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Design & Development of a BLDC Hub Motor Testing Device for Electric Mobility and Industrial Applications

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ABSTRACT

This paper presents the design, development, and application of a Brushless DC (BLDC) Hub Motor Testing Device aimed at evaluating motor performance in electric vehicles, renewable energy systems, and robotics. With increasing dependence on BLDC hub motors across various sectors, the need for reliable testing under dynamic load conditions has become critical. The paper explores the fundamental working principles, essential components, prototyping advantages and challenges, and future innovations such as AI integration and IoT-enabled testing.

1. Introduction

BLDC hub motors are rapidly replacing traditional motors in electric mobility and automation due to their superior efficiency, compact design, and reduced maintenance. As these motors are directly integrated into the wheel hub, accurate testing of their performance becomes essential for ensuring safety, reliability, and optimal energy usage.

2. Literature Review

The increasing adoption of Brushless DC (BLDC) motors in electric mobility and automation has led to significant academic and industrial interest in their testing and optimization. Several works have addressed both the operational characteristics of BLDC motors and the methodologies for evaluating their performance.

3. Fundamental & Design approach

Krishnan (2010) provides a comprehensive foundation on the design and control of BLDC motors, emphasizing their advantages such as higher efficiency, longer lifespan, and lower maintenance compared to brushed motors. Miller (1989) similarly explores the physics behind brushless permanent-magnet motors, providing insights into rotor-stator interactions and electronic commutation techniques.

Hughes and Drury (2019) extend this discussion to applications, highlighting the importance of precision in control systems for variable load scenarios, which aligns with the core objective of the BLDC Hub Motor Testing Device—accurate parameter testing under dynamic conditions.

3.1. Testing Methodologies and Tools

Several researchers have proposed testing frameworks using both hardware and simulation environments. For instance, Wang and Liu (2020) developed an AI-based predictive maintenance model for BLDC motors using real-time sensor data and historical trend analysis. Gupta and Singh (2021) further implemented a digital twin approach to simulate and validate motor behavior in virtual environments, thereby reducing the dependency on physical prototypes. National Instruments and Texas Instruments have released technical documentation emphasizing the integration of DAQ systems with LabVIEW and other control platforms for precise motor diagnostics. Their insights inform the sensor-based architecture of the current testing device.

3.2 Trends in Industry and Standardization

Industry reports such as those by MarketsandMarkets (2023) and Frost & Sullivan (2022) note a sharp growth in demand for smart testing solutions that integrate AI, IoT, and modular design. These trends are evident in new testing devices that support predictive fault detection and cloud-based data storage. Compliance with international standards such as IEC 60034 and ISO 9001:2015 ensures consistency and quality across deployments.Siemens and ABB have published white papers on AI-driven motor testing in industrial environments, stressing the need for fault-tolerant systems, energy efficiency, and sustainability—core features that the proposed device seeks to implement.

4. Proposed Methodologies

The BLDC Hub Motor Testing Device is designed to analyze and ensure the performance, safety, and efficiency of hub motors in electric mobility and industrial applications. This section outlines the methodology followed in designing, fabricating, and testing the prototype.

4.1 Design Approach

The methodology adopted follows a systematic process:
Problem Identification: The need to test BLDC hub motors for real-world performance under varying load, speed, and thermal conditions.
Requirement Analysis: Defining essential parameters to be measured (torque, RPM, voltage, current, temperature, vibration).
Component Selection: Choosing cost-effective, reliable, and readily available components.
Prototype Development: Constructing a functional unit to simulate testing scenarios.
Testing and Validation: Verifying accuracy and repeatability of measurements.

4.2 Hardware Configuration

The key components in the hardware setup include:
Arduino Uno Microcontroller: Central processing unit for sensor data.
Sensor Array: Hall effect sensors for rotor position, digital voltmeter and ammeter for electrical data, and temperature sensors.
Load Bank: Applies varying resistive loads to simulate road or application conditions.
Power Supply Unit: Provides regulated power to the motor under test.
1N4007 Diode: Protects the circuit from reverse polarity
Push Switches: Used to start and stop the motor and testing routines.
Images of these components and their setup were documented and included in the design validation phase.

4.3 Software and Control Logic

The testing system was coded using the Arduino IDE. The logic includes:

- Initialization of sensor pins and serial communication.
- Real-time monitoring of Hall sensor outputs.
- Triggering data acquisition when there's a change in sensor state.
- Outputting values through a serial interface for analysis.

Sample Arduino Code Snippet:

```
// Define sensor pins const int
sensorPin1 = 2; const int
sensorPin2 = 3; const int
sensorPin3 = 4;
// Variables to store previous sensor states int
previousState1 = LOW;
int previousState2 = LOW; int
previousState3 = LOW;

void setup() {
  // Initialize the serial monitor Serial.begin(9600);
  // Set sensor pins as input pinMode(sensorPin1,
  INPUT); pinMode(sensorPin2, INPUT);
  pinMode(sensorPin3, INPUT)
  // Print column headers
  Serial.println("Hall Sensor 1\tHall Sensor 2\tHall Sensor 3");
}
void loop() {

  // Read the state of each sensor

  int sensorState1 = digitalRead(sensorPin1); int
 sensorState2 = digitalRead(sensorPin2); int
 sensorState3 = digitalRead(sensorPin3);
  // Check if there has been a change in the sensor states
```

```
if (sensorState1 != previousState1 || sensorState2 != previousState2 || sensorState3 != previousState3)
{
  // Print the sensor names and their states (LOW or HIGH) Serial.print("Hall Sensor 1: ");
  Serial.println(sensorState1 == LOW ? "LOW" : "HIGH"); Serial.print("Hall Sensor 2: ");
  Serial.println(sensorState2 == LOW ? "LOW" : "HIGH"); Serial.print("Hall Sensor 3: ");
  Serial.println(sensorState3 == LOW ? "LOW" : "HIGH");
  // Update previous states to current states
  previousState1 = sensorState1; previousState2 =
  sensorState2; previousState3 = sensorState3;
}
// Small delay before checking again delay(500);
```

4.4 Parameter Measurement Techniques

Each key performance metric is measured as follows:

Parameter	Method
Torque	Load application and inferred from current draw
Speed (RPM)	Based on Hall sensor signal frequency
Voltage/Current	Digital meters in series/parallel configuration
Temperature	Thermistors or digital sensors
Vibration	Qualitative and mechanical frame observation
Efficiency	Calculated via input vs output power comparison

4.5 Testing Procedure

1. Connect the motor to the testing rig.
2. Initialize the Arduino and DAQ system.
3. Power the system and gradually vary the load.
4. Record real-time data from sensors.
5. Repeat under different speed/load conditions.
6. Analyze data for anomalies, thermal behavior, and overall efficiency.

4.6 Safety and Calibration

- Calibration of sensors was performed before each test cycle using standard instruments.
- Emergency stop buttons were included in the design.
- Electrical insulation, current limiting, and fuse-based protection were used to safeguard components.

List of Components and images:

Arduino uno

1. Voltage / Ampere Meter
2. Diode 1N4007
3. Switches

Arduino uno:

Arduino Uno - Overview, Uses, And Applications Overview:

- **Type:** Microcontroller Board
- **Microcontroller:** Atmega328p
- **Operating Voltage:** 5V
- **Input Voltage (Recommended):** 7–12V
- **Digital I/O Pins:** 14 (6 PWM Capable)
- **Analog Input Pins:** 6
- **Clock Speed:** 16 Mhz
- **Memory:** 32 KB Flash, 2 KB SRAM, 1 KB EEPROM
- **Communication:** USB, UART, SPI, I2C
- **Programming:** Via Arduino IDE (USB)

Uses And Applications:

- DIY Electronics And Hobby Projects
- Robotics (E.G., Obstacle-Avoiding Robots)
- Iot Devices And Smart Home Automation
- Educational Tools For Coding And Electronics
- Quick Prototyping Of New Hardware Ideas
- Industrial Automation (Simple Control Systems)
- Wearable Technology (Basic Level)
- Interactive Art And Lighting Installations

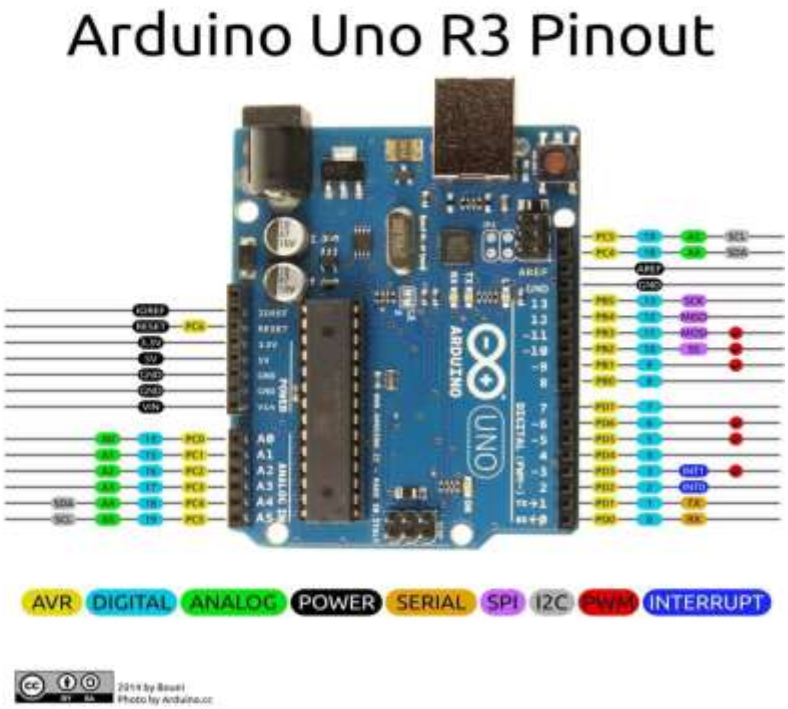

Fig. 1

Voltmeter & Ammeter – Basic Info and Applications

Voltmeter:

Purpose: Measures Electrical Potential Difference (Voltage) Between Two Points.
Unit: Volts (V)
Connection: Always Connected In **Parallel** With The Circuit/Component.
Types: Analog And Digital
Internal Resistance: Very High (To Avoid Drawing Current)

Ammeter:

- **Purpose:** Measures Electric Current Flowing Through A Circuit.
- **Unit:** Amperes (A)
- **Connection:** Always Connected In **Series** With The Circuit.
- **Types:** Analog And Digital
- **Internal Resistance:** Very Low (To Avoid Voltage Drop)

Common Applications:

- **Electronics Labs:** Circuit Testing And Diagnostics
- **Ev And Battery Systems:** Monitoring Voltage And Current Levels
- **Industrial Control Panels:** Power Monitoring
- **Educational Setups:** Learning Basic Electrical Measurements
- **Diy Projects & Arduino:** Real-Time Sensing Of Voltage/Current
- **Automotive:** Checking Battery Health And Charging Current

Voltmeter & Ammeter

fig. 2

Type: General-Purpose **Rectifier Diode**

- **Max Repetitive Reverse Voltage (V_{RRM}):** 1000V
- **Average Forward Current (I_F):** 1A
- **Peak Forward Surge Current:** 30A
- **Forward Voltage Drop:** ~0.7V (At 1A)
- **Package:** DO-41 (Axial Lead)
- **Polarity:** Cathode Marked With A **Silver/White Band**

Applications:

- AC To DC Conversion (Bridge Rectifiers)
- Power Supplies
- Reverse Polarity Protection
- Freewheeling Diode In Motor Circuits
- General Rectification In Low To Medium Power Electronics

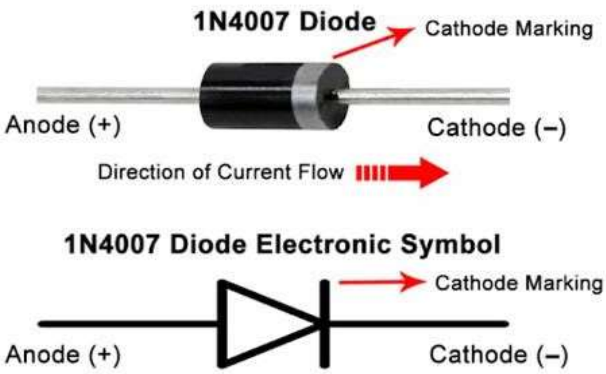

Fig. 3

Push Switch – Quick Info

- **Type:** Momentary switch
- **Operation:** Makes (ON) or breaks (OFF) a circuit **only while pressed**
- **Types:**
  - **NO (Normally Open):** Circuit connects when pressed
  - **NC (Normally Closed):** Circuit breaks when pressed
- **Reset:** Returns to original state after release
- **Common Forms:** Tactile switch, push-button, micro switch

Applications:

- Electronic circuits (reset, start, stop functions)
- Arduino/embedded systems input
- Doorbells
- Keyboards and control panels
- Toys and consumer electronics
- Safety or emergency stop buttons

Fig. 4

Working Principle

The BLDC Hub Motor Testing Device operates by measuring key performance parameters of a BLDC hub motor under controlled conditions. The motor is powered through a regulated supply, and **Hall effect sensors** detect rotor position for synchronized switching via an **Arduino Uno**. Real-time data such as **voltage, current, speed (RPM), torque, and temperature** is collected through sensors.
As the motor runs, a **load bank** simulates real-world resistance. The Arduino processes sensor inputs and displays the data via a serial interface. This setup helps evaluate the motor's efficiency, thermal stability, and performance under stress, enabling accurate diagnostics and optimization.

Proposed Conclusions (In Short)

The BLDC Hub Motor Testing Device effectively evaluates the performance, safety, and efficiency of hub motors used in electric vehicles and other applications. The prototype demonstrates reliable measurement of key parameters such as torque, speed, voltage, and temperature. With simple components like Arduino, sensors, and a load bank, the device offers a low-cost, flexible, and scalable solution for motor testing. It supports further innovation in motor design, ensures quality assurance, and promotes the development of energy-efficient technologies.

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- ISO 9001:2015: Quality Management Systems – Requirements for Testing Equipment.

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