluation of Frictional Properties of Surfaces

Team #20

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Abstract

Extensive research efforts have been devoted to understanding the complex mechanisms of friction wear to minimize their effects in sliding systems. Improvements in the instruments used to characterize the phenomenon of friction and wear are required to enhance the effectiveness of the research method. In this project, we present an experimental platform that evaluates surfaces' frictional behavior. Our platform generates friction by rotating the sample material to be tested fixed on a rotating disc, which rubs against a small ball fixed on a force sensor. Furthermore, the normal force applied on the ball and the sample material could be modified by the users to be any value and object. Meanwhile, the platform is also installed with a conveyor system, allowing users to change the spot of rubbing.

Keywords

Friction, Lever, Step-in Motor

Contents

1 Introduction

1.1 Objective and Background

1.1.1 Problem

Extensive research efforts have been devoted to understanding the complex mechanisms of friction wear to minimize their effects in sliding systems. Improvements in the instruments used to characterize the friction and wear phenomenon are required to enhance the effectiveness of the research method. In this project, our goal is to design and build an experimental platform that evaluates surfaces' frictional behavior.

1.1.2 Solution

The platform will be a modular friction test platform, which is capable of accurately measuring the friction, wear rate and contact behavior between surfaces of different materials. It will include high precision sensors, controllable condition system and data acquisition system and allow researchers to conduct experiments under a variety of conditions, such as load and angular velocity.[1]

There are many circumstances when people can benefit from this platform. For instance, with this platform around, when carrying out an experiment that needs the friction data of unfamiliar materials, or multiple friction data sets under different conditions, instead of searching for the numbers for a long time, researchers could directly use the platform to get everything they need simply and quickly. In addition to measuring the friction, the platform could also quantize the wear condition of the materials. There are many application scenarios for this platform. Friction and wear measurements are needed in all mechanical related scenarios, such as laboratories and factories. The modular design of this platform is the key to its marketability. The platform will be divided into several parts that are independent from each other, and users can take any parts off in order to maintain or take it to other places. Both maintenance and transportation of the platform will be convenient.

1.2 Functionality

As shown in the block diagram for our design Fig.1, the platform is divided into two major systems: the software system and the hardware system. Between the two systems, the hardware system is the more important one, followed by the software system. [2]

1.2.1 Hardware System

This platform has a great connection to mechanical, so the hardware system accounts for 80% of our workload. The hardware system is divided into three subsystems, as shown in Fig.1, one is the stationary subsystem, one is the sensor system and the other one is the dynamic subsystem.

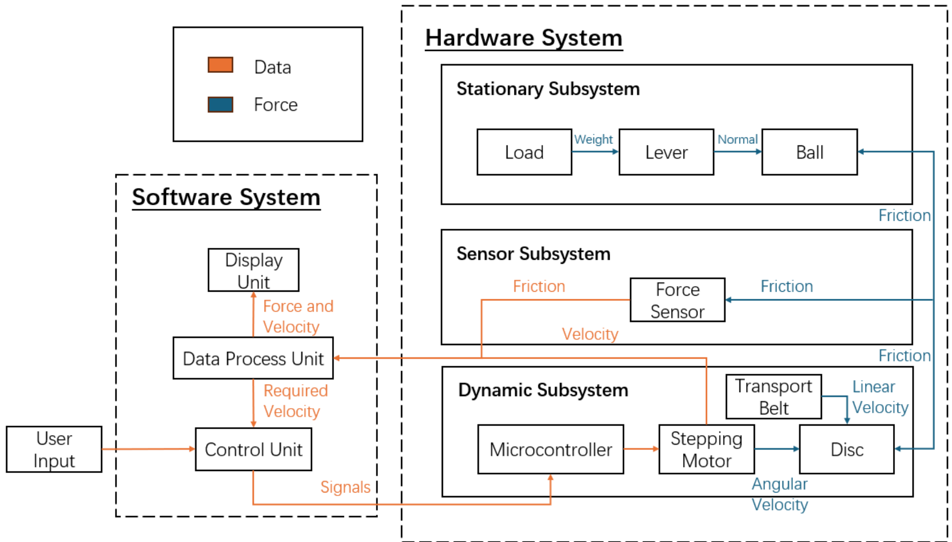

Figure 1: Block Diagram for our design

- Stationary Subsystem: Consists of the load, lever mechanism and a stationary ball. The ball, typically made of a rigid substance, is the subject that interacts with the material to be measured. The ball's radius should be around 3 centimeters and its weight should be around 150 grams. The weight may be different based on the material used. When conducting measurements, users can set the quantity of normal force on the ball by changing the weight of load. The load's weight is changeable from 0 to 50 grams. The weight will be transported to the ball by a lever mechanism and become normal force that acts on the ball. The magnitude range of load should be from 0 to 5 N and the ball is changeable, making it possible for measuring a wide range of materials.

- Dynamic Subsystem: Consists of a microcontroller, a motor, a transport belt and a disc. The disc is made of materials to be measured, its radius is 10 centimeters and height is around 1 centimeter. When the disc is interacting with the ball, spinning the disc will produce friction. The motor is the power source that makes the disc spin, and it requires a voltage of around 24 V DC. Its power should be controllable so that users can control the angular speed of spinning within the range of 100 rpm. The transport belt allows users to change the position where the ball rubs against the disc. . It moves the disc horizontally and the changing range is within 10 centimeters. The microcontroller requires a voltage around 5 V DC and it sends signals to users through the software system, which enables users to monitor the force collected timely.

- Sensor Subsystem: Consists of a force sensor, which has a measuring range of 5 kg, and requires a voltage input between 5 to 12 V DC. Its output is between 5 to 12 mV DC, differing based on the input voltage. This subsystem is the bridge between hardware and software. It gathers data from the hardware system and sends them to the software system. Force sensor measures the friction force between the ball and the disc.

1.2.2 Software System

This system consists of three units: data process, control and display. The data process unit is the core unit that takes in data collected by sensors and processes them into the form needed by the other two units. The control unit is controllable by users, where users can set the speed they want here before starting the platform. After the platform starts working, it will receive data from data process units and automatically adjust the microcontroller in the hardware system according to the real time data and the target. The display unit shows users real time data, such as the friction force, spinning speed of the disc and so on, ensure that users are in control of the platform's status at all times.

1.2.3 Changes Made

One major change has been made for the stationary subsystem. In the early version of our design, the load part is not as shown in Fig.**??**. Instead of simply using some objects of known weight as load, the weight was provided by the combination of a motor and a spring. The motor applied pressure on the spring, thus the spring lifted one side of the lever and provided normal force on the ball on the other side of the lever. This method was considered feasible first. However, after several times of tests, we found that due to the slightly shaking of the spring and the low precision of the minimum displacement of the motor, we were not able to control the normal force accurately. After discussing and redesign, we chose this simpler but preciser way to apply normal force.

2 Design

2.1 Design Procedure

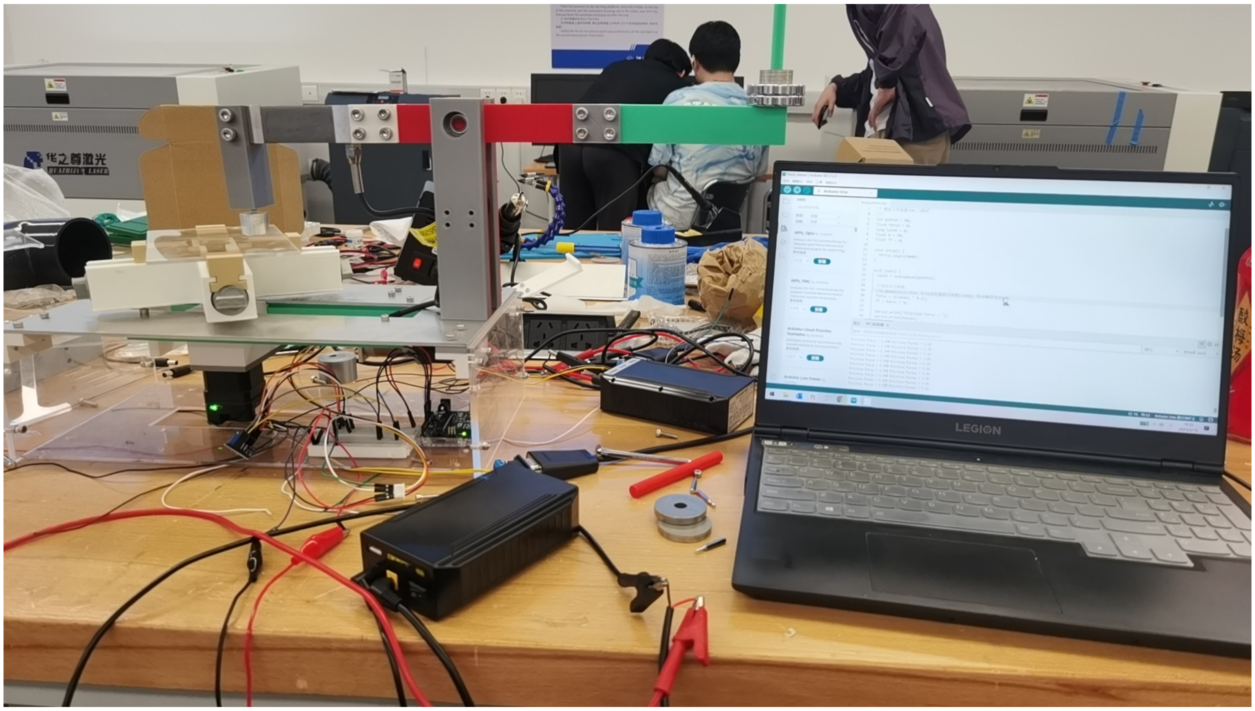

Figure 2: Photo of Product Connected to PC

There are many different forms of friction meters, and their differences lie in different load positions, friction objects, friction methods, and so on. For example, we initially considered obtaining the frictional force of the object being tested by moving two objects horizontally relative to each other, rather than by rotating, which is an alternative to our design. We could modify our current design into that one by changing the disc to a horizontally moving agent. We chose the rotating disc type, mainly for two reasons. Firstly, the horizontal one requires slightly less technical difficulty than the rotating one and has already been produced by most tribometer manufacturers. Secondly, after some calculation, we found that horizontally moving requires more stable materials that a rotating disc, which increases the cost a lot.

For the stationary subsystem we have some considerable alternatives. One is the combination of motor and spring discussed in Section 1.2.3, and another is a simple lever system. The latter one was chosen in the end and there are two major reasons of this decision. First, a simple lever system is more controllable and more reliable than the spring-motor combination. As discussed before, the instability of the spring and the low accuracy of the motor's displacement leads to the instability of the force provided. According to the Hooke's law: $F = -k \cdot x$, we can't determine the x and the direction of the F, so we can't precisely know the magnitude of the normal force generated. On the other side, although the lever system seems to be too simple, it's straight away and provides reliable force. All we needs is to make the lever balanced before we put on any additional weights. The second reason is that after calculating all the costs, we found out that if we chose the first method, we would exceed the budget greatly, which could be easily avoided by turning to the second choice.

We mainly used two design equations, one is the friction equation: $F = \mu \cdot N$ to calculate the final result μ. Another is the torque equation: $F_1 \cdot l_1 = F_2 \cdot l_2$, which is used in the lever system to calculate the weight of balancer and is used to compute the torque needed for the motors.

2.2 Design details

2.2.1 Mechanical Design

- Lever System

  If unaddressed, the weight of the force sensor would affect the accurate measurement of the friction force. A lever mechanism is used to balance the weight of the force sensor.

  According to the data Table B, the length l_b between the center of the lever and balancer is 250 mm and the length l_l between the center of the lever and load is 190 mm. The weight of load, force sensor and the ball is 600 grams. Then, according to the torque equation: $F_l \cdot l_l = F_b \cdot l_b$, we can calculate that F_b is approximately 450 grams. We bought several weights with a total weight of 500 grams so that we can control the lever's balance.

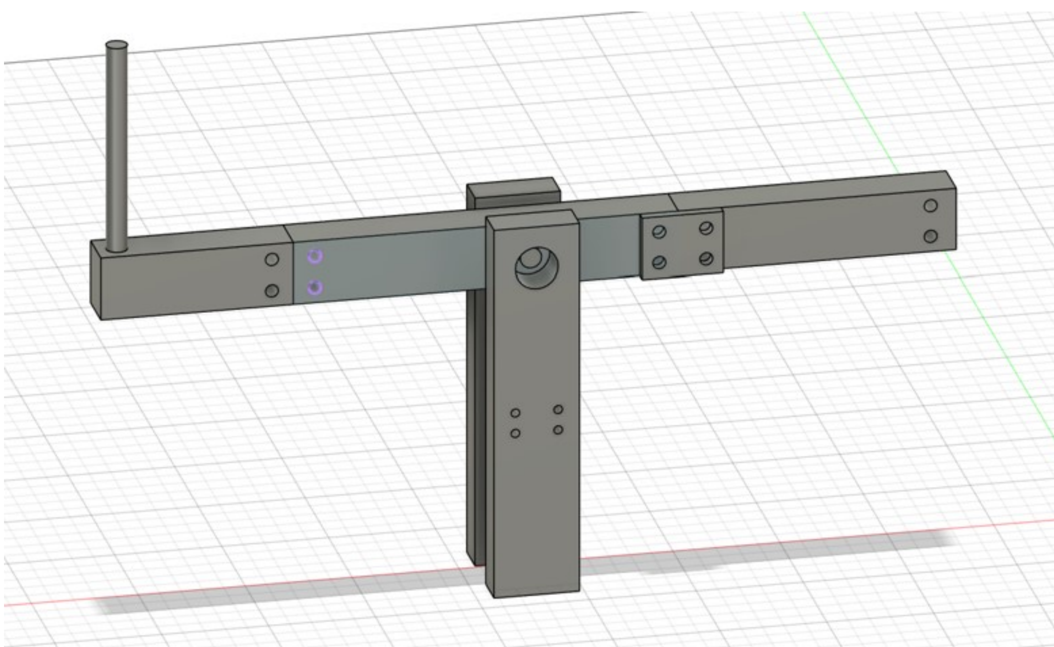

Figure 3: Model for Leverage

- Clamping Plate

  Our design of the clamping plate is inspired by the effective chucks used in machine tools. Its primary function is to firmly hold the test material or component during the friction measurement process, preventing slippage. It has four manually adjustable ends, designed to fix the disk to be placed on it. This design makes it possible to put ”disks” of various shapes on the plate to be tested, not only circle, but also rectangles, triangles, and even irregular shapes.

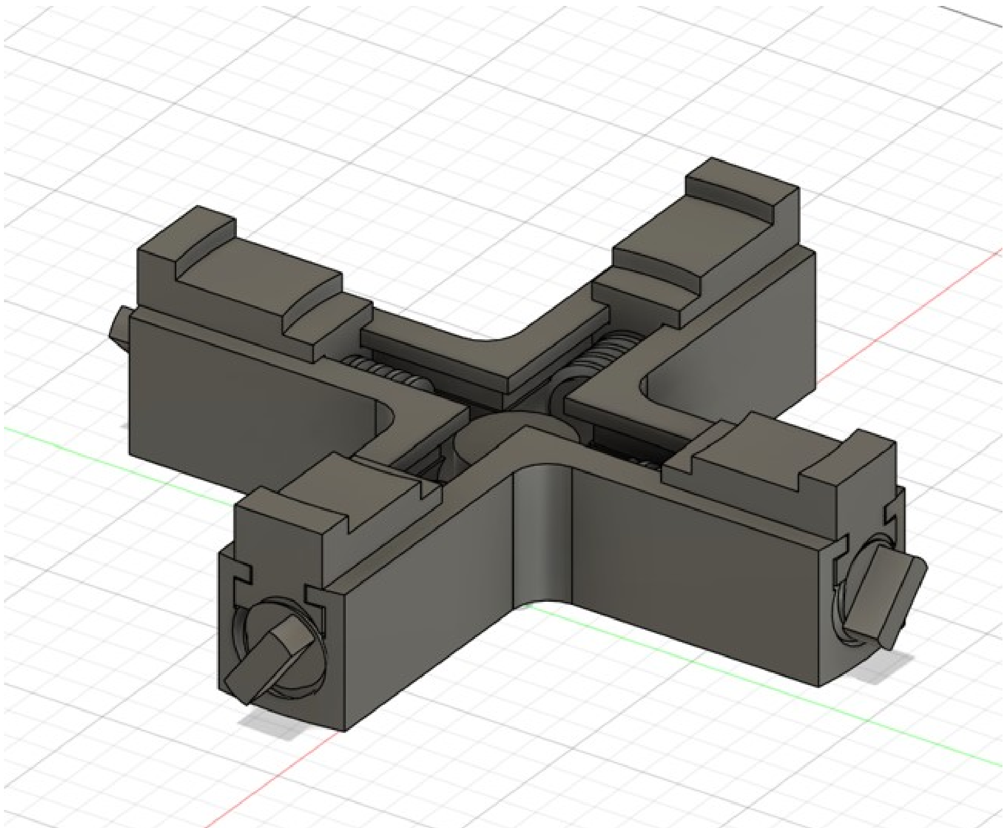

Figure 4: Model for Clamping Plate

- Friction Part

  Our design changes the normal force applied on the friction element (e.g., a rigid substance ball) by placing different counterweights into a load container. Under the specified load, the ball is frequently biased against the disk, resulting in the generation of relative motion between the ball and the disk.

- Transportation

  To change the spot of rubbing, the disk, motor that spins the disk needs to be moved together. The total weight of these objects is around 700 grams. We chose a motor with a relatively large torque, 7.14 N·m, to drive the transport pipe. Since the total length of the pipe is 20 cm, the force provided by the motor is at least 35 Newton. So the disk and its motor can be moved together.

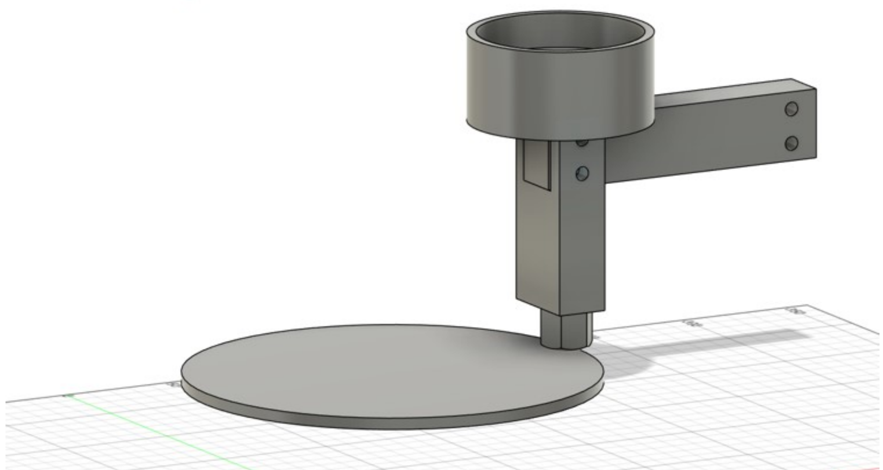

Figure 5: Model for Friction Part

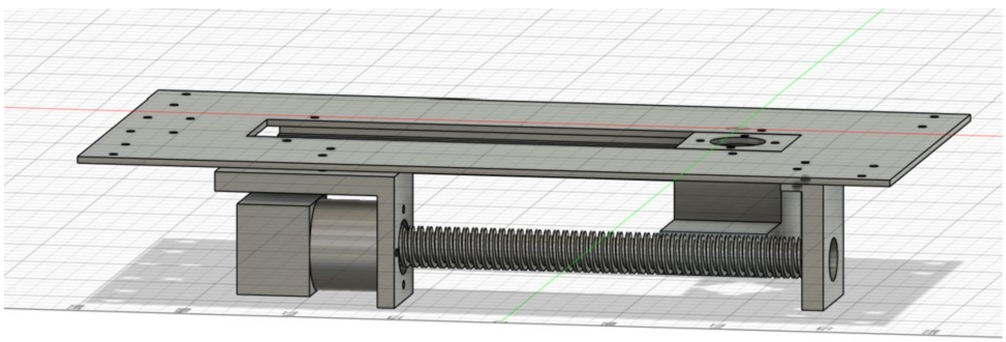

Figure 6: Model for Transportation

2.2.2 PCB Design

Main components includes:

- AD620: Constructed by two level op-amps. A1,A2 is in-phase input, A3 is used for increase adjustable range. AD620 is used to amplifier small signal from S+ and S-
- LM358: Constructed by two op-amps, which is used to suppress temperature-induced voltage drift and to suppress the uncertainty caused by signals without pull-up resistors

2.2.3 Software Design

Our design uses an Arduino board to transmit output of the force sensor to the PC. We program the Arduino to transform the output from voltage signal into analog signal and calculate the force based on the analog value.

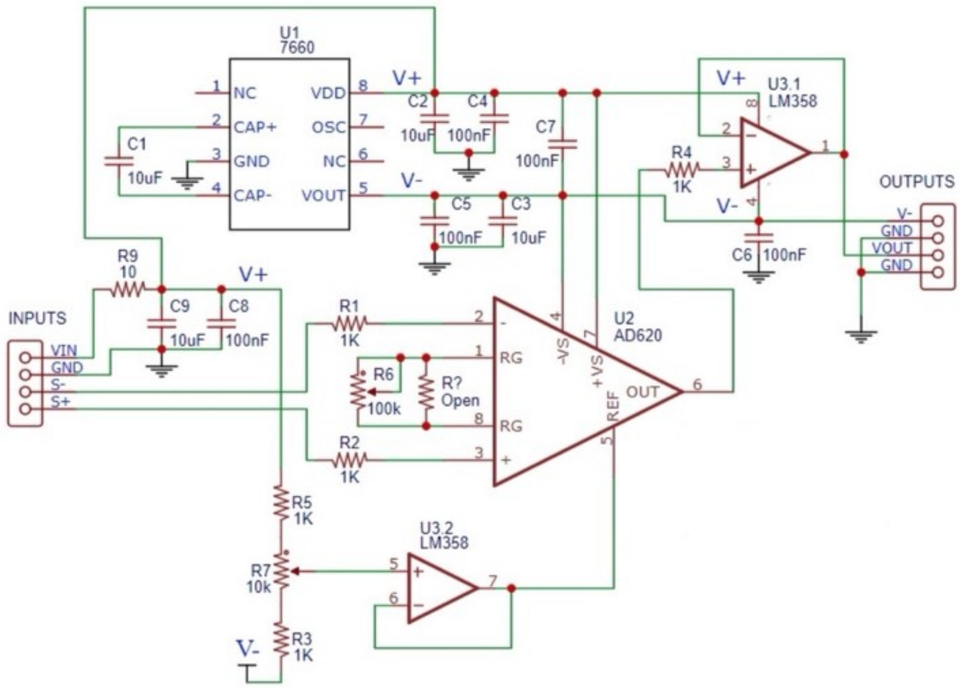

Figure 7: Overall Schematic

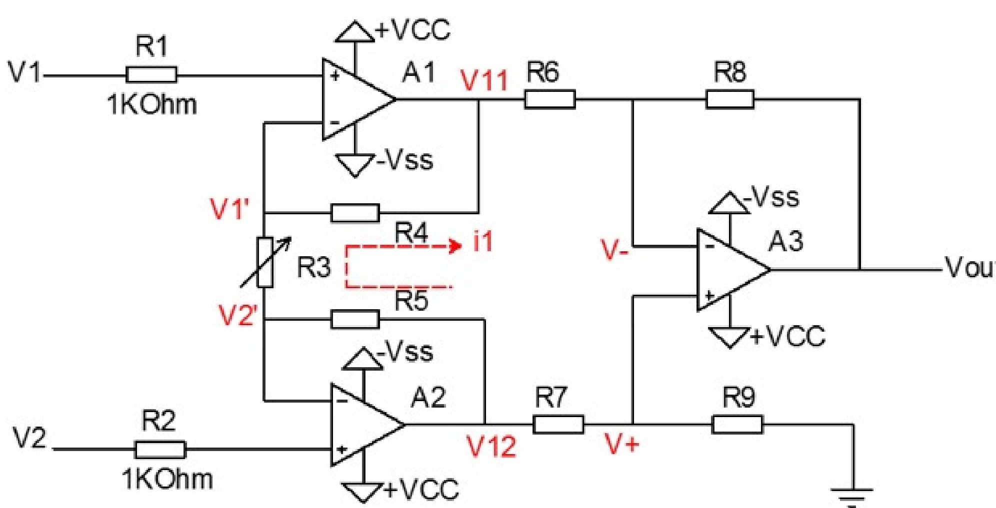

Figure 8: AD620

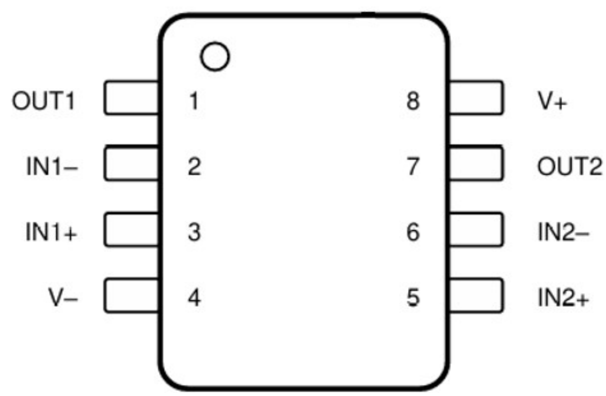

Figure 9: LM358

```
int potPin = A0;
double force_sum = 0;
double force = 0;
long value = 0;
float N = 19.6;
double ff = 0;
int loopcounter = 0;

void setup() {
  Serial.begin(9600);
}

 void loop(){
  if (loopcounter < 100) {
  value = analogRead(potPin);
  //Convert voltage to force:
  force_sum+= ((value) * 0.040);
  loopcounter++ ;
  delay(100);
  }else if (loopcounter = 100) {
    ff = force_sum * 0.01 / N;
    force = force_sum * 0.01;
    loopcounter++ ;
    Serial.print("Friction Force = ");
    Serial.print(force);
    Serial.print("N Friction Factor = ");
    Serial.println(ff);
    delay(1000000000) ;
  }else{
    while(1);
  }
  }
```

Figure 10: Arduino Codes

3 Verification

As seen in the Requirement and Verification TableA, our design have four major requirements to be verified.

- Lever System: Our design uses a simple lever system to balance the weight of the ball and the force sensor, which is in total 500 grams. According to the torque equation: $F_{weight} \cdot l_{weight} = F_{load} \cdot l_{load}$, F_{weight} is around 5 Newton, l_{weight} and l_{load} is around 15 cm, so we need F_{load} to be 5 Newton as well. We bought nine weights, range from 10 grams to 100 grams, to be the balancer. They will be hang on the extension part on one side of the lever. By adjusting the number of weights, we could balance the lever.
- Disk: To make sure that the motor can drive the disk, we used a motor with relatively large torque, which is 3.65 N·m. Since the lengths in the design are all within 30 cm, the motor can easily drive objects of 12 Newton weight. The weight of the disc can hardly go beyond 1 kilogram, thus the motor can definitely bear the weight.
- Motor: We bought stable voltage source which outputs 24 V DC voltage to charge the motors we use. After testing by connecting the charger and the motor, we confirmed that the charger could work.
- Transport Belt: In order to meet the requirement of controlling the friction points at all distances on the disc, we used a conveyor device larger than 20 cm, with a total length of approximately 25 cm. After weighing, the load of the motor driving the transport belt is about 1 kg. We chose a motor with a torque of 7 N·m, since the length of the transport belt is 25 cm, according to the torque equation, the minimum force that this motor can load is 20 Newton, which is much greater than the force we need. Thus, we verify that the transport belt can move all the objects on it.

4 Costs

- Labor Fee: After careful discussion in our project group, we decided that every of us works for the project voluntarily. No one poses a request for a salary. Thus, we can save some budget for buying equipment, materials and all the other stuff we need to complete the project.
- Parts Fee:

Name	Material	Labor Time/day	#	Cost/RMB
Motor	/	/	2	596
Motor Driver	/	/	2	538
Chassis	Aluminum	5	1	240
Ball	Aluminum	3	1	330
Barrier	barrier	5	1	240
Total	/	/	/	1647

Table 1: Parts Fee.

5 Schedule

In March, we have been making theoretical efforts on the entire project, including reading papers, designing drawings, modeling, and so on.

In April's first two weeks, we bought and produce all the parts we need and tried to complete the upper part of our platform, which includes the lever, the ball, loads and the force sensor. We also learned how to control the force sensor through connecting it to a PC. In April's third week, we completed the lower part, which includes the disc, motor and the moving part. Additionally, we learned how to use the motor and write driver for them. During the last two weeks before final demo, we tested our prototype, fixed it if there's any bug and improved its stability. In the team, the student from Mechanical Engineering major is responsible for modeling of all components and producing some of them in the laboratory. The students from Electrical Engineering major are responsible for the design and development of the PCB board to control the motors and making the motors work properly. The Electrical and Computer Engineering student writes all codes needed by the software system.

6 Uncertainties, Future Work and Ethics

6.1 Uncertainties

- Amplifier

  The multiplier knob and zeroing knob of the amplifier are too sensitive, causing the case that a slight rotation to result in a huge change in the outcome.

- Mechanical Design

  The dynamic subsystem must be the one that poses a risk to the success of our project. The first problem is that the sample material on the disc must be changeable because it's the material to be tested, which makes its volume and weight variable. However, the motor that spins it cannot be changed easily. Thus, if the user puts some heavy samples on the disc, the motor may not be able to make it move because it cannot provide enough torque. Another problem is related to the transport belt. We use it to make the motor and disc move horizontally, but we cannot stick them on the belt. Therefore, if the force from the belt is too heavy, those things won't be stable and they will fall, causing damage. Meanwhile, the lever mechanism, made from 3D printed material, has been observed to deform when the disk rotated and frictional forces are applied. Friction force vector is no longer perpendicular to the sensitive axis of the force sensor.

6.2 Future Work

We will first replace all 3D printed parts with aluminum materials to increase component strength, reduce shaking and internal distortion to improve result's accuracy. Meanwhile, we will redesign the amplifier, mainly to make the internal sliding rheostats less sensitive, or to design a locking function for the knobs to prevent them from being accidentally changed.

6.3 Ethics

If our platform causes harm to anyone, we will compensate and apologize accordingly.We believe our platform has very few security risks. The loads' weight of our platform is too small to cause any damage to the user. The spinning speed is also too slow to hurt the user. The voltage needed for the electrical components is too low to cause any substantial harm. We could add some warning marks on the display unit or on the platform to tell users how to operate the platform properly. Our platform may need to collect data from users to see what weights, speeds, and materials they generally use to improve the platform. In addition to this, we will never cause any privacy breach of our users. Our platform also won't have any problems with fairness and discrimination.

7 Conclusions

We have successfully built a workable and precise tribometer with a limited budget. The platform is easy to use and to be transported. There are still some places that can be improved for the platform. Firstly, all the individual components can be replaced with aluminum, which is more solid than the PLA material we are using, while the overall weight remains almost the same. Secondly, the choice for the motor could be preciser so that the cost of the device will be much lower than now.

If we are able to improve the precision of the platform and lower its manufacture cost, we believe the design can be put into use in mechanical laboratories and factories.

References

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[2] e. a. Mahmud Dayang nor Fatin, "Influence of Contact Pressure and Sliding Speed Dependence on the Tribological Characteristics of an Activated Carbon-epoxy Composite Derived From Palm Kernel Under Dry Sliding Conditions.," *Friction, vol. 7, no. 3*, pp. 227–36, May, 2018.

Appendix A Requirement and Verification Table

Requirements	Verification
Lever System 1. When there is no load, the lever must be balanced with the weight of the ball and force sensor, which is in total around 590 grams	1. When choosing the weight for the ball and the balance load, make sure they satisfy the equation: $F_{ball} \times L_{ball} = F_{load} \times L_{load}$
Disk 1. The disc's weight must lie within the maximum force capacity limit of the motor. Its weight is around 150 grams	1. When producing discs of new materials, calculate its weight by the equation: $W = \pi \times r^2 \times h \times \rho$ r is the radius of the new disc, around 10 cm, h is its thickness, and p is the density of the material.
Motor 1. The power source for the motor must be 23V to 25V DC to make it work normally	1. Every time before starting up the motor, check the power source to see if it has been set correctly.
Transport Belt 1. The length of the belt should be longer than the diameter of the disc, which is 20cm 2. The motor that drives the belt must be able to stand the weight of all the stuff on it, approximately 10 N	1. When producing the belt, set its length longer than 20 cm, best length is 25 cm 2. Use motor with relatively large torque, around 5 Nm.

Figure 11: Requirement and Verification Table

Appendix B Data Table

Components	Data
Transport Pipe	Length: 200 mm
Lever (balancer side)	Length: 250 mm
Lever (load side)	Length: 190 mm
Disk	Radium: 100 mm Weight: 150 g
Motor (disk)	Torque: 3.65 Nm Weight: 550 g
Motor (transport)	Torque: 7.14 Nm Weight: 650 g
Force Sensor & Ball	Length (Sensor): 130 mm Weight: 600 g

Figure 12: Data Table