Design of Centrifuge System with Digital Control Based on Microprocessor

Dhruv Patel
Computer Science and Engineering
Indian Institute of Technology, Gandhinagar
Gandhinagar, India
patel.dhruv@iitgn.ac.in

Kush Patel
Mechanical Engineering
Indian Institute of Technology, Gandhinagar
Gandhinagar, India
patel.kush@iitgn.ac.in

Patel Vrajesh
Electrical Engineering
Indian Institute of Technology, Gandhinagar
Gandhinagar, India
patel.vrajesh@iitgn.ac.in

Prithviraj Shaw
Material Science and Engineering
Indian Institute of Technology, Gandhinagar
Gandhinagar, India
prithviraj.shaw@iitgn.ac.in

R Yeeshu Dhurandhar
Electrical Engineering
Indian Institute of Technology, Gandhinagar
Gandhinagar, India
r.yeeshu@iitgn.ac.in

***Abstract*—The process of centrifugation covers a wide range of laboratory and industrial applications. The method is used to separate the dissolved particles of a solution on the basis of their viscosity, shape, size, and density. It is used to separate a mixture that contains two different miscible liquids. Centrifugation takes advantage of the different densities of the two liquids, and thus achieves the separation. The technique is also used to help analyze macro-molecules and their specific hydrodynamic properties. Another application of centrifugation is the fractionation of numerous sub-cellular organelles and the analysis of membranes. Aside from the applications mentioned above, centrifugation is used in many more real-world scenarios such as to collect cells, precipitating DNA, purifying virus particles, and many more. In this course, we have designed a robust centrifuge system that can be controlled using Arduino. The main objective of our work was to design a speed control centrifuge system that can reach upto 10000rpm.**

***Index Terms*—Centrifugation, Hydrodynamic properties, Fractionation, Sub-cellular Organelles**

I. Introduction

Centrifugation is a mechanical procedure that separates mixture components based on density and/or particle size by applying a centrifugal force field. It is intuitively clear how centrifugation-related particle behaviour is governed. In today's world, centrifuges are often utilised in a wide range of fields, from large-scale business operations to laboratory-scale scientific investigation. Its applications include everything from the commonplace, large-scale dewatering of coal particles to the supply of a crucial tool for scientific research [1]. In principle, there are three different types of centrifugation techniques as illustrated in Fig. 1

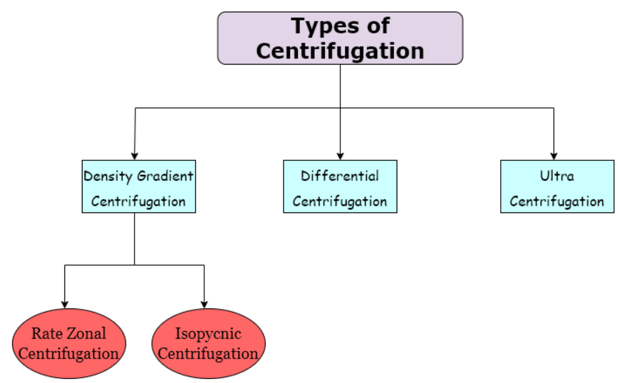

Fig. 1. Types of Centrifugation Processes

A. Density Gradient Centrifugation

It is used to separate sample containing molecules in a highly dense medium. It uses substrates sucrose and glycerol to develop the density gradient. The sample should be stored in a uniform mixture for some time before we send it for Density Gradient Centrifugation. It is further classified into two types.

Rate Zonal Centrifugation: The particle separation occurs depending on their velocity. The rate of segmentation depends upon the mass and shape of the particles. It uses high density sucrose (5% to 20%) to create density gradient.

Isopycnic Centrifugation: The particle separation in this type of centrifugation is independent of their shape and size. The segmentation of particles depend on the buoyant density. As evident, it is used for particles having the same size. Around 20% to 70% sucrose is used to generate density gradient.

B. Differential Centrifugation

This method utilizes the differences in the sedimentation rate of the particles which majorly depends on the mass, shape, and density. It is generally a slow process and it collects larger molecules at the bottom and lighter at the top. The centrifugal force is slowly increased with time which adds up to overall time of centrifugation.

C. Ultra Centrifugation

This is one of the most powerful centrifugation techniques available. It can separate the most minute of particles in the solution. Also the time taken for the centrifugation process to complete is much less than the other two types for a given solution. This is because it involves very high rpm of around 60000 for separation.

II. Background

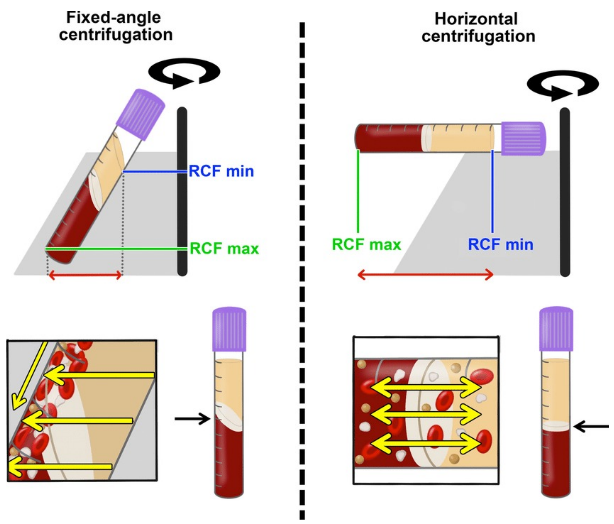

Fig. 2. Types of Centrifuge Designs [3]

Over the past decade, several Centrifuge designs have been proposed for centrifugation process. The two major designs for the centrifuge are the **Fixed Angle Rotor** and the **Swing-out Rotor**. The Swing-out type is also referred as horizontal rotor centrifugation. The working of fixed angle and horizontal rotor centrifugations is shown is Fig. 2. As it is evident the figure that for the given power the centripetal force experienced by the fixed angle rotor will be less as compared to the swing-out rotor (the mathematical explanation to the same is as shown in the below equations). However, the segmentation of the particles in the swing-out rotor is not inclined and hence it is easier to take them out from the test-tube as compared to the fixed angle rotor.

Let P denote the power given to the system and τ denote the torque on the rotor rotating at angular speed ω. Then the the relation between the three is given as

$$P = \tau * \omega$$

. Since for the swing-out rotor, the Moment of Inertia(I) will be higher, as more mass of the rotor will be far from the axis of rotation. This will increase the torque τ which is directly proportional to I. But since, we have constant power, the ω will decrease which will ultimately lead to fall in the centripetal force(F) given by

$$F = mass * r * \omega^2$$

. Clearly, there is square dependence of centripetal force with the ω. Hence, there will be significant reduction in the centripetal force. However, we will get much precise separation in case of swing-out rotor. Hence, industry is moving towards this solution though the swing-out rotors are not mechanically strong enough to sustain high angular speeds. However, in this course we have designed a fixed angle rotor based centrifuge system.

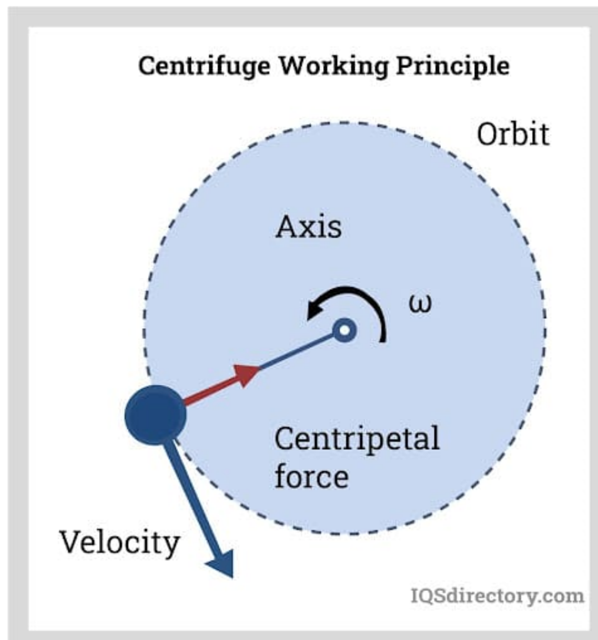

Fig. 3. Centrifuge Working Principle [2]

III. Methodology

As we know, in a centrifuge system, there is a rotor that is mounted on a motor, rotates at a certain rpm by giving power to the motor, and a mixer of liquid differentiates into its original liquids based on its densities as a result of radial acceleration. Here, our objective through this project is to control the motor's rotation using a micro-controller, set it to a certain high rotation, and try to sustain the whole system. The whole system contains electrical and mechanical components. The electrical part of our centrifuge consists of a motor driver, a motor, an Arduino, an encoder, and a laptop. The mechanical part of the centrifuge included the body, a rotor, and shafts. The power flow diagram is shown in Fig. 4. Note that the motor driver requires a 48V DC voltage hence we add a SMPS that converts 220V AC voltage signal to 48V DC signal. Also note that the encoder in the feedback ensures that the motor is actually rotating at desired angular speed. Through an interface, we control the Arduino that ultimately controls the motor driver that drives the motor/rotor at different angular speeds by changing the voltage supplied to the motor. These points are discussed in detail below.

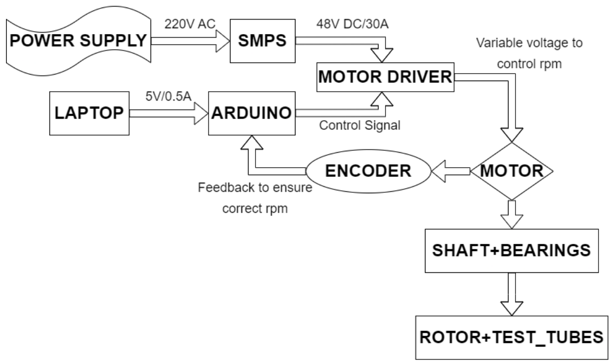

Fig. 4. Energy Flow Diagram

The Switch Mode Power Supply(SMPS) supplies a rated DC voltage and current that can be used to drive the motor driver. The motor driver cannot sustain AC power supply, hence we need SMPS. The software part of the centrifuge consists of a coded Arduino. The code will ask for some parameters, such as the value of the rpm at which a user wishes to rotate the rotor and the time required to achieve the given rpm as input from a user. The code is uploaded from the laptop to the Arduino microcontroller board. Arduino is connected to the motor driver that runs a motor based on the command coming from the Arduino board. Motor drivers will drive the motor in such a way that it attains a high rpm at the given time. The motor driver gives high power to the motor by using a small voltage signal from a microcontroller or a control system. There is also a feedback loop present in the system, as shown in the figure. The feed back loop is encountered using an encoder. An encoder measures a rotor's rotation speed and gives the signal back to the Arduino, and based on this signal, the Arduino will give the command to the motor driver. This loop will continue to run until the rpm reaches its desired value. The tubes with suspensions and immiscible liquid will be fixed on the rotor.

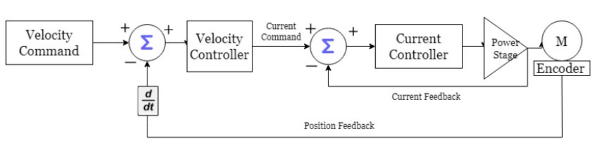

Fig. 5. Control Algorithm [4]

As we can see in Fig. 5, we have implemented closed loop control algorithm. The motor controller is a cascaded style velocity and current control loop. Each stage of the control loop is a variation on a PID controller. A PID controller is a mathematical model that can be adapted to control a wide variety of systems. This flexibility is essential as it allows the motor driver to be used to control all kinds of mechanical systems. Here, the velocity controller, current controller and power stage are the essential parts of motor driver. In velocity control loop, there is a velocity feedback and in current control loop, there is current feedback. Encoder is attached to the motor which gives the information of the position of the shaft of the motor but using derivative function, we are converting position into velocity for velocity feedback. Initially, we gives velocity command using a laptop to Arduino. This command gets added by negative of previous velocity. Then, this combine input goes to the velocity controller. This controller gives the current command towards the further system. Now, this output is again gets added by negative of previous current. Then, this combine input goes to the current controller. The current controller is regulate the current value and change the duty cycles. This change leads a power stage to regulate the voltage value according to the requirement of the motor. This voltage is directly given to the motor. Here, load is applied on the motor in terms of rotor. This control algorithm makes sure that whatever the user gives the required velocity command, the motor rotates at that velocity. So, this is how the whole control loop is working.

IV. Numerical Analysis

$$\tau = I \times \alpha$$

Here τ is the torque, I is the moment of inertia and α is the angular acceleration. Let's assume our rotor system to be a disc with a total weight of 2.5 kg.

$$\Rightarrow \tau = \frac{MR^2}{2} \times \frac{\omega}{t}$$

Here ω is the angular velocity and t is the time taken to achieve the maximum input RPM in seconds.

$$\Rightarrow \tau = \frac{2.5}{2} \times 10^{-2} \times \frac{w}{t}$$

We want to achieve a target speed of $10,000$ revolutions per minute, so we will have the value of $omega$ to be $10,000$.

$$\begin{aligned} \Rightarrow \tau_{\text{max}} &= \frac{2.5 \times 10^{-2} \times 10^4 \times 2\pi}{60t} \\ &= \frac{13.085}{t} \end{aligned}$$

If we assume that the rotor takes ten seconds to reach the required maximum speed, then we can substitute t with 10.

$$\tau_{\text{max}} = 1.308 \text{ N} \cdot \text{m}.$$

Approximate power required to rotor

$$P = T \cdot \omega$$

$$\Rightarrow P_{\text{max}} = 1.308 \times \omega = 1.308 \times \frac{2\pi \times 10^4}{60}$$

$$\Rightarrow P_{\text{max}} = 1370.25 watt$$

The power rating of our motor is 270KV implies motor will rotate with 270 RPM per voltage. The max voltage rated for our motor is 48V, hence the maximum achievable RPM through this motor is 12960.

Note, the maximum speed mentioned is at no load. The characteristic curve of the BLDC motor revals that even at full load, which is 2.5 kg in our case, the motor will be able to achieve the max rpm by adjusting the torque requirements.

V. Proposed Design— **Link to Working model**

Fig. 6 shows the Computer Aided Design(CAD) model of the proposed Centrifuge system. The motor is placed over a base below which the encoder is attached. The SMPS which will provide the signal to the motor-driver is attached at the right side of the motor-rotor assembly to minimize the area occupied by the system. The rotor is not directly mounted on the shaft to ensure that the load on the shaft is minimal. Hence we have connected the bearings. These bearings will ensure that the load of the shaft is equally distributed over the designed platform.

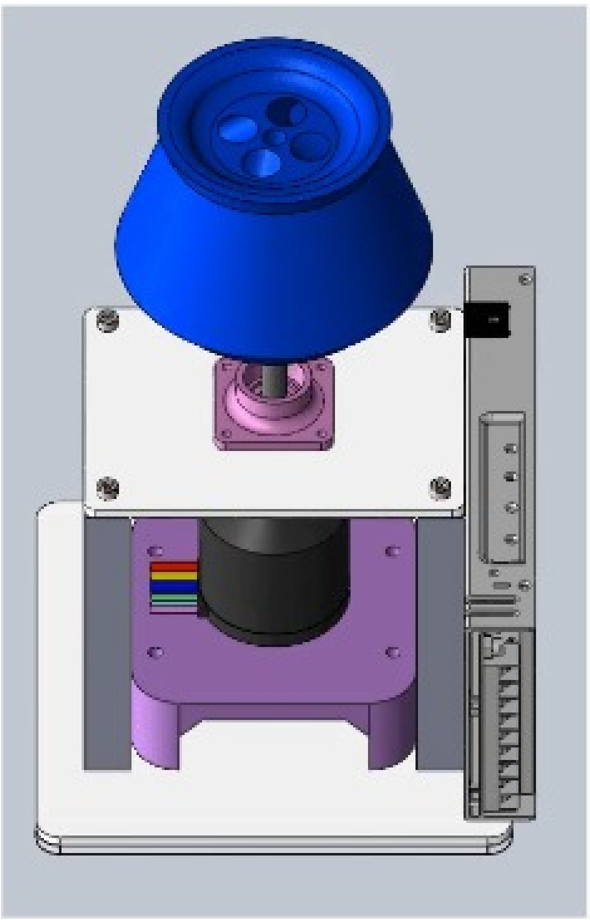

Fig. 6. CAD Model of the proposed Design

Prototype 1:
Fig. 8 shows the first prototype. It is static and made to check the mutual dimensional compatibility among different components.

Prototype 2:
Fig. 9 shows the second prototype. It is made to test out the speed-controlling algorithm. Users can vary the speed by varying the input to the laptop.

Prototype 3:
Fig. 10 shows the third prototype. The rotor is attached to

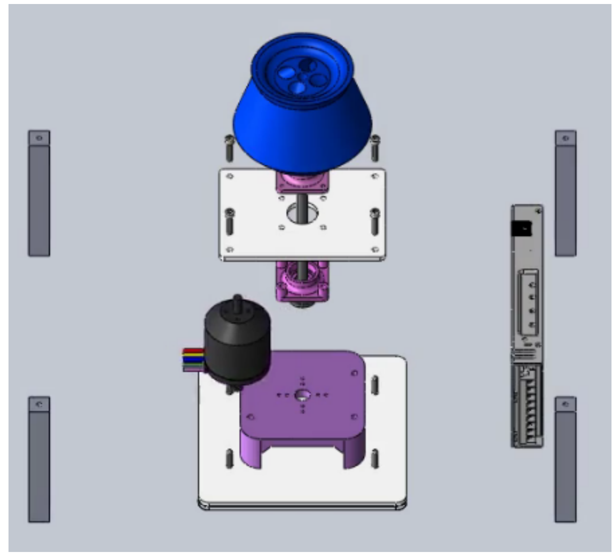

Fig. 7. CAD Model of proposed Design (Exploded view)

the motor, and it rotates with motor and speed can be varied.

VI. Conclusion

At the completion of our project, we were able to assembled the whole centrifuge system and were also able to control the motor speed using arduino. Moreover, it can also be concluded that BLDC motors are among the best choices for such types of centrifuge design. The current design of the centrifuge controls the speed via laptop (wired), but it can be enhanced and the control system can be made fully wireless using bluetooth/wifi modules present in nodeMCU.

VII. Acknowledgement

In the accomplishment of completion of our project on **'Centrifuge System with Digital Control Based on Microprocessor'** we would like to convey our special gratitude to Mr. Gopinadhan Kalon, Assistant Professor, Physics Department at IIT Gandhinagar. Your valuable guidance and suggestions helped us in various phases of the completion of the project. We will always be thankful to you in this regard. We would also like to thank Naman Vyas and Shubhankar Riswadkar, Member of Mechanical Research Lab for their continuous motivation and support. Special thanks to Prof. Harish PM for letting us use the resources of Mechanical Lab and Prof. Rajendran for his guidance.

VIII. Contributions

Patel Vrajesh: Majorly contributed in research of components, assembly of the whole system, mid-semester presentation, and report, end-semester presentation and report, idea conceptualization. Minor contribution to CAD drawings.

Kush Patel: Contributed towards the literature review, research of components, numerical analysis, coding, CAD drawing, mid-semester report, end-semester presentation, and

Fig. 8. Prototype 1

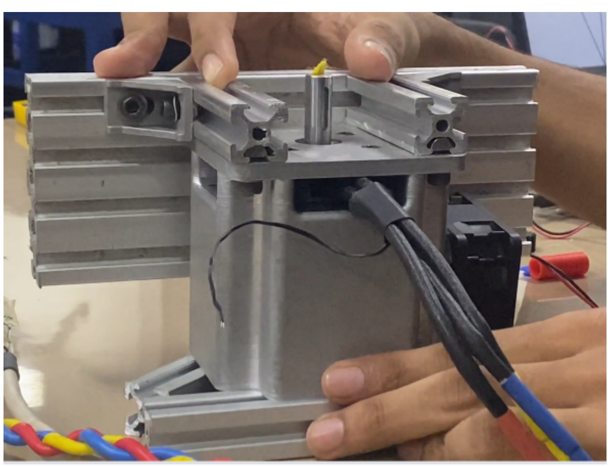

Fig. 9. Prototype 2

report.

Dhruv Patel: Majorly contributed towards the numerical analysis part and 3D printing of the components. Minorly contributed towards literature review, research of components, CAD drawings, mid-term/end-term report and presentations.

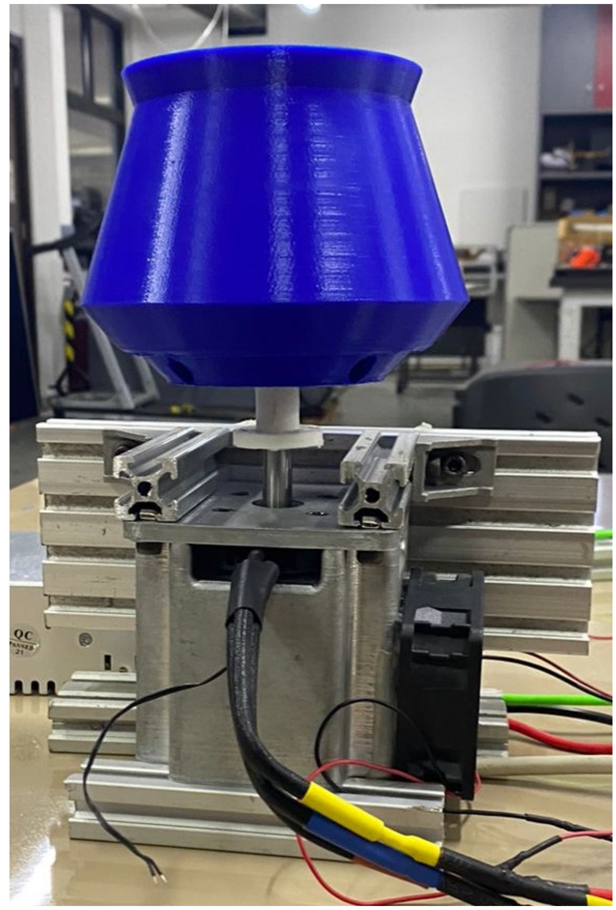

Fig. 10. Prototype 3

R Yeeshu Dhurandhar: Contributed in 3D printing, coding, CAD drawing, idea conceptualization, mid-semester report, and presentation. Minor contribution to the research of components, end-semester presentation, and report.

Prithviraj Shaw: Contributed to the literature review, research of components, rotor design, mid-semester report, and presentation, and working on an alternate design of the system.

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