Pulse Width Modulation Driven Brushless Direct Current Motor Speed Controller

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Abstract- Brushless Direct Current (BLDC) motors are universally used in industrial and domestic applications owing to their high efficiency, reliability, compact design, and low maintenance. Conventional Hall-sensor-based BLDC motors provide precise rotor position detection feedback and closed-loop regulation. These techniques commonly lead to problems such as the nonlinearity of motor properties, complexity, and higher system costs. Moreover, the non-appearance of mechanical commutators in BLDC motors requires innovative microelectronic control systems for commutation and drive regulation. This paper presents an effective method via Pulse Width Modulation (PWM) driven BLDC motor speed controller. The developed system uses an ESP32-WROOM microcontroller for wireless control and includes components such as an Infrared (IR) sensor, Electronic Speed Controller (ESC), and a 16X2 LCD display for better monitoring, control, and speed measurement. The proposed technique is anticipated to provide a cost-effective, flexible, and reliable solution for advanced motor control systems.

Keywords– Brush-less DC Motor (BLDC), ESP32-WROOM, Infrared Sensor (IR), Electronic Speed Controller (ESC). I2C LCD Module, 16X2 LCD Display.

1. INTRODUCTION

The rapid growth of power electronics, embedded systems and automation technologies has strongly influenced the control and design of modern electrical machines used in industrial drives, electric vehicles, drones, robotics and household appliances. Among the different motor technologies available, Brush-less DC (BLDC) motors have emerged as a highly preferred choice due to their compact structure, high efficiency, low acoustic noise and reduced maintenance compared to conventional brushed DC motors [1]. By eliminating mechanical brushes and commutators, BLDC motors significantly reduce friction and sparking which leads to improved reliability and longer operational life. However, this mechanical simplification shifts the complexity toward the electronic drive and control system which must manage commutation, torque generation and speed regulation with accurate timing. Traditional BLDC drives often employ Hall-effect sensors or encoders for rotor position detection but these solutions can increase overall system cost, wiring complications and sensitivity to installation errors or electromagnetic interference, especially in low-budget and educational setups [2]. Therefore, there is a significant requirement for regulation that retain the performance advantages of BLDC motors while minimizing hardware overhead and implementation difficulty. To meet these requirements, Pulse Width Modulation (PWM) based speed control has become a widely adopted approach because it allows efficient regulation of the effective voltage applied to the motor without experiencing significant power losses. When PWM control is combined with modern microcontrollers, it becomes possible to create compact systems that integrate drive control, sensor interfacing and user interaction within a single platform [3]. In conventional low-cost BLDC arrangements, Electronic Speed Controllers (ESC) are frequently used, but many of these setups only provide basic throttle input without integrated speed feedback, data display or wireless connectivity. As a result, users often lack real-time information about motor performance parameters such as speed or load response. Furthermore, external sensing and monitoring circuits, when added separately, can complicate the overall wiring and timing coordination [4].

In this System, a BLDC motor speed control and monitoring system is developed using an ESP32-WROOM microcontroller as the central control unit. The BLDC motor is driven through an ESC, while an infrared (IR) sensor is employed to measure the rotational speed by detecting the passing of motor blades or markers. The measured speed data is processed by the ESP32 and displayed on a 16×2 LCD module interfaced via the I2C protocol, providing clear and immediate feedback to the user. At the same time, PWM signals produced by the microcontroller regulate the ESC input to attain the desired motor speed, enabling smooth and precise control. The built-in Wi-Fi capability of the ESP32 further allows the implementation of wireless control and web-based monitoring, offering greater flexibility than conventional wired systems. Overall, the proposed setup aims to deliver a cost-effective, compact and user-friendly BLDC control platform that combines PWM-based drive regulation, sensor feedback, display functionality and wireless interaction, making it suitable for academic demonstrations, small-scale prototypes and embedded control learning environments [5].

2. PROBLEM STATEMENT

Conventional BLDC motor speed controllers are Hall sensors or encoders based which provide accurate rotor position detection and closed-loop control. So, this system requires specialized motor control hardware, separate signal conditioning circuits, and complex firmware algorithms [6]. Due to this overall system cost, design complications, and development time increases. Hence, these outdated approaches are often not suitable for academic laboratories, small scale prototyping, and low budget research environments.

Other limitation in existing low-cost BLDC motor speed controller setups is the lack of integrated real time monitoring and wireless control abilities. Standard ESC based motor systems generally allow throttle control but do not provide built-in speed feedback, IoT connectivity, or remote monitoring interface [7]. It is challenging to maintain system stability while integrating external sensing mechanisms, especially when using Wi-Fi enabled microcontrollers which simultaneously handle PWM generation, interrupt-based sensing, and network communication. Considering reliable operations without signal interference, timing instability or missed pulses becomes a critical design concern.

3. PROPOSED SOLUTION

This system presents an integrated BLDC motor speed control and RPM monitoring system using a single ESP-32 embedded platform in a cost effective manner. The proposed solution combines PWM based ESC control, RPM measurement using an IR sensor with interrupt-based pulse detection, and wireless web-based interaction within an ESP32 microcontroller. The objective of this system is to minimize hardware complications and decrease whole system charges while considering reliable motor speed regulation, accurate real-time RPM calculation and stable wireless communication. It eliminates the need for dedicated motor control hardware and multiple sensing circuits. The design focuses on simplicity, efficiency and ease of implementation [8][9].

The system achieves speed control through PWM signals produced by the ESP32, allowing precise adjustment of the voltage delivered to the BLDC motor through ESC. Wireless connectivity allows users to set and monitor motor speed through a web interface, which overall improving accessibility and flexibility. An IR sensor provides real-time feedback by generating pulses proportional to motor rotation, which are processed using interrupt-based techniques for accurate RPM measurement. The calculated speed is displayed on an I2C-based LCD which reduces wiring complexity and improving system integration. By unifying control, feedback, and monitoring in a compact and scalable design using accessible parts, the proposed solution is well suited for drone experimentation, small electric vehicle, small scale prototypes and embedded motor control education [10].

Figure 1 shows the schematic diagram of PWM-driven BLDC motor speed controller for RPM monitoring.

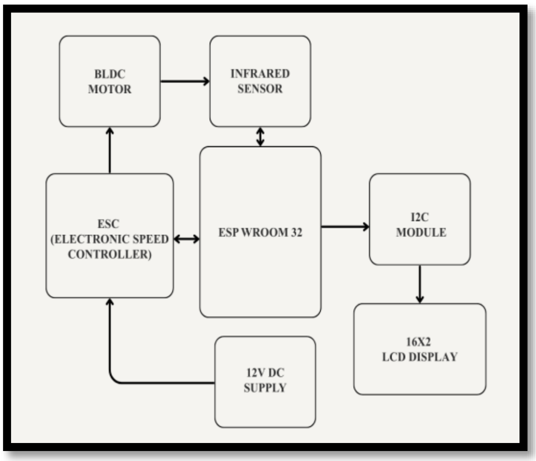

Figure 1: Schematic diagram of PWM-driven BLDC motor speed controller

4. DESCRIPTION OF COMPONENTS

The suggested BLDC motor speed controller and RPM monitoring system is developed via numerous hardware modules that work together to perform motor control, sensing, communication, and display functions. The ESP32 microcontroller acts as the main controller of the system, generating PWM signals to control the motor through the Electronic Speed Controller (ESC). An infrared sensor is comprised to detect the mechanical rotary motion of the motor shaft, while a 16×2 LCD module displays the calculated RPM and system status. An I2C interface module simplifies communication between the ESP32 and LCD display. The entire system is powered using a rechargeable 11.1V/12V Li-Po battery pack, ensuring portable and established supply unit for all components.

List of Components

1. ESP32-WROOM Microcontroller Module.
2. Brushless DC (BLDC) Motor (A2212/13T).
3. Electronic Speed Controller (ESC).
4. 16×2 Liquid Crystal Display (LCD).
5. Infrared (IR) Sensor (HW-201).
6. I2C LCD Interface Module.
7. 12V DC Power Supply.

The section below elaborates the specifications and functions of the key components in the system.

a) ESP32-WROOM: ESP32-WROOM is a popular Wi-Fi and Bluetooth-enabled microcontroller module manufactured by Espressif Systems. The module integrates the ESP32 which contains a dual-core Xtensa LX6 32-bit processor running at up to 240 MHz frequency with 520 KB of on-chip Static RAM, 448 KB ROM, and external SPI flash memory for program storage and It provides the platform for wireless connectivity and sensor interfacing in this BLDC motor control System [11].

The board features 38 GPIO pins with multiple functions including 18 digital I/O channels (16 PWM-capable), 12-bit SAR ADC channels, 2x8-bit DAC outputs, SPI, I2C, UART, and I2S interfaces for peripheral connectivity. Built-in Wi-Fi (802.11 b/g/n up to 150 Mbps) and dual-mode Bluetooth (Classic + BLE) eliminate the need for external wireless modules. The ESP32-WROOM-32 can be programmed using three different software frameworks: the ESP-IDF framework, the Arduino IDE, or Micro Python. Programming is accomplished through a USB-to-UART interface, which connects to the module via either a USB Type-C or Micro-USB cable [12].

Figure 2 shows the configuration of PIN of the ESP32-WROOM-32 module illustrating the GPIO pins, ADC channels, communication interfaces, and power pins allocated for peripheral with external devices.

b) Brushless DC Motor: BLDC motor produces mechanical rotary motion from electrical energy via commutation. Unlike traditional brushed DC motors with mechanical brushes and commutators, the BLDC motor uses permanent magnets on the rotor and electronically switched stator windings to create rotating magnetic fields that produce continuous shaft rotation. The ESC precisely times the current flow through three stator phases to maintain smooth operation without physical contact between rotor and stator. The A2212/13T model is designed to deliver up to 150W of continuous power output. With a motor constant (kV) of 1000 RPM per volt, this motor accelerates in direct proportion to the input voltage. These specifications make it well-suited for tenders that mandate high efficiency and require precise control over motor speed.

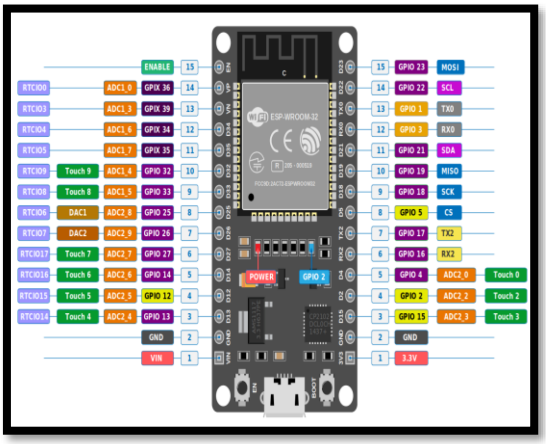

Figure 2: PIN Diagram of ESP32-WROOM

Figure 3 shows a BLDC motor used in the system.

c) Electronic Speed Controller: ESC is an electronic circuit which contain switching devices that receives DC electrical power and generates the output of controlled three-phase AC output to drive BLDC motors. The ESC accepts standard servo-style PWM input signals where pulse width (typically 1-2 milliseconds at 50Hz) which determines the motor speed. Internally, the ESC decodes these timing signals and switches power transistors arranged in a three-phase bridge configuration to energize stator windings in precise sequence, creating revolving magnetic field that relates with permanent magnets on the rotor to produce continuous rotary motion and a voltage regulator IC (AMS1117) was used to step down the voltage to approximately 3.3V, making it suitable for powering the ESP32 [13].

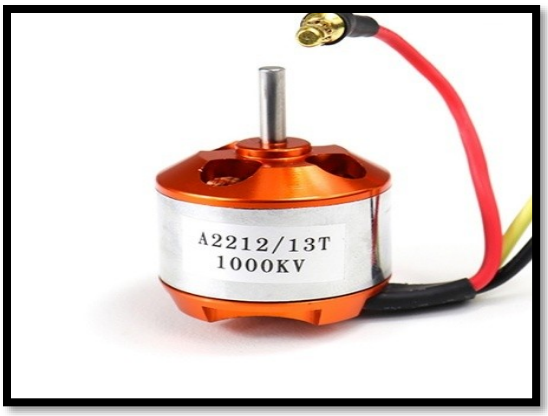

Figure 3: Brushless DC Motor

Figure 4 shows the ESC used to control the BLDC motor.

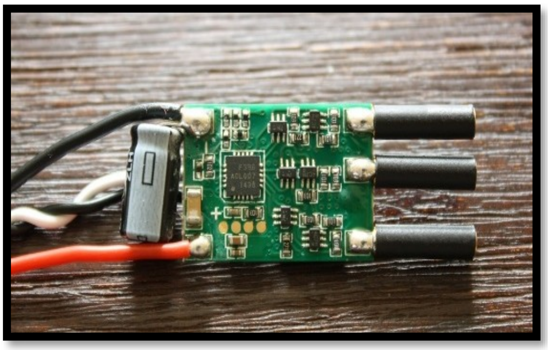

Figure 4: Electronic Speed Controller

d) Liquid Crystal Display: The 16×2 LCD Display is that classic little screen you hook up to microcontroller Systems when you need to show numbers, text messages, or basic information and it have two rows with 16 characters each,32 spots total and where every character is actually a tiny 5x7 grid of LCD dots controlled by an HD44780 chip. The microcontroller sends it commands and data over wires, and the chip lights up the right segments to make letters, numbers, or simple symbols from its built-in font library [14].

Figure 5 represents the LCD module used for displaying RPM of the BLDC motor.

e) Infrared Sensor: Infrared sensor (HW-201) is a microelectronic unit that detects reflective surfaces or measures rotational speed by emission of infrared light and It's mainly consists of two components named as transmitter and receiver. The IR LED transmitter emits near-infrared light and a phototransistor receiver senses the reflected beam from target surface and to know the rotational speed between the motor shaft and sensor, the sensor calculates the frequency of reflections from a reflective mark passing through its detection gap.

The calculation is done as follows: RPM = (Pulse Count × 60) / Pulses per Revolution [15].

Figure 6 presents the IR sensor used for RPM monitoring in the system.

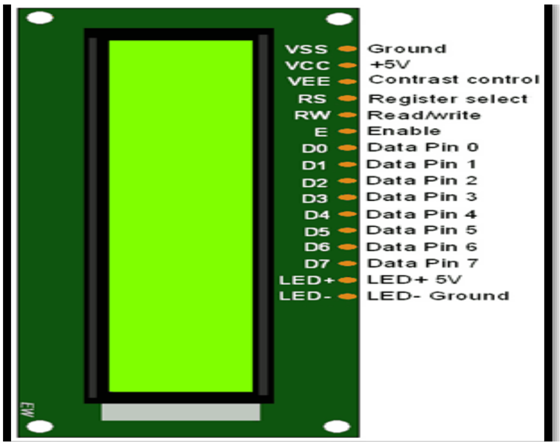

Figure 5: Liquid Crystal Display

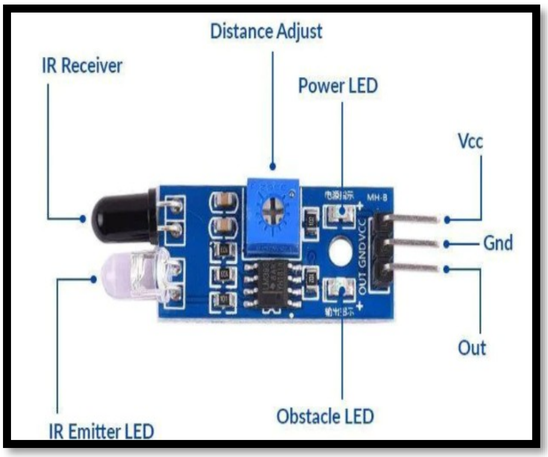

Figure 6: Infrared Sensor

f) I2C LCD Module: I2C Segment is a compact interface adapter module and broadly used to simplify LCD connections in microcontroller Systems. It provides the platform for serial communication between ESP32 and 16x2 LCD displays using just four wires instead of 12 parallel connections. The module has a fixed I2C address, 8 quasi-bidirectional I/O ports mapped directly to LCD data/control pins, and onboard 4.7kΩ pull-up resistors for stable bus operation. The board features clearly marked pins-VCC (3.3V/5V power), GND (ground), SDA (serial data line connected to ESP32 GPIO21), and SCL (serial clock line connected to ESP32 GPIO22) which connect directly to the ESP32 with standard jumper wires.

Figure 7 illustrates the I2C LCD module used for interfacing the LCD with the ESP32.

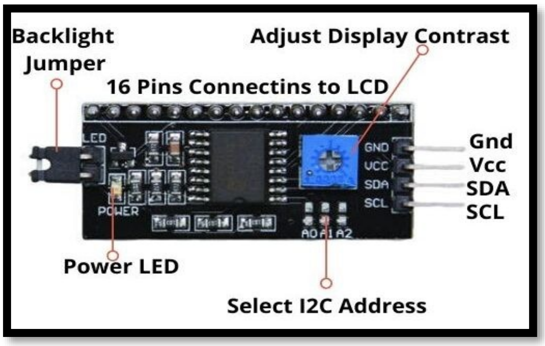

Figure 7: I2C LCD Module

g) 12V DC Power Supply: The 11.1V/12V Rechargeable 3S Li-Po Battery Pack is a high-discharge lithium-polymer power source consisting of three 3.7V cells connected in series, delivering nominal 11.1V output with fully charged voltage reaching 12.6V.And it's mainly used for RC applications and portable electronics, it provides the high current capability required to drive BLDC motors and associated control electronics and for that reasons they're perfect when you need lots of power without carrying heavy weight.

Figure 8 illustrates the 12V DC power supply used to provide power to the system.

Figure 8: 12V DC Power Supply

5. WORKING

The suggested system is intended to control and monitor the speed of a BLDC motor speed controller using an embedded controller and wireless interface. It integrates power management, motor control, speed sensing, and real-time display into a single platform. The system allows the user to remotely set the motor speed through a Wi-Fi connection, while continuously measuring the motor's rotational speed and displaying it on an LCD module for monitoring purposes.

The working of the suggested system is carried out through the following sequential steps.

- Initially, the system was powered by 11.1V/12V Rechargeable 3S Li-Po Battery Pack that supplied voltage to the ESC and other control components get supply form a voltage regulator IC (AMS1117) was used to step down the voltage to approximately 3.3V, making it suitable for powering the ESP32.

- When the system was switched on, the ESP-32 microcontroller established a wireless connection with a mobile device via Wi-Fi, allowing the user to set the desired motor speed remotely.
- Based on the user input, the ESP32 generates PWM signals and transmits them to the ESC.
- The ESC converts the direct current signal into a controlled three-phase output and drives the BLDC unit at the required speed.
- As the motor rotates, the infrared sensor send an infrared light waves through it's transmitter which reflections from the rotating surface and received by sensor receiver and generates pulses corresponding to each revolution.
- These pulses were received by the ESP-32, which calculated the motor speed in terms of RPM.
- The processed data were then sent to the LCD module through the I2C communication protocol.
- The LCD displays the real-time RPM and system status, thereby enabling easy monitoring the performance of motor.

Figure 9 illustrates the circuit diagram of the suggested model, showing the interfacing of all components with the ESP32 and the BLDC motor.

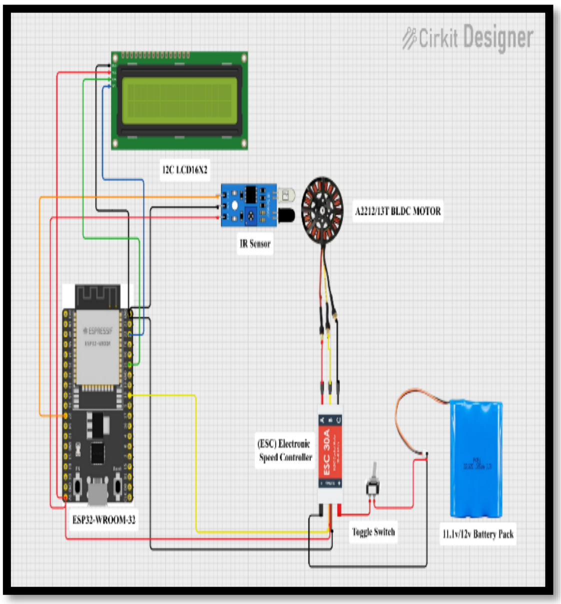

Figure 9: Circuit Diagram of the Working Model

6. RESULTS AND DISCUSSION

The aim of the ESP32-Based BLDC Motor Speed Control project is to design and implement a cost effective, integrated solution for real-time motor speed adjustment and monitoring. The system uses an ESP32 microcontroller to produce PWM signals for monitoring an ESC which controls the BLDC motor. An IR reflective sensor detects shaft rotation and significant pulse variations are used to calculate RPM through interrupt-based counting. The system successfully achieved stable motor control and accurate speed estimation along with wireless monitoring through a web interface.

The key outcomes and system performance observations are summarized as.

- The LCD shows real time motor speed percentage and calculated RPM according to the controller's response.
- The PWM generation mechanism enables smooth throttle control and stable motor operation across different speed levels.
- The interrupt-driven IR sensor measures shaft rotation and provides accurate pulse feedback to the ESP32.
- The web server interface allows wireless speed adjustment to users and monitor RPM in real time through a browser.
- The ESC ensures safe, smooth and efficient motor commutation.
- When the motor is running, the system continuously updates speed and RPM values which demonstrates reliable multitasking of PWM generation, interrupt handling and Wi-Fi communication.

The figure 10 shows the web-based control dashboard accessed via the ESP32's WiFi access point, displaying real-time motor speed in RPM values along with a "SET SPEED" button for user input.

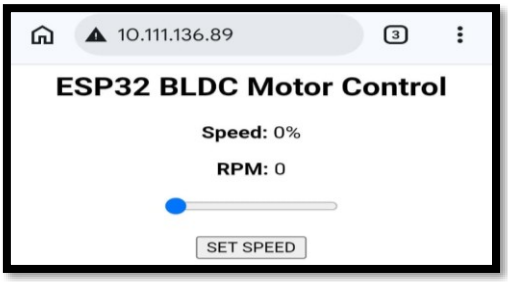

Figure 10: Web interface Display

The figure 11 illustrates the complete working model integrating all hardware components-ESP32 microcontroller, I2C LCD module, IR sensor for RPM detection, BLDC motor with ESC driver, and LiPo battery-interfaced seamlessly on a single breadboard platform.

The figure 12 illustrates the real-time RPM measurement displayed on the LCD screen with the help of the ESP32 WROOM module, where the speed is set by user input on the mobile screen.

7. CONCLUSION

The main contribution of paper is by eliminating Hall sensors; the project significantly reduces circuit complexity and minimizes physical failure points, resulting in a cleaner, more reliable hardware design. This sensorless approach lowers the overall costing by reducing the bill of materials, making it a highly economical solution for small-scale applications. Instead of relying on extra hardware, the system leverages the ESP32's processing power to handle commutation through firmware, demonstrating a sophisticated and cost-effective balance between hardware simplicity and advanced software control.

The suggested BLDC motor speed controller automatically adjusts motor speed using PWM and shows live RPM readings no manual tweaking needed. In contrast to traditional techniques utilizing Hall sensors or costly encoders, our system operates more swiftly, is significantly cheaper, consumes less energy, and provides results more rapidly. All parts like the A2212 motor, ESCs, and ESP32 boards are easy to buy anywhere. The percentage error of BLDC is 5.5% at full-load for rated speed of 12,000 rpm. The design is simple too, so it can be used for large projects without spending much money first. It runs great whether you're testing in a lab or using it for real. In this system, we made a cheap, low-power controller that makes motors work better and safer. The prototype test showed it measures speed right and wireless control works fine. Results prove this new design makes motor systems much more reliable. The tentative cost of this project work is Rs. 4000-4500.

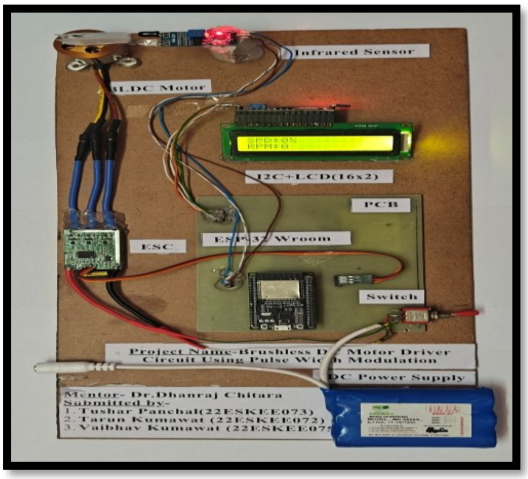

Figure 11: Hardware Model

(a) Motor Operation at 4320 RPM

(b) Motor Operation at 8940 RPM

(c) Motor Operation at 10080 RPM

(d) Motor Operation at 11340 RPM

Figure 12: BLDC Motor Operations at Different RPM Levels

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