Control System Design for Motor based on Temperature Dynamics

Esam Faleh Esam Alajmi[1], Soud Mohammed alhajri[2]

[1]Specialist Trainer (C) in Public Authority for Applied Education and Training, Arab Academy for Science, Technology & Maritime Transport, Egypt.
2 Specialist Trainer (C), the Public Authority for Applied Education and Training, Mechanical Engineering, USA.
**Corresponding Contact

Abstract:- This study investigates and discusses thermal compensation errors. The disadvantages of the thermal stresses on the bearing and shafts are discussed, the impacts of the thermal stresses on the CNC machines' shafts are investigated in the literature review. The DC motor's control process is conducted based on the microcontroller basics and principles; the Arduino can control both the DC motor's direction and speed depending on the temperature variation. The knowledge and attachment of the temperature sensor are evaluated and demonstrated by the control of the temperature sensor in Arduino, and the appropriate coding is used. A prototype for the motor and temperature sensor is also built, and the necessary coding and wiring concepts are utilised. The H Bridge is used to investigate the motor control unit. Its logic and wiring are clarified, and then the connection to the circuit is made. The results give the correct wiring. The elements of the data sheets are examined and utilised to wire the circuit correctly.

The findings confirm the advantages of utilising thermal control for the motor. The resulting stress is reduced if the thermal stress is considered. When the shaft temperature rises, the lubricants' viscosity will decrease and consequently reduce the shaft performance. The use of cooling fans is constructive in this case. After obtaining and discussing the results, some recommendations are made about the thermal compensation and the shafts' cooling process; the recommendations include the selection of appropriate fans to the volume in the present shaft, the suitable selection of lubricant viscosity, which reduces some of the high-temperature disadvantages, as well as the proper selection for the shaft fixing and bearings, which reduces the thermal stress impacts on the performance of the shaft as well as failure acceleration.

Keywords;- *Motor Control, DC Motor Direction, H Bridge, Thermal compensation Errors, Shaft Performance, Temperature Sensor.*

I. INTRODUCTION

Motors are commonly used as rotating equipment for driving machine shafts. Through the use of the main gears, the output shaft is driven from the motor's internal structure, and both torque and speed are used to define the motors. Motors are used to drive machines such as sliders in the car window and others.

There are several types of motors, such as direct current motors. DC motor starts with high torque and gets a broad range speed control. DC motor is essential in modern industry, as there are many applications in which the load on DC motor varies with different speeds that require a high dynamic response.

One of the essential processes in controlling the motor's direction and speed is changed according to the application type. Depending on the input, which may be pressure, temperature, or light, the motor's direction and speed are compensated in the modern control process. The compensation process is defined as the engine's constant speed and varies according to the measured value. One of its common types is thermal compensation. In this type of compensation, the motor is linked to the sensor's temperature values, and based on measured values , the motor speed changes.

Several studies have discussed the impact of higher temperature values on the life and performance of rotating devices. The lubricant's low viscosity is one of the effects of temperature rise, as it weakens the link between the shafts and the bearings. Also, the friction values between components rise, and the desired speed and torque decrease, the motor performance will be impacted, and the overall system performance will be impacted.

II.   AIMS AND OBJECTIVES

The study aims to develop a thermal compensation system for temperature-sensitive rotating devices and control the speed based on temperature values. This is achieved through the following objectives:

a) To examine the basic principles of hardware programming, microcontroller, and motor control operations.
b) To check types and methods of DC motor control and pulse width modulation.
c) To describe the functions and components of the essential Arduino chip from each integrated circuit.
d) To study the effect of thermal stress and compensation for thermal error by literature review.
e) To create a model that controls the rotor motor's direction and speed depending on the temperature values.

III.   LITERATUR REVIEW

Overview

There is a need for synchronization in the industrial environment between many devices, so there must be synchronization between the motors. A system is designed based on these factors; it can control DC motors and be multiple RPS or speed. DC motor is widely used due to ease of control. One of DC motors' advantages is the speed drops smoothly to zero without the need to switch the power circuit, which leads to the formation of acceleration in the other direction. There are DC motor control methods such as pulse width modulation (PWM) motor voltage control. The motor direction is controlled by precise control of the programming language (Singh, 2014).

Motors consume electrical energy to produce mechanical energy, as they use many devices and engines to operate easily programmable purposes. DC motors are used in industrial, marine, and other applications that require high torque and change in speed (Singh, 2014).

An important variable is temperature, as it is widely measured for most conditions. Depending on the temperature in the area to be measured, the measurement method will vary. It is necessary to control difficult measurements such as the exhaust gas's temperature leaving the missile and the flue gas in the power supply (Mike, 2015).

The speed and torque control the motor's power, so controlling the power leads to controlling the power. The effect of temperature on a brushless DC motor's performance was studied (Ewa Garnewa, 2019). The effect of temperature on the KARTING electric vehicle engine has been studied in Indonesia. The study results were to note the change in the car engine's performance due to the change of temperature, as the speed changes depending on the temperature.

DC Motor Definition

DC motor is one of the types of electric motors that convert electrical energy to mechanical energy. DC Motor contains an internal electromechanical or electronic device that.changes the flow in the motor. Most types of DC motors are circular motors (Reddy, 2016). One of the suitable devices for controlling the movement of the mechanism and automation systems is the DC motor's speed control devices (Rida, 2016).
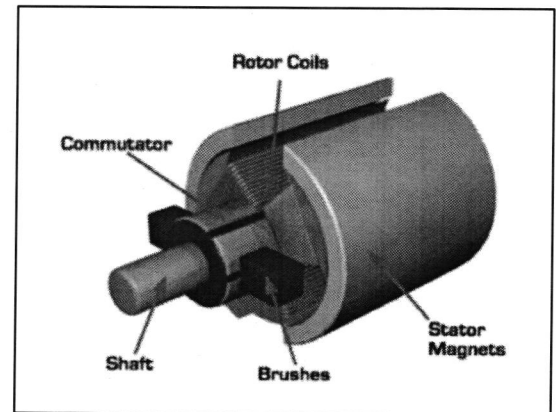

Figure 1: The DC motor (Reddy, 2016).

The DC motor operates when the conductor is facing a mechanical force in a magnetic field. One way to control the speed of the DC motor is the addition of series resistance. The DC motor block diagram is shown in Figure 2 (Raza, 2016).
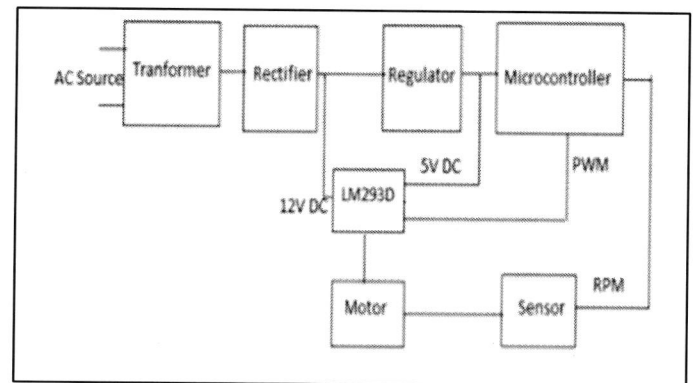

Figure 2: The DC motor block diagram (Raza, 2016).

DC motors are widely used in industrial fields such as robotics and operation as well as manipulative. To control the different speeds, several available control techniques are used. During the control process, electrical control systems are widely used. In several industrial uses, the DC motor would be a successful piece of machinery that requires variable power to speed features for simple power.

Brushed DC motors adopt an electrical system as they are used due to their simplicity and cost. This kind of motor is used in cars, inkjets, hand drills, electric trains, etc. These

engines need to run at specific speeds during different periods. The DC motor's speed is effortless to control due to the characteristic of the electric voltage speed as it is linear. The PWM control process is used in a DC motor to control and adjust the motor's speed during short pulses as the filling rate of these pulses is named the duty cycle (Ozer, 2017).
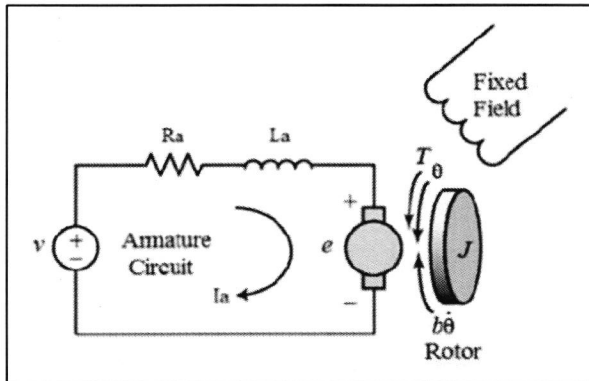

Figure 3: The DC motor circuit (Ozer, 2017).

Through the use of PWM signals, the DC motor's rotation and speed and the voltage change applied to the DC motor will be controlled. The speed increased when the voltage increased. High power will be lost due to voltage regulation in the control circuit, so several DC motors use PWM. By switching in and out of the switch between the load and the supply at high speed, the mean feed value was regulated through voltage. The higher the switch was switched on, the higher the load power it saves relative to shutting it off (Ozer, 2017).
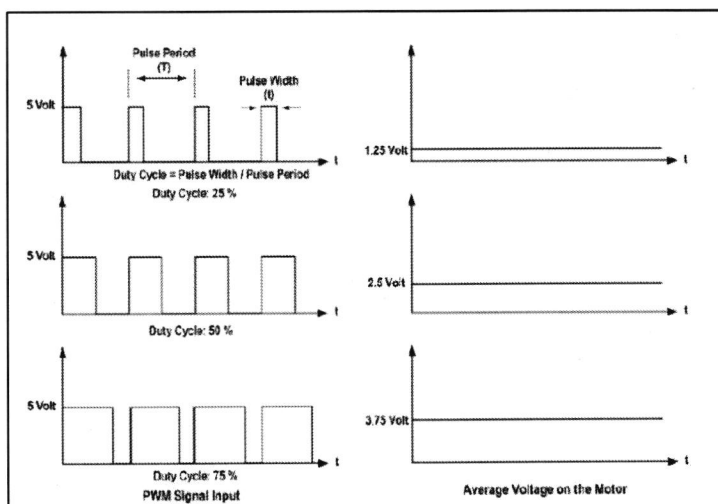

Figure 4: PWM timing diagram (Ozer, 2017).

The technique of pulse width modulation (PWM)

Pulse width modulation is known as one of the standard techniques that control devices' electrical power through the use of a modern electrical power switch (Lathi, 2007). One of the techniques for controlling the DC motor's speed is the pulse width modulation by controlling the driving voltage. PWM could be used instead of standard voltage regulation in several systems since standard regulation can result in high energy losses throughout the control system (Raza, 2016). The waveforms for several of the duty cycle signals are shown in Figure 5.
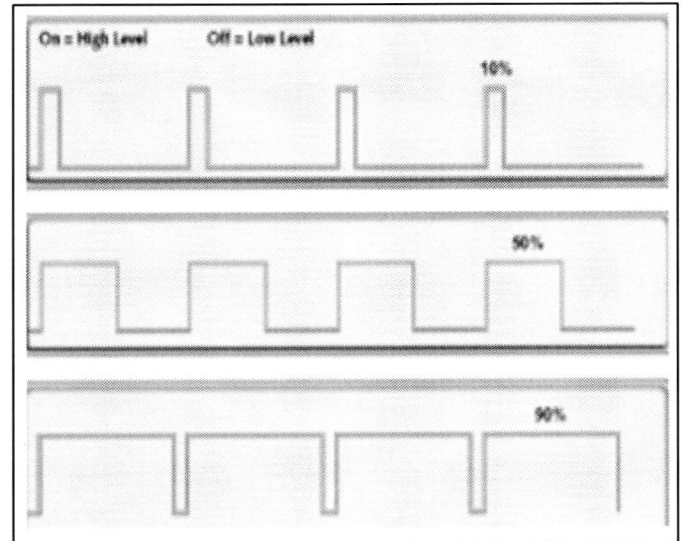

Figure 5: The waveforms for several of the duty cycle signals (Raza, 2016)

Thermal error compensation

Several industrial machinery producers have attempted to minimize the impact of heat errors on machine operation accuracy; however, these errors have always been the most successful variable in actual production, particularly in ultra-fine machines and precision, such as the set of control computers (Shi, 2019). Deformation or thermal errors in the circuitry of the computer significantly decreases its precision. A research carried out on several 55 machinery device plants in eight various regions such as Germany, China, and Japan, the findings of this research represent that temperature errors would significantly impact mechanical device operation and precision. This research also indicated that the level of temperature errors on devices was higher than those of vibrant, fixed, and geometric errors (Putz, 2018).

In addition to the accumulated experience and new high-tech production, no solution has been found to reduce thermal error in machine tools and remains the main factor that reduces the accuracy and quality of machine tools and contributes 50% to product defects. The formation of the production process, the environment, and the internal heat source all have an equal impact on developing the machine's thermal error. Also, the use of thermal stabilization systems has been found to address energy efficiency issues. However, about 75% of industrial manufacturers give priority to process stability (Aguado, 2014).

Temperature sensor

Sensors are used to calculate and measure the temperature depending on the microcontroller (Oyebola, 2017). One of the most significant factors calculated on a broad scale was temperature. Based on the appropriate temperatures in the particular area, the temperature calculation differs in multiple places. At some points, specific manufacturing processes need particular temperatures, so certain processes need temperature control or regulation. In certain situations, more complicated temperature calculations will be needed, like, for measure temperature of the smoke pile product from the kiln, the ingested rocket gas, or power generation plant, but the most typical measuring temperature was its liquid temperature throughout the method of supporting systems or the temperature of measuring solid objects, such as shafts as well as metal plates (Mike, 2015).

IV.   METHODOLOGY

This chapter involves the project methodology that will be followed to improve the thermal error compensation system, particularly for temperature-sensitive rotary machines, concentrating on controlling the speed depending on the temperature values throughout the operation.

Firstly, the DC motors and the microcontrollers will be studied, before starting the wiring and application, several related studies will be collected and reviewed, and the main concepts will be investigated in the introduction and literature review. The steps of conducting this project are discussed in this chapter:

Arduino UNO board elements and their functions.

The Arduino UNO board is a collection of the essential Integrated Circuits and components for creating both simple and advanced control circuits. Figure 6 shows the basic elements of the Arduino UNO.
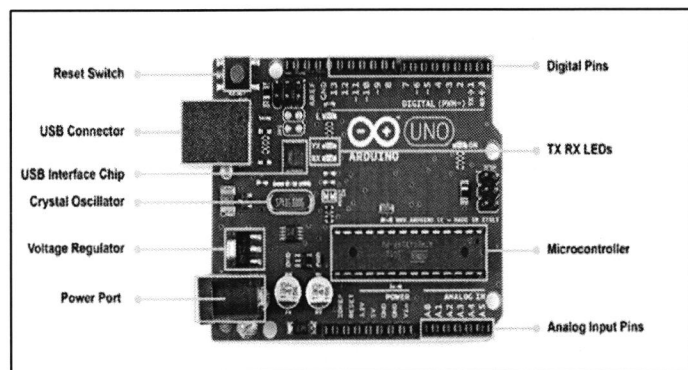

Figure 6: The essential elements of the Arduino UNO.

The functions of Arduino UNO board elements:

- **The Microcontroller**

This is considered the main component of the Arduino, and the board's brain, and the factory, which proceeds all the needed functions.   It transforms written codes into real commands. It is well-known for its ease. It's also compacted enough to be connected to the Arduino frame.
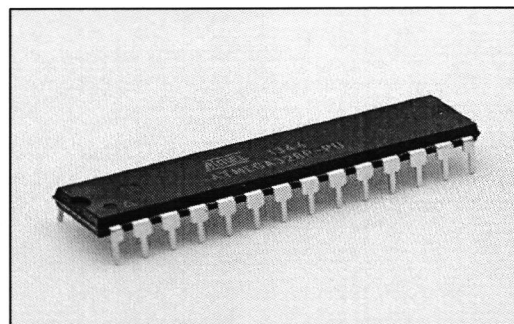

Figure 7: The Arduino microcontroller.

There are two types of pins in the microcontroller, which are the input and output pins; the input pins involve analogue and digital pins.

The digital pins read the measured values that have only two values (1 and 0) or (ON and OFF).

The digital output pins are utilised to write a value (zero-one) on a device, such as allowing a pin of the motor, controlling a LED, and forcing a cylinder to retract or extend.

On the other hand, the analogue pins can read or write a time-varying value, like pressure and temperature. The analogue input pins are used to determine a value from an analogue sensor like force resisting sensor, potentiometer, or temperature sensor.

The digital output pins are utilised as analogue output pins using the mapping process and the Pulse Width Modulation (PWM) by linking the relative output with the measured value; this is done by managing the signal width; therefore, the pin duration to give the maximum voltage. Figure 8 illustrates the process of Pulse Width Modulation.
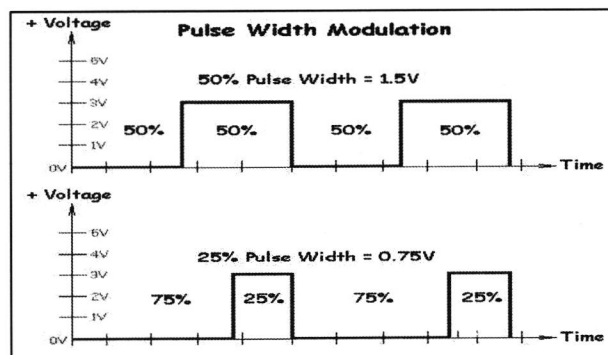

Figure 8: Pulse Width Modulation (PWM) process.

This process can effectively control the speed of the DC motor; the motor speed can be connected to any pin which has this (~) sign.

- The voltage regulator

The Arduino drives small devices like sensors, which require a regular and constant voltage level which equals 3.3 or 5 Volts. Thus, the voltage regulator is used to regulate the required value of voltage. Figure 9 shows the voltage regulator circuit.
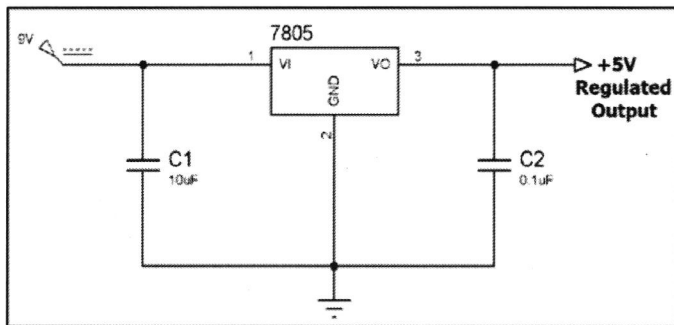

Figure 9: The voltage regulator circuit.

The voltage regulator involves three pins (output, input, and ground). This circuit is a simple filtration circuit that involves two capacitors, which raise and down the input voltage, depending on the required output value. In this study, the used Arduino UNO is powered with voltages equal to 5 Volts.

- The crystal oscillator

The Arduino crystal oscillator has a high frequency; it vibrates 16 million times per second. At every vibration, the Arduino performs a function, like adding numbers, reading a value, or storing a variable. Figure 10 shows the used oscillator in the Arduino UNO board.
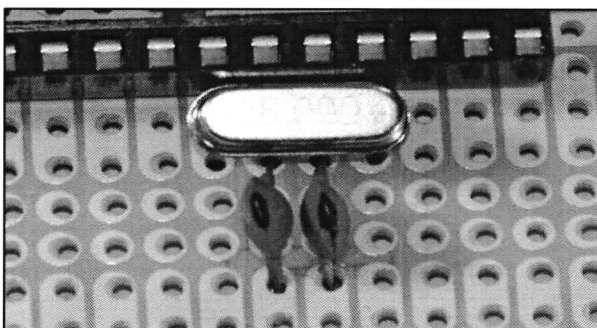

Figure 10: Crystal oscillator.

- Digital pins

The digital pins are identified from 0 to 13. They are utilised to act the ON-OFF tasks. The Pulse Width Modulation processes use the pins with (~) value.

- Analogue input pins

These pins are identified from A0 to A5; the analogue sensors are connected to these pins. The sensor output is treated in the Arduino microcontroller and sent to carry out the circuit purpose.

- Ground pins

This type of pin is utilised to ground all the power supplies and devices in the circuit. The circuit components' ground must be unified, including the external power source ground, connected to the Arduino ground.

- Power pins

The Arduino board involves two power pins with 5 Volts as well as one power pin with 3.3 Volts. The needed voltage is defined from the device datasheet or sensor.

Motor Control Board On-board L293D Dual H-Bridge Motor Control Driver Module

This part specification involves:
- The value of the operating voltage equals 5 volts,
- The motor drive voltage value is between 4.5 and 36 volts,
- The screw terminals' dimensions are 43 ×27 mm, (The datasheet of this element is presented in the Appendix).
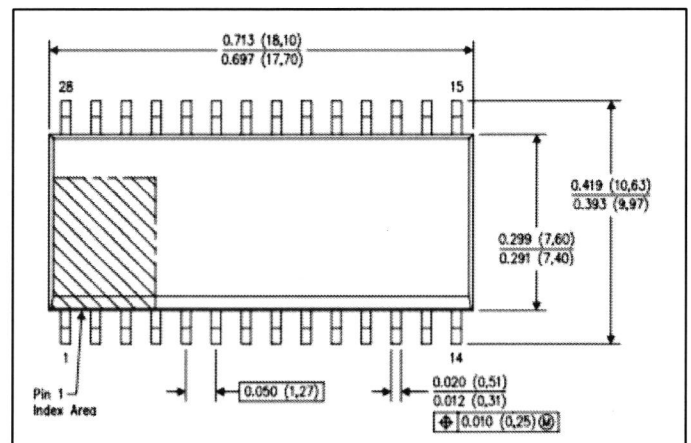

Figure 11: L293D pins' driver layout.

Temperature sensor

In this project, the temperature sensor is utilised to monitor the DC motor direction and speed, where when the temperature increases, the motor direction will change.

DC Motor

This selected DC specification involves:
- It can be utilised for slot machines, labelling machines, automatic voltage electricity, remote control curtains, printing machinery, waste disposal machines, towel disposal. Stage lighting, washing machine, household appliances, automatic actuator, and a banknote recognition.

- It involves a two-phase reduction gear motor outfitted by the encoder,
- It has a long service life,
- It has a large torque.
- It has a low noise level.
- Its performance is considered reliable and stable,
- It can be reversed and rotated,
- It provides a high-level of accuracy.

Breadboard

The breadboard is used to install the designed circuit elements; it is the base of the circuit, which involves all circuit elements; Figure 12 shows the breadboard.
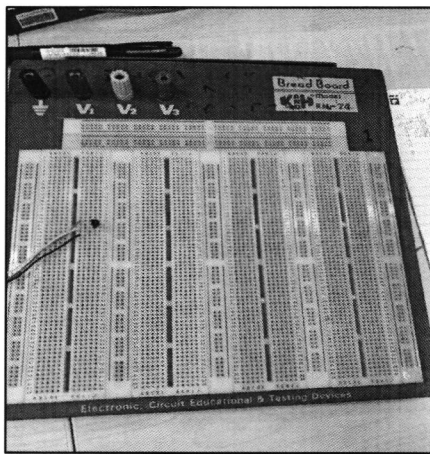

Figure 12: Breadboard.

Jumper wires

The jumper wires are used to connect the elements of the designed circuit together, and these wires must be checked and tested before being used.

DC Power supply

This DC power supply is used to provide the required power for the operation process. The used circuit in this project, 12 volts are required.
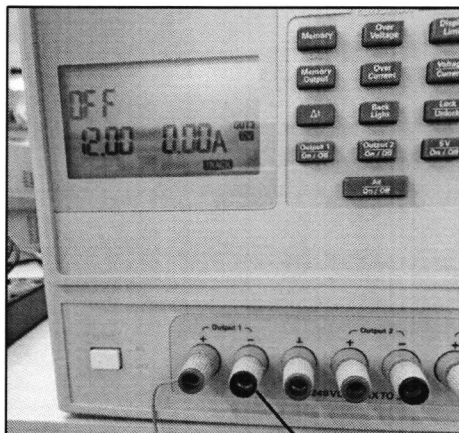

Figure 13: The usedDC Power supply.

V. RESULTS AND DISCUSSION

In this section, the preparations that took place on the circuit components were presented and using a simulation tool, the circuit was created to ensure that all connections are made. Using Fritzing Tools and the Arduino IDE the Arduino was coded for control. There are several functions to be performed by the circuit in this project where there will be speed control depending on the temperature values and the change of direction at a certain temperature and a fan will be turned on in case the temperature increases.

The circuit components with a description.
a) **DC 12V High Torque Turbine Worm Turbo Geared Motor Reduction Motor with Encoder Strong Self-Locking 60 RPM**

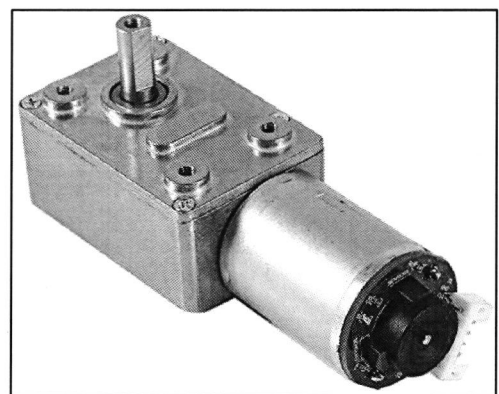As shown in Figure 14, a self-locking stepper motor was used in the experiment.

Figure 14: The self-locking stepper motor.

The motor operates voltage equal to 12-volt obtained from an external source, which may be laboratory power or a DC battery.

The Arduino controller sends directions and speed which writes the values to the motor pins. The engine produces a speed equal to 60 revolutions per minute, as it is considered low when compared to the speed of other engines.

b) **L298N Motor Drive Controller Board Module Dual H Bridge DC Stepper motor (20 – 100 RPM)**
The H Bridge is one of the tools which control the motor direction. It consists of a group of transistors as shown in Figure 15 as they prevent the flow of voltage or change the direction.
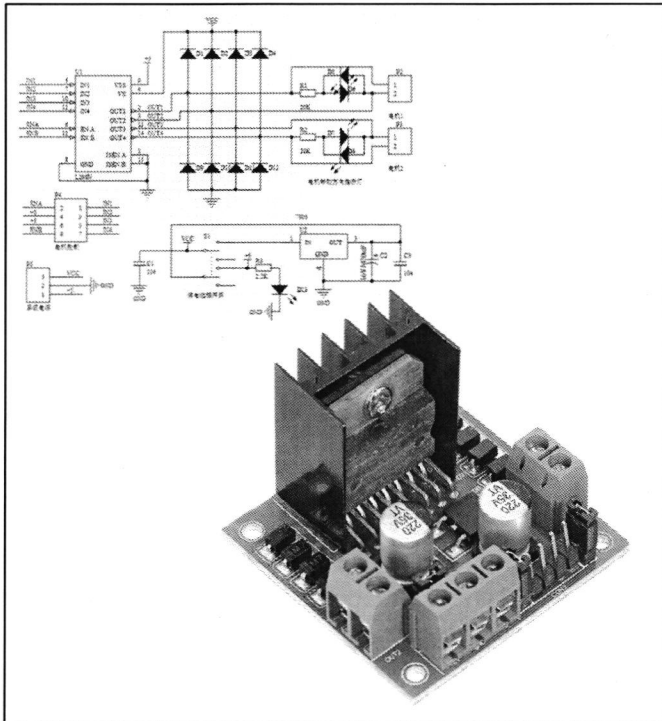
Figure 15: H bridge tool and diagram.

This type consists of four pins that are connected to the motor, as shown in Figure 22. The power is up to 12 volts for the other three screws. For proper current to flow the enable pins are connected to the Arduino. In Figure 16 the schematic diagram of the H Bridge is shown.
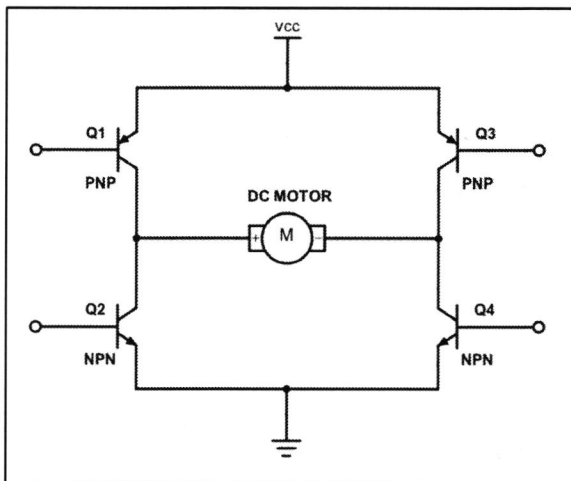

Figure 16: the schematic diagram of the H Bridge.

The control is performed by NPN and PNP transistors in the motor direction, and the direction of the rotation is determined by the enabler leg. The power supply drives the 12-volt H Bridge.

c) The sensor of temperature (LM35).

The LM35 sensor that was used in the experiment is one of the most used sensors as it consists of three pins connected to the Arduino. The output pin is the middle pin where it is attached to the analogue pin, reads, and converts the voltage into temperature. Figure 17 shows the temperature sensor.
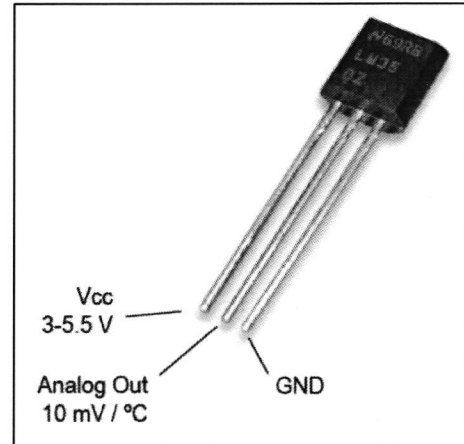

Figure 17: Sensor of temperature (LM35)

The tool that controls the engine speed is a temperature sensor, which is placed near the engine to sense the temperature and transmits it as the engine speed. The sensor is connected to a power source and the circuit ground.

d) DC Brushless Cooling Fan Heatsink Cooler Radiator Connector Separating One-to-Two Interface, 5 V

The temperature will be decreased by the cooling fan in case the temperature increases, and this is the adjustment of the circuit. Figure 18 shows the cooling fan.

Figure 18: The cooling fan.

Arduino 5 Volts drives the fan, powered by the power of the Arduino. The fan is characterized by high speed and low power. To maintain the assurance and stability of the system, the fan is grounded.

e) Arduino UNO board

The brain is the main of all parts in the circuit. In the first section, the components of the Arduino are selected. The circuit is connected to a microcontroller and on the board, the code is loaded. Figure 19 shows the Arduino UNO board.
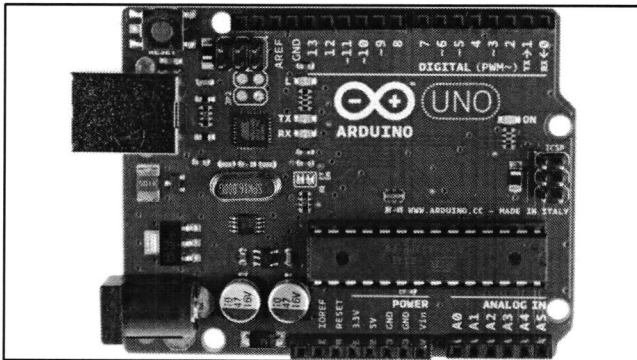

Figure 19: The Arduino UNO board

Method of connecting components.

The configuration of the circuit is performed based on the written code, the creation of the code as well as the specification are done concurrently because when the code was prepared, the role is ensured and there are no failures. The circuit layout is shown In Figure 20.
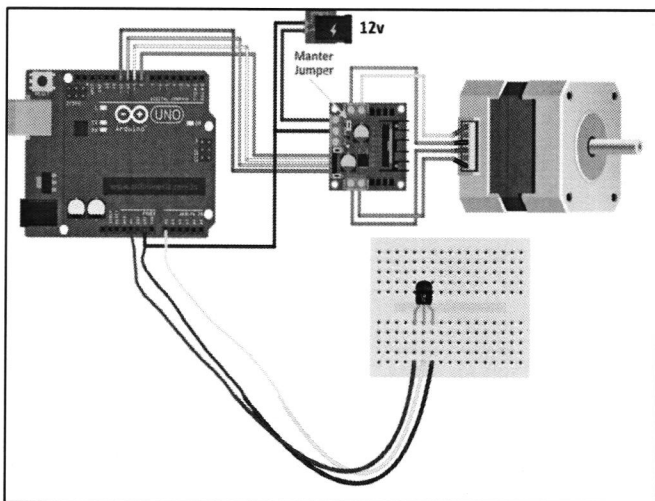

Figure 20: The circuit layout components.

The simulation examines the circuit. In the laboratory, the circuit was completely installed, as shown in Figure 21.
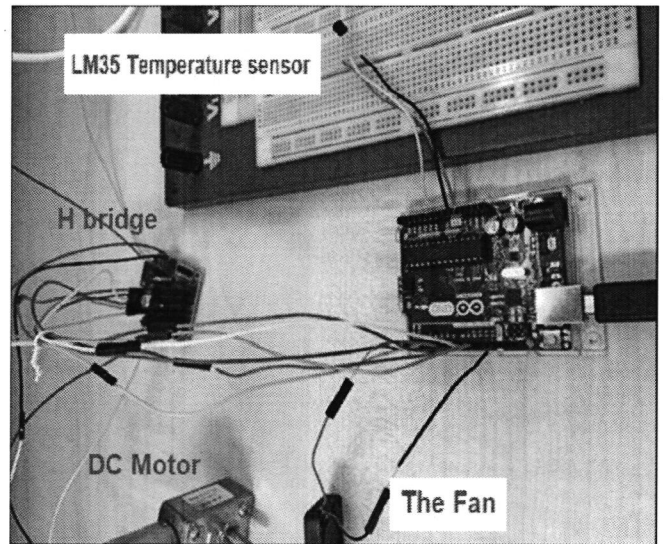

Figure 21: The circuit layout at the laboratory.

The engine and temperature sensor are the parts of the circuit that control the speed. As the sensor records the temperature that is transmitted as speed. The Arduino controller is controlling in cooperation with the H-bridge. The H Bridge controls the direction of the motor, by enabling a single leg, to complete the required rotation.

The function of each component is defined and then the pin is determined, and this is done in a non-random way, the connections are checked, first on the input pin and then the four pins in the H Bridge as they connect at the edges of the motor and then the external power source is connected to drive.

The obtaining results.

A serial screen is displayed as shown in Figure 22 by loading the code in the Arduino UNO. The temperature values measured by the sensor are listed in the serial screen. The temperature display is 9600, which is a default value.
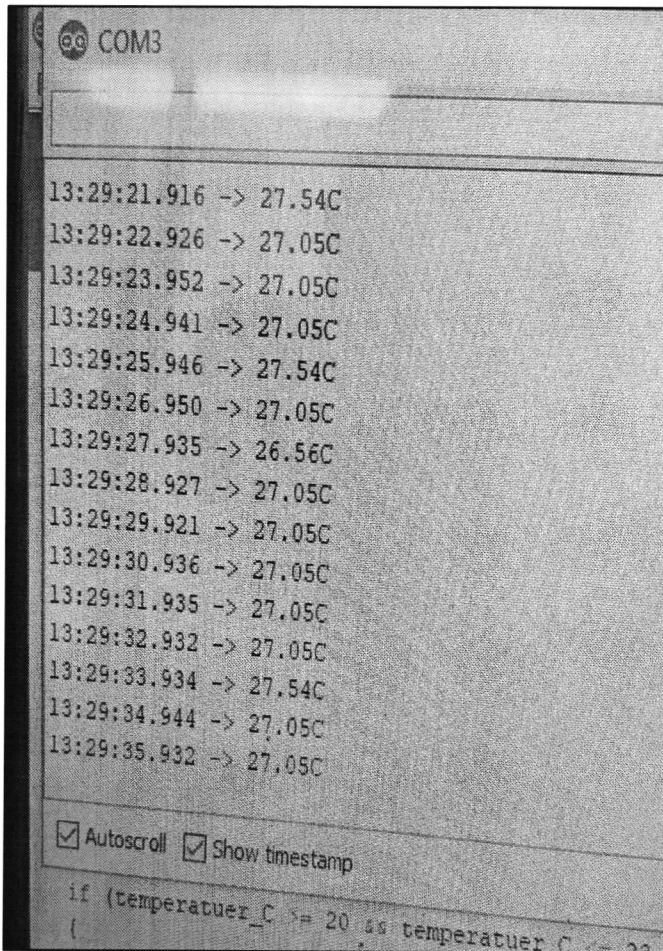
Figure 22: The serial screen

The motor was moved counter clockwise at 23 ° C, in conjunction with the cooling process from the fan. When the engine rotates clockwise, the temperature is reduced to 20 and below. Low shaft temperature is not observed in the laboratory, as the rotation direction is reversed at higher temperature values. Depending on the temperature values of the sensor, temperature control of the engine is enabled. The measured temperature is close to the shaft heat value.

A cooling fan was used to obtain lower temperature values. The temperature was hardly reduced to 21.8 by placing the experiment towards the outside flowing air. Large fans are required to perform the cooling process, and the temperature sensor is indicated on the engine through a sticky substance in the case of large projects. The engine starts to change its direction of rotation in the direction of clockwise when the temperature is reduced. Figure 23 shows the temperature values after they have been reduced.
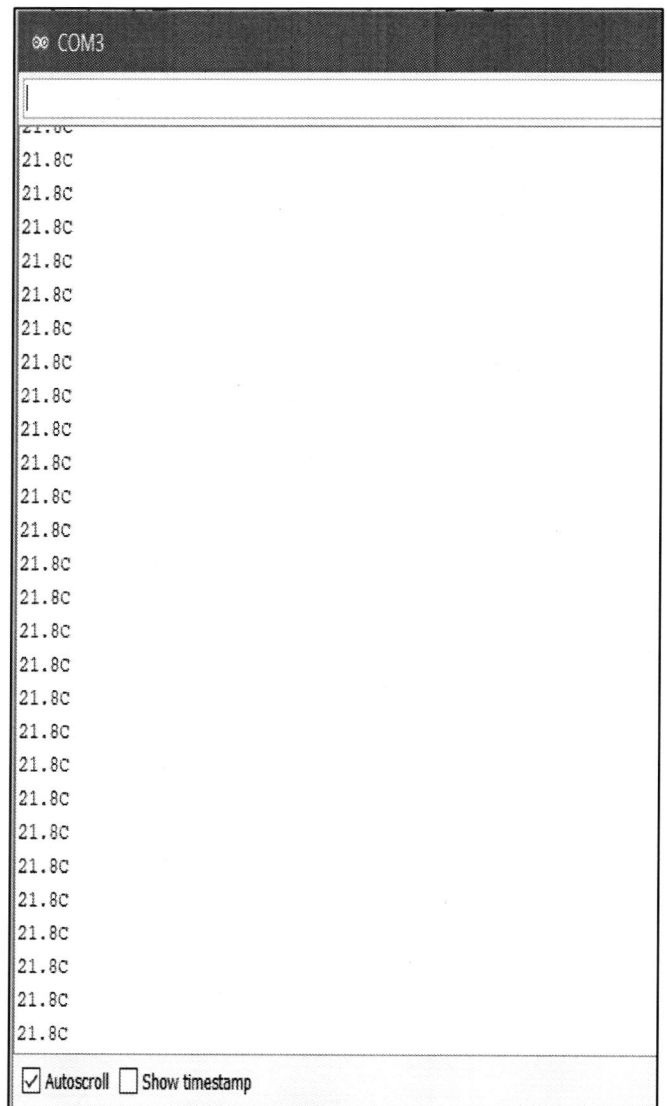

Figure 23: the temperature values after they have been reduced.

At this temperature, the motor rotates clockwise but stops before changing the direction of rotation. After a short time, the engine began to rotate clockwise. To reduce the temperature if it is high, the fan is turned on, which reduces the thermal pressures, and this enhances the heat load. Figure 24 shows the values of temperature and velocity.
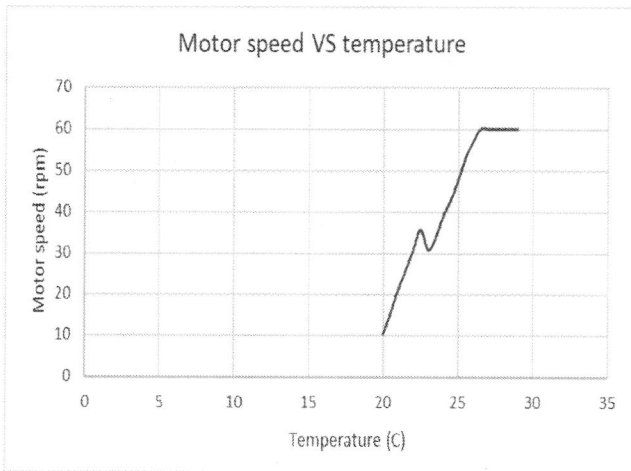
Figure 24: Temperature Vs velocity of Motor

The linear relationship between the temperature and velocity values was observed, the decrease in speed was observed at 23°C due to the reversal of the motor's rotation direction, and it was observed that the motor needs time to return to a linear relationship. The maximum engine speed is 60 revolutions per minute, and this speed has been reached.

The temperature of 20°C is the minimum that is reached in the laboratory under normal conditions. While the temperature of 27°C is not reached in laboratory conditions through fan cooling. The engine speed will drop if the temperature reaches 27°C. Figure 25 shows the results of changing the direction of the motor. 0 is used to denote the direction of the clockwise, and 1 is used to denote the direction counter clockwise.
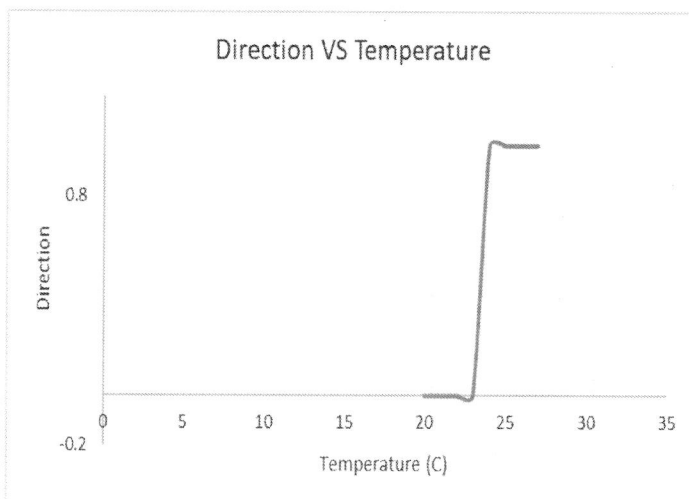

Figure 25: Temperature Vs Direction of Motor

To insert a diagram and display the results, the direction of rotation of the motor was determined using the numbers 0 and 1. The rotation direction was represented at temperatures 20 to 23 in terms of 0, while the rotation direction was represented at temperatures 23 to 27 in terms of 1.

To control the motor, the direction of rotation of the motor is changed by the H-bridge unit as it is good at 3D printing spindles and CNC machines as its task for the machine. As a result, the H-bridge unit controls the direction of rotation of the motor.

VI. CONCLUSION

The following conclusions are reached after observing and reviewing the experiment, explaining, and discussing the findings and observations from the laboratory:

- When the motor's activity is influenced by temperature, the control of the motor speed is a vital operation. The most popular form for eliminating thermal stresses from the motor shaft is to perform a control process dependent on the temperature of the motor.
- The Arduino microcontroller is the most popular option for small-scale projects because of it's ease of understanding and uses, availability in the markets, the ease of wiring and operation. Also, actuators, displaying chips, and sensors are easy to programming.
- The experiment is influenced by the laboratory's overall temperature, but in the large-scale plants, the temperature is regulated, and the temperature variation is mainly caused by the machines and shaft.
- The H-bridge module employs transistors to control the speed of the motors peed and alter its direction. It is indeed easy to link and program using Arduino.
- Due to the internal friction between the motor parts, the reversal of the motor direction does not happen at the same time; it takes a few moments to rotate the motor normally again.

Depending on the experiment results, the following recommendations are obtained:

- The thermal protection of the shaft components is an essential process because it helps to keep the shaft in good working order and decreases the possibility of fracture.
- Utilising the H-bridge module instead of the chip is preferred since any faults, or unattached wires would be immediately noticeable.
- The basic Arduino code is favoured because detecting logical errors and fixing them is quicker and easier than complex codes.

REFERENCES

[1]. Aguado, S. Santolaria, J. Samper, D. and Juan, J. A. (2014). Protocol for machine tool volumetric
[2]. Al-Yoonus, M.(2019). Understanding analog to digital conversion and pulse width modulation using Arduino, University of Mosul Electrical Engineering.
[3]. Christopher A. Adkins and Michael A. Marra, "Modeling of a Phase-Locked Loop Servo Controller with Encoder Feedback". IEEE Spectrum, 2009. 51-56.

[4]. Garniwa, Iwa & Dipantara, Bima & Nugroho, Muhammad & Sudiarto, Budi & Noorfatima, Nadya. (2019). Analysis of the Effect of the Motor Temperature to Brushless Direct Current Motor Performance on KARLING Electric Vehicle..

[5]. Guo, Q. Yang, J. (2011).Application of projection pursuit regression to thermal error modeling of a CNC machine tool. AdvManuf Tech, 129, (1), 619:623.

[6]. He G, H. Ma, W. Sang, Y. and Yu, G. (2017). CAD-based measurement planning strategy of complex surface for five axes on machine verification, Adv. Manuf Techno, 91.

[7]. Khan,R. Shatil, A. and Faisal, A. (2011). PWM SPEED CONTROL OF DC MOTOR BY TEMPERATURE SENSOR, Islamic University of Technology, 3.

[8]. Lathi B.P. (2007). Modern Digital and Analog Communication Systems. Oxford University, 260:263.

[9]. Li, Y. Wei, WM. Su, DX.and Zhao, WH. (2018).Thermal error modeling of spindle based on the principal component analysis considering temperature changing process, Adv Manuf Technol, 99, 1341:1349.

[10]. Machine tools, Prod Resource Development, 12, 723:36.

[11]. Martinos, J. and Martinos, T. (2018).Digital Thermometer Using Arduino and MCP9808 Digital Temperature Sensor.

[12]. Mike. (2015). Digital Temperature Circuit, Electronics Hub.

[13]. Muhammad H. Rashid. "Power Electronics Circuits, Devices and Applications". 3rd edition. United States of America: Prentice Hall. 2014

[14]. Norman S. Nise. "Control Systems Engineering". 2nd Edition. Redwood City, California: The Benjamin/Cummings Publishing Company, Inc. 2016.

[15]. Omega. (2015). History of Temperature Measurement. Omega Engineering.

[16]. Oyebola, B. and Toluwani, O. (2017). LM35 Based Digital Room Temperature Meter: A Simple Demonstration, Equatorial Journal of Computational and Theoretical Science, 2 (1): 6-15.

[17]. Özer, T. Kivrak, S. and Oğuz, Y.(2017). H Bridge DC Motor Driver Design and Implementation with Using dsPIC30f4011, International Journal of Innovative Research in Science, Engineering and Technology, 6.

[18]. P. C. Sen and M. L. MacDonald. "Thyristorized DC Drives with Regenerative Braking and Speed Reversal". IEEE Transactions on Energy Conversion, 2015, Vol. IECI-25, No. 4: 347-354.

[19]. Polyakov, A. and Parfenov, I. (2019). Thermal error compensation in CNC machine tools using measurement technologies, Journal of Physics: Conference Series, 1333.

[20]. Putz, M. Richter, C. Regel, J. and Bräunig, M. (2018). Industrial consideration of thermal issues in.

[21]. Raza, K. Kamil, M. and Kumar, P.(2016). Speed Control of DC Motor by using PWM, International Journal of Advanced Research in Computer and Communication Engineering, 5.

[22]. Reddy, N. (2016). L293D H BRIDGE DC MOTOR CONTROLLER WITH ARDUINO.

[23]. Shi, X. Yang, X.Mu, Y. Wang, Y .and Wang, W. (2019). Thermal error compensation model for a motorized spindle with shaft core cooling based on exponential function, The International Journal of Advanced Manufacturing Technology, 103.

[24]. Singh, R. and Kumar, S. (2014). Synchronisation, Speed and Direction Control of DC Motor, International Journal of Electronic and Electrical Engineering (IJEEE), 7.

[25]. Theophilus, W., and Setiawan, B. (2012). A Microcontroller- based Room Temperature Monitoring System. International Journal of Computer Applications.

[26]. Verification using commercial laser tracker, Adv. Manuf Techno, 75, 425:44.

[27]. Yang,H. (2005). Dynamic neural network modelling for nonlinear, no stationary machine tool thermally induced error. MachTools Manuf, 45, 455:465