Islamic University of Technology

Department of Mechanical and Production Engineering

SPEED AND DIRECTION CONTROL OF STEPPER MOTOR

A Thesis by

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Student ID: 200033103

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

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SPEED AND DIRECTION CONTROL OF STEPPER MOTOR

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CERTIFICATE OF RESEARCH

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DECLARATION

I hereby declare that this thesis titled "Speed and direction control of stepper motor" is an authentic report of my study carried out as requirement for the award of degree Bachelor of Science in Technical Education with Specialization in Mechanical Engineering at Islamic University of Technology, Gazipur, Dhaka, under the supervision of Prof. Dr. Nurul Absar Chowdhury, MPE, IUT in the year 2022.

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

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This is to certify that the above statement made by the student concerned is correct to the best of my knowledge and belief.

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ABSTRACT

In today's modern world most of industries are reliant on the robotics and advanced motion control mechanisms. Stepping motors providing accurate positioning are used in a variety of fields, including military, medical, and industrial applications. However, not much is known about its historical background and recent advancements; a comprehensive comparison of its types and to other electric motors to provide comprehensive knowledge and clarity in choice of stepping motor implementation for a specific application. The control of stepper motor is usually done manually, which hardly can be embedded in modern enhanced control systems operated via computers. The aim of this thesis is to explore the stepper motors historical background and recent advancements; the comparison of their various types and with other electric motors; design and implementation of a step motor control system which is operated via PC using a simple and efficient Graphical User Interface (GUI) to control its direction & speed accurately. An in-depth literature survey has been done to explore the historical background and recent advancements of step motors and the comparison of them with other electric motors such as servo & DC motors and among its various types. Moreover, a control system circuit and a GUI designed in visual studio software to control the direction & speed of the step motor remotely via a PC is designed and implemented.

The main findings of the thesis incudes: a considerable amount of research have been conducted to improve the efficiency, accuracy, costing, performance, and other stepping motors aspects from its first known forms in early 1920s until present day. Stepper motors in comparison to servo and DC motors are less efficient and are not the optimum choice when efficiency is of concern. Hybrid Stepper motors having best performance characteristics is an ideal choice to be applied in most of the motion control applications. Bipolar type of step motors due to their high torque & efficiency are generally better compared to unipolar type. Moreover, based on the control system described and successfully implemented in this thesis utilizing the designed GUI and the hardware components the direction & speed of stepper motor is accurately controlled.

Moreover, this study can be further improved by; conducting a more in dept research on the step motors recent advancements covering a wider range of literature also to compare the stepper motors with other electric motors not covered by this thesis work. Furthermore, the designed GUI designed and implemented in this study can be further enhanced adding more control options and the control of several step motors to be further integrated in much more advanced applications.

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Chapter 1
INTRODUCTION

Stepper motors are viewed as brushless direct current motors that rotate in predetermined angular increments when their stator coils are configured to be powered. Whenever there is a magnetic interaction of step motor rotor and its stator windings the rotation occurs. In spite of the lack of electrical coils, the rotor has prominent and magnetic poles. In contrast to the smooth rotational movement of a typical motor such as a DC motor, the stepper motor revolves in discrete incremental steps. Mechanical degrees are used to measure increment size, which might vary based on the system's application [2]. In the field of electromechanical motion, stepping motors are viewed as electronic devices which are employed to convert digital data to mechanical rotary motion though the use of a controller and motor driver. Typically, it is common for stepper motors to have all their windings housed in their stators, whereas the motor rotor is either made of attached magnetic toothed blocks to the rotor or a permanent magnet, or a composition of both in case of Hybrid Stepper Motors. All commutation in a stepper motor is handled externally via motor controller. Because the motor controller is responsible for all commutation in a stepper motor, the motor and controller are often designed such that the motor may rotate in either direction, clockwise or anticlockwise, while being kept in any specific position [3]. Audio frequencies can enable most stepping motors to spin at higher speeds, and with a proper controller, the stepper motors can be started and stopped at desired control positions.

In certain applications there can be an option of choice between the stepper motors and servomotors. Accurate positioning is provided by both types of motors, although they differ in various ways. Servomotors need some kind of analog feedback control system; this is often achieved by providing feedback on the current position and rotor through a potentiometer. When deciding between stepper motors and servomotors, a variety of factors can be examined; the importance of each factor varies according to the application [4]. For example, the type and shape of the motor rotor has an impact on the positional rotation of the stepper motor, while in the feedback circuit the stability of the potentiometer and additional mechanisms involved has an impact on the rotational movement and positioning of the servomotor. In basic open loop control systems, stepper motors may be utilized; they are often adequate for mechanisms which function at moderate and low speeds with loads which are static; however, for systems that operate at high speeds with different loading conditions may necessitate a closed loop control configuration as used in servomotors. Moreover, the application of excessive torque to the stepper motor in an open loop control system may lead to loss of entire data about the motor’s rotor position and necessitating the control system to be restarted, whereas servomotors are not affected by such problems [5, 6].

Whenever adequate and precise positioning of a motor's rotor is considered, Typically, the optimum choice can be a step motor. The stepping motors function in a different way compared to other regular electric motors such as DC motors; rather than applying current and revolving the rotor continuously, stepper motors activate the motor's stator windings by a sequence of electrical pulses. Each pulse precisely turns the rotor. Steps are the terms used to describe these pulses, which is how the term *"stepper motor"* originated. Historically, various motion control mechanisms, systems and applications have relied on stepper motors. The design and manufacture of stepper motors is quite simple compared to other electric motors, and easy to operate and control. In addition to being cheap in cost, manufacturing process and easy to control, at low speed they provide a significant amount of torque which makes them ideal for a broad range of low-power, computer-controlled, and other motion control applications. They can be controlled manually or through the use of a PC. In case of its digital control, the stepper motor can be connected to a computer through a few transistors and made to spin incrementally via use of simple software (Arduino IDE) and a motor driver. Stepper motors have a high degree of rotary precision and are used to control and operate robots, computer peripherals, medical equipments, and etc [7].

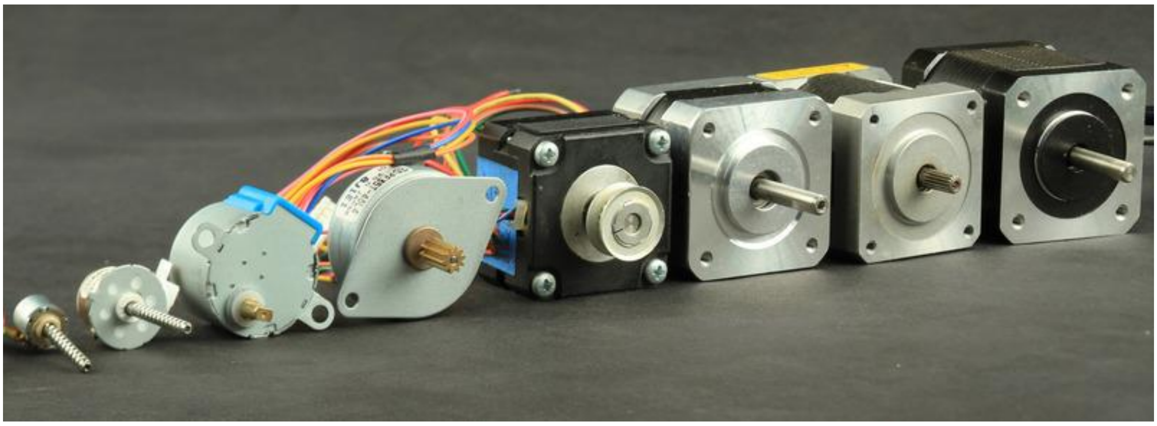
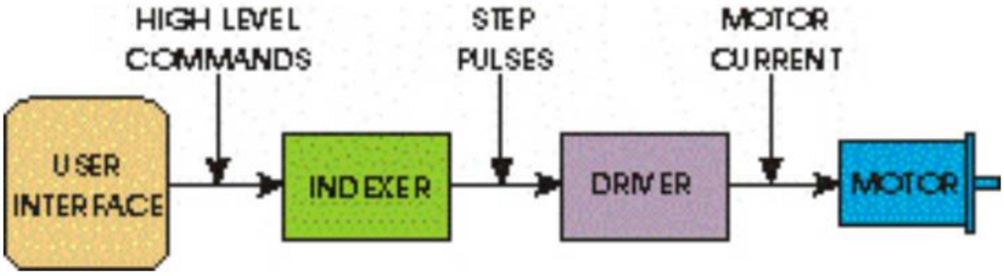


Figure 1.1 Different kinds of Stepper Motor [8]

Moreover, stepping motors are available in a variety of angular resolutions. Their angular resolution may differ based on their type, internal structure of rotor which can be a permanent magnet, variable reluctance, or a blend of both. Permanent magnet stepper motors with a high resolution may frequently turn the rotor of the motor up to 0.72 degrees every step. Hybrid and Permanent magnet stepper motors with the right kind of controller can have the ability to operate in half steps, which have better angular resolution than the full step. and the application of some sophisticated controllers can operate micro-step in a stepper motor [5].

Stepper motors are simple and synchronous motors which utilize electronically controlled magnetic windings to revolve the rotor magnets. As shown in the figure below, the control and operational mechanism of a step motor generally is composed of three fundamental components (motor, driver, & controller), which are often paired with different kinds of user interfaces such as PLC and Personal Computers (PCs).



The User Interface features a collection of motion control commands. These commands by the UI direct the controller to produce the motion signals. The controller (indexer) generating signals of the direction and step pluses for the motor driver is a subsystem that has the ability to understand high-level motion instructions received form the user interface. The directional signals and step pluses received through controller are translated via driver to appropriate current levels to activate the motor windings. The stepper motor alters the waveforms received from driver into mechanical rotor rotation [9].

In order to precisely control an object's motion, one must take into account parameters like as the object's speed and direction, as well as its inertia and various loading conditions in order to do so. Many different motion control mechanisms and devices exist, such as servomotors, direct current motors, induction motors, stepper motors, and etc. The focus of this thesis is on stepper motor, its types, its comparison with other motion control devices such as servomotors, brushless and brushed DC motors, a comprehensive comparison of its different types, its historical background and recent advancements, and the control of its speed and direction.

1.1 Functioning Principle of Stepper Motors

Stepper motors consist of stator which is a fixed component and a rotating component (rotor). The coils are winded in the teeth of the motor fixed stators, whereas the motor rotor may be either an iron core variable reluctance, permanent magnet, or mix of the two (Hybrid).

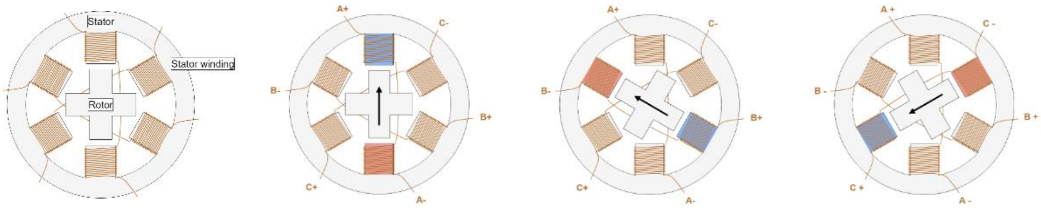


Figure 1.2 Stepper Motor Working Principle [1]

For instance, when one of the stator phases (winding) is activated by applying current to it, there will be a magnetic field generated due to the flow of current through the windings of stator, then the motor rotor is forced by the electromagnetic filed produced by the windings of stator to adjust itself with the coil generated electromagnetic field path. Through the sequential activation of various stator phases, the rotor can be rotated a predetermined fixed step angle in order to achieve the positioning required. The operating concept is shown in figure above. Initially, as soon as the current flows through the Coil A, the rotor comes into an alignment with the electromagnetic field path generated by it. Then, in order to line up with the newly generated magnetic field, the rotor must revolve 60 degrees right to left once coil B is activated. The same thing happens whenever coil C is turned on. The rotor of the motor continues to rotate if we constantly apply current in the windings of the stator coils in a sequential way. The motor rotor speed is decreased or increased by the pulse rate or frequency of pulses applied to the stator windings, and applying the current in the stator windings in opposite sequence changes the direction of the rotor rotational motion. The diagrams above depict the stator teeth's color-coded magnetic field path formed by the windings of the motor stator.

1.2 Stepper Motors Features and Characteristics

- Simple to position, it moves in stages in response to stator winding pulses.
- By inverting the sequence of pulses, the rotational direction can be changed.
- Pulse rate or frequency of the applied pulses regulate the motor’s rotor speed.
- Typically, stepper motors have a voltage rating. While surpassing a motor's specified voltage might help in getting the desired torque, but it can also cause the motor to overheat and shorten its lifespan.
- The amount of current which the stepper motor consumes, its torque, and optimum speed is determined by the motor windings’ resistance.
- A stepper motor's degree-per-step characteristic may be the most important criterion when choosing one for a certain application. This value indicates the degree at which the motor rotor will revolve for one complete step.

1.3 Advantages and Drawbacks of Stepper Motors

Stepper motors due to their accuracy and open feedback structure are capable of doing tasks that most of electric motors are incapable of. While they are not the first option for high speed or continuous output applications, their torque is accessible at rest, they have great repeatability with no cumulative error, they are reversible, reliable, simple to build, operate, control, utilize, and function at a broad range of speeds. Moreover, stepper motors at low speeds provide high torque, and are excellent for positional control with a very simple controlling methodology.

The main disadvantage of stepper motors is the stepper motors reliance on electronic control, which means that any malfunction in the electronics would immediately impair output performance. Additionally, they are less efficient than conventional DC motors and are often unmanageable at high speeds because of their continuous switching poles nature.

To conclude, stepper motors are advantageous when a low-cost, easy-to-control solution is required and when great efficiency and high-speed torque are not essential.

1.4 Stepper Motors Applications and Usages

Stepper motors are utilized in a broad number of industrial applications, including computers and its peripherals, robotics, medical equipments, telescopes, motion control, recirculation valves for exhaust gas, laser cutting, robotics, and etc which all fall under the category of machine tool applications and motion control. Moreover, stepper motors can be used in any area in which repetitive placement of fixed step angles at high frequency, positioning that necessitates a lengthy pause because of breadth adjustment, and other factors, changing loads and rigidity, and shafts of motors necessitating synchronous operation are required. When stepping between positions is demanded, whether it is in industrial applications, medical equipments or military machineries, a stepper motor is often employed.

1.5 Research Problem Statement

When it comes to motion control stepper motors are one of the best choices because they provide step by step angular motion, which can rotate in both the directions (clockwise and anticlockwise). And in today’s modern world most of industry is reliant on the robotics and advanced motion control mechanisms, and other devices which are operated via computer. Step motors are used in various fields, including military, medical, and industrial applications. However, not much is known about its historical background and recent advancement in an organized manner, the comparison of its different types so that when there is a need by anyone for stepping motors to be applied in any relevant project or application, it’s easy for them to choose the right kind of stepper motor for their project. Because every project is unique and they require different type of stepper motor that matches the requirements of that specific project. Moreover, the speed and direction control of stepper motor was usually done manually through the use of a potentiometer, which can be hardly embedded in other modern complex systems which are controlled through computers.

1.6 Goals and Objectives of the Study

The general goal of this study is to explore the stepper motors historical background and recent advancements, different kinds of its comparison among its types and other motors, as well as, designing and building a stepper motor control system which is operated via computer using a simple and efficient Graphical User Interface to control its speed and direction very precisely.

Specific Objectives of the Study

- To explore the historical background and recent advancements of stepping motor technology.
- To compare stepper motor with servo motor, brushless and brushed DC motors, as well as the different types of stepper motor.
- To design and construct a computer-based control system through which the direction and speed of stepper motor is precisely controlled remotely via a designed graphical user interface.

1.7 Contribution of the Study

This study contributes to better understanding of stepper motors historical background and recent advancements; and providing a comprehensive comparison of stepper motor types and its comparison with other motors bringing about an ease and clarity in choosing the right kind of stepper motor as per needed in any specific project that may require use or integration of stepper motors. Moreover, designing and building a system in which the direction & speed of stepping motor is accurately controlled remotely via the use of a personal computer which costs very low and is much easier and more convenient that manual control of stepper motor, which later on can be integrated into much complex systems to achieve bigger purposes, wide areas of application and usage.

1.8 Historical Background and Recent Advancements

The subject of who invented the stepper motor still remains debatable, in part because the early forms of same type motors operating as today's stepper motors were not denoted stepping motors. However, it is largely ascribed to Frank W. Woods, this is due to the reason that he designed a motor that had the capability of being charged in different configurations to generate step-by-step movement, and it was composed of five stator coils, according to the vast majority of engineers. Furthermore, Stepper motor development dates all the way back to the nineteenth century and more; the contemporary stepper motor was invented in 1957 by Thomas and Fleischauer as a variable reluctance stepper motor type [2].

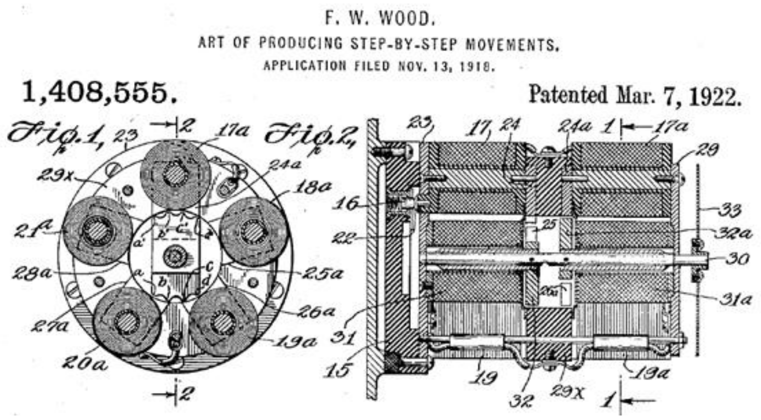


Figure 1.3 Frank W. Woods Invented Motor [10]

The British Royal Navy was the first to employ a stepper motor in a practical implementation, the system was designed and made to control the turrets of the cannons and guns on big ships in the 1930s. Such form of primary stepper motors started to phase out in the 1960s in favor of permanent magnet stepper motors, which had larger stepping angles than of those used nowadays. However, these motors encountered a variety of problems. Due to the lack of precise stepper motor controllers, position precision was restricted, and resonance difficulties inside the motor casings sometimes required the motor to be halted and restart again. During the 1970s and 1990s, substantial advances and improvements were made in the design of controllers that addressed stepper motor resonance problems, as well as in production and manufacturing processes that resulted in stepper motors cost reduction. On the other hand, still the stepper motors were very costly at the time and were primarily employed in military and aerospace applications. There were so many significant improvements and advancements in stepper motor controllers and stepper motors that they became affordable enough to be used and employed in a wide array of uses where they had been very costly before the early 2000s [11].

Although stepper motors have been studied extensively for long, no reference was identified that combined a stepping motor with a low-cost sensor. The partial use of stepper motors in high-end applications may be a contributing factor. As a consequence of its drawbacks, such as its poor accuracy and detent torque than the brushless DC motors and synchronous permanent magnet motor it is used much less often than the mentioned motors. As a consequence, they are less often used than the alternatives. However, certain industry research initiatives, such as Karlsson [12], have been conducted in recent years to determine the viability of replacing current systems with stepper motor applications and implementations.

In terms of stepper motor control, research has been conducted on a variety of fronts. For several years, the researchers centered their effort toward boosting the accuracy of stepper motor's open-loop control by optimizing and enhancing the algorithm of micro-stepping [13, 14]. Several subsequent efforts, such as Derammelaere, et al. [15] have advanced load angle compensation by attempting to achieve better accuracy in open-loop mode. As a result of this, a recent ABB study Liu, et al. [16] deployed the load compensating algorithm in a closed-loop manner.

Alternatively, there are also studies that sought to construct closed-loop control without the use of sensors, relying on estimating algorithms for improving the efficiency of positional accuracy of the permanent magnet stepping motor like the study done by Feng [17]. Additionally, several damping schemes have been devised to compensate for the stepper motor's detent torque Le, et al. [18]. Furthermore, the work which was done by ZHOU [19] for a hybrid stepper motor combining with a sensor that costs very less the author develops a high-resolution control solution that has the potential to be implemented at a cheap cost. Furthermore, in the study which was done by Ghanooni, et al. [20] an ACNFC (*“adaptive critic-based neuro-fuzzy controller”)* is designed to track the hybrid stepper motor speed trajectory with a high accuracy and robustness. Moreover, the torque density of standard hybrid stepper motors has been enhanced by more than 200 percent based on the novel construction described in the research conducted by Hojati, et al. [21].

Chapter 2

LITERATURE REVIEW

Direct current (DC) motors as the name implies are always supplied with direct current. They function on the principle of energizing their stator windings causing their rotor to rotate. The generation of magnetic fields in them is due to the passing of direct current via their stator coils and use of permanent magnets. Because of the electromagnetic interactions with the stator, the motor rotor spins on its axis. During motor operation, the magnetic fields attract and repel one another, maintaining rotation of the rotor. DC motors are classified into three varieties based on their construction: Stepping Motors, Brushless Direct Current Motors, & Brushed Direct Current Motors, discussed as follows.

2.1 Brushed Direct Current (DC) Motors

Brushed DC Motors being one of the main kinds of direct current motors uses mechanical commutation to switch the current, eliminating the need for controller external switch making it simple to operate compared to other motors. The stator is composed of electromagnetic windings or a permanent magnet, which are alternately referred to as field windings or field poles. The rotor is made up with windings, referred to as armatures, which are connected to a commutator-brush arrangement. Furthermore, armature is a DC motor component that is electrically connected to the spinning shaft. The brush-commutator mechanism supplies current to the armature. The commutator is made of copper and is divided into two or more pieces (Fig. 2.1). Carbon brushes skim across the commutator. Brushes move over different portions of the commutator when the motor rotates. The armature different windings are connected to these commutator sections, causing the current in each winding to reverse direction at the appropriate moment for that winding. Additionally, the commutator assists the motor in reversing its direction of motion, so altering the voltage's polarity. This voltage fluctuation induces a magnetic field fluctuation around the armature, reversing the armature's forces.

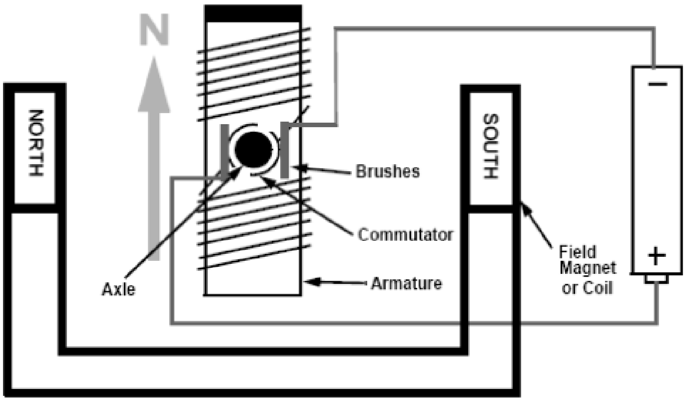


Figure 2.1 Internal structure of Brushed DC Motor [22]

2.2 Brushless Direct Current Motor

Brushes on a brushed DC motor deteriorate with time, which may result in sparking. As a result, brushless DC motors are utilized to operate costly equipment that requires long-term, trouble-free operation. Brushless DC motors provide the similar output like brushed DC motors, but are constructed differently.

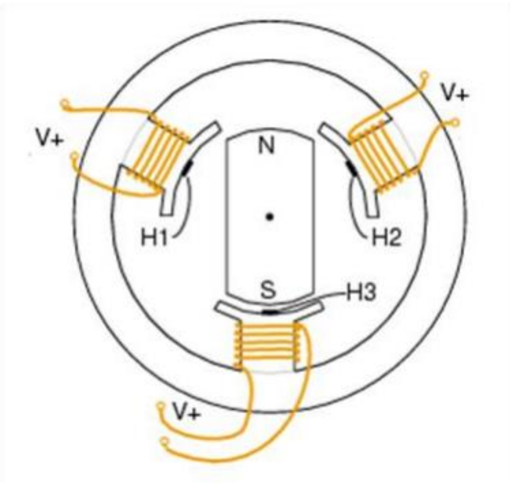


Figure 2.2 Connections for 3-phase brushless DC motors. The Hall-effect sensors H1, H2, & H3 detect and activate the rotor windings. [23]

The brushless dc motor stator is composed of coils and its rotor is comprised of permanent magnets as well as hall-effect sensors to detect the rotor position and activate the respective stator coil to rotate the motor's rotor in a sequential order desired, as seen in the illustration. By applying direct current to every set of coils, they will get energized and produce an electromagnet field and turn out to be electromagnet. The rotor revolves because of the in between interaction of stator coil electromagnet and the rotor permanent magnet. The stator coil generated polarity is the same as the rotor attached permanent magnets. Thus, the rotor's and stator's opposing poles are attracted to one another. When attracted poles are in close proximity, the following set of coils is activated. This process continues, and the rotor continues to revolve.

There is one disadvantage to brushless DC motors. It occurs because just one set of coils is activated, resulting in a loss of power in the system. It can be resolved by energizing the system in such a manner that when the first set of coils rotates the rotor, the subsequent coils push the rotor. This is accomplished by sending current with the same polarity through the second coil. Controlling the coil energization process requires the use of an electronic controller and sensor.

2.3 Stepping Motors

Stepper motor, or stepping motor, or step motor is generally regarded as brushless DC electric motor which splits a whole 360 degrees revolution into equal number of steps. A stepper motor's rotor is composed of permanent magnets and stators composed of windings. A single magnet aligned with the rotor shaft and two pole segments with several teeth are used to create the rotor. The teeth are spaced in order to create several prominent poles. It is an easy to use stepping motor that rotates in step-by-step in response to pulses delivered to the stator coils section. The control of direction in step motor is through inverting the pulse sequence, and the pulse rate or number of pulses applied to stator coils controls the speed of the motor. The second phase becomes ignited when the rotor coincides to a stator pole. The two phases switch between on and off states and also have the ability to change the polarity. The procedure is mostly comprised of four phases. One phase is one step behind the other. This is one-fourth of an electrical cycle, or 90 degrees. Typically, in a stepping motor the degree of every rotational movement is dependent on the number of rotor teeth and stators.

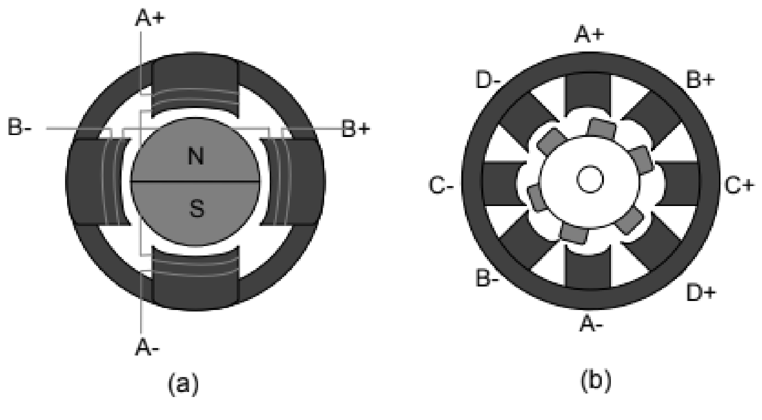


Figure 2.3 Design of (a) PM & (b) VR step motors' stator & rotor arrangement [24]

2.4 Comparison of Brushed DC Motors with Stepper Motors

Both types of motors are utilized in several industrial applications, making it difficult to distinguish between the two. This study compares the motor characteristics of these two systems. For each attribute, a succinct explanation is provided to illustrate why one motor is superior to another.

Criteria	Stepping Motors	Brushed Direct Current Motors
Controllability	There is the necessity of a microcontroller to assist in synching the rotor of them from one position to another.	In to two of their leads they just need an input voltage. Regulation of the input voltage regulates the motor speed, and the motor's rotor direction is changed via reversing the leads.
Speed Range	From 10 to 2000 RPM, when their speed increases their torque decrease. not suitable for constant usage, due to becoming hot if used for long time.	Under 10000 RPM, capable of running continuously for long but require continuous brush maintenance.
Service life	10000 hours	One to three thousand hours
Torque	In slow speeds, they have a torque at maximum level rotating incrementally.	High torque in low speeds but rotating in a continuous manner.
Efficiency	Low, because when the stator poles are activated, they use current at maximum load, due to the heat, lowering the energy efficiency.	Moderate about 80 Percent
Cost	Inexpensive	Inexpensive

Table 2.1 Comparison of Brushed DC Motors with Stepper Motors

This comparison demonstrates that both motors fulfill distinct objectives. While stepper motors are inexpensive and easy to operate, they perform best when employed as a device that controls the angular rotation of a load applied to it with high precision and accuracy. Brushed DC motors are utilized in applications that need the motor's rotor to rotate continuously and maintain a consistent torque output over the motor's speed range. Additionally, stepper motors should be employed when incremental movement and great precision are required. Furthermore, when it comes to efficiency, stepper motors fall short of brushed DC motors. Moreover, the brushes of brushed DC motor may need consistent replacement and maintenance while stepper motor not having brushes are not affected by such concerns.

2.5 Stepper Motor Comparison with Brushless DC Motors

There are several similarities between stepper and brushless DC motors. Both are direct current powered. Both energize the stator coils to cause the rotor of the motor to revolve. They change the sequence of the drive circuit's excitation phases to control forward and backward rotation. Both of these scenarios need electronic commuting and a commute to work. They both create the necessary torque via the interplay of stator windings produced electromagnetic field and the rotor attached permanent magnets.

Criteria	**Stepper motors**	**Brushless DC Motors**
Controlling	Pulse commands are used to regulate the speed and direction. No need for feedback circuit, however, having out-of-step issues.	For maintaining a steady rotational speed, they need data from speed sensors and the torque can be easily controlled because the current level is directly proportional to the torque in them.
Lifespan	Approximately five years	Thousands of hours, based on the lifespan of the bearings
Speed Range	Proportional to frequency of input pulses, in most of application in between 650-1700 RPM	Proportional to the armature supplied voltage, max speed of fourteen thousand RPM
Torque	Particularly at low speeds, high amounts of torque.	Significant initial torque, increased torque at moderate and high speeds.
Availability	Readily available in industry-standard mounting sizes with different varieties.	Custom-built for a particular application, No standard industry sizes.
Efficiency	Low	High up to ninety percent
Noisiness	Noisy particularly at low speeds	Less noise

Cost	Low	High because of positional sensors

Table 2.2 Stepper Motor Comparison with Brushless Dc Motors

Both kinds are synchronous permanent magnet motors in concept. The distinction lies in their unique properties and operating modes. When comparing the features and performance of stepper motors with brushless DC motors, an evaluation of their characteristics and performance may be used as a guide. However, since the same category of motors has a wide range of parameters, the comparison provided in this stud can act as reference in choosing the optimum and suitable stepper or brushless dc motor for a specific application meaning that the final selection should be backed up by the thorough information included in each motor's technical specifications depending upon the usage in each particular project or application required.

2.6 Stepper Motor Types

Stepper motors operate on a fairly basic principle: they alter the rotor rest position with a fixed angle revolution via switching stator windings excitation from one to the next. This is the fundamental concept behind all kinds of stepper motors working principle. However, stepper motors are classified into three types depending on their rotor design and functioning mechanism as follows.

2.6.1 Permanent Magnet (PM) Step Motor

Permanent magnet stepping motor rotor is comprised of two significantly offset permanent magnet of south and north poles. In order to keep the rotor shaft parallel to the magnetic field, the south and north poles of the rotor magnet are alternately positioned in a straight line. As a result of this, the strength of magnetic flux is enhanced. Because of this reason their torque is higher than the other type of stepper motor called variable reluctance stepping motors which will be discussed in details in next sub-heading.

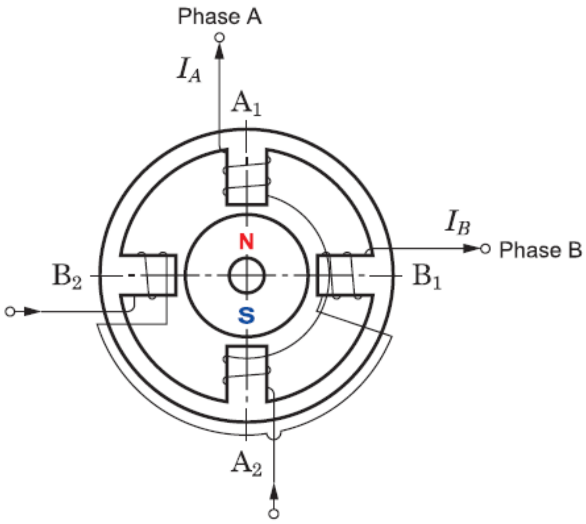


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Figure 2.4 PM Stepping Motor Internal Design [25]

As shown in the illustration above, the rotor and the stator are magnetized by a current such that the A1 and A2 poles are magnetized to opposing poles of the rotors' permanent magnets, pulling the polar opposites to each other. The rotor would revolve 90 degrees clockwise if phase A is de-activated & phase B is activated which is consisted of B2 and B1 stator windings each forming south and north poles to either attract or repel the rotor of the motor.

Without any external stator windings generated excitation, the motor rotor in a fixed stationary position due its magnetic structure. Energizing windings of the stator cause the rotor to move from its resting position. The motor’s rotation is regulated and controlled through alternating the excitation between consecutive phases of the motor. The rotor of the motor can rotate in both forward and backward directions with a step angle of ninety degrees by reversing the pulse direction. To reduce the step angle for having a better angular resolution the we can add more stator teeth increasing the number of windings and excitations and also increasing the number of phases which will result in reducing the step angle and achievement of better angular resolution.

2.6.2 Variable Reluctance (VR) Stepping Motor

These motors are comprised of stators with windings and a rotor which is made of iron and has teeth embedded on it. From a constructional standpoint, the fundamental operating concept is more easily seen. Whenever there is a flow of direct current in stator windings of the motor the poles get magnetized. Rotation occurs as a result of stator pole (s) activation and attracting or repelling the teeth of the rotor. The stator and rotor both feature a high permeability, allowing a considerable quantity of magnetic flux to flow through. When the teeth of the rotor come in an inline position to stator poles of the motor, the rotor is in the position with the least resistance to the magnetic flow.

Thus, the rotor continues to rotate when the current phase sequence is de-activated and the next phase sequence is energized. This phase angle may be altered by altering the stator poles and teeth of the rotor for achieving better resolution.

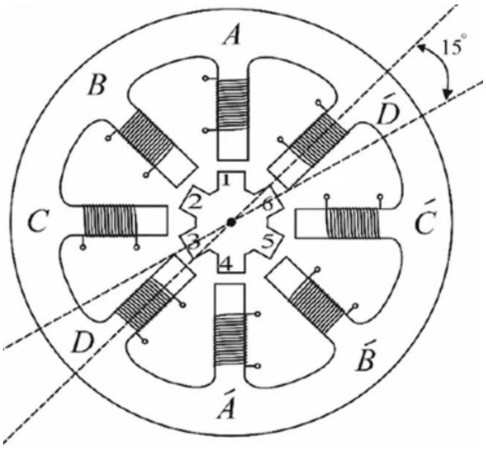


Figure 2.5 VR Stepper Motors [26]

Stepper motors in general from a practical point of view have relatively smaller step angles, less than 30 degrees in most cases. By increasing the phase count and the number of rotor teeth, smaller step angles can be achieved and thus achieving higher resolution. In the motor shown above, one single step results in the generation of a 15-degree rotation with six rotor teeth and four phases. This motor trades off simplicity of control for a greater step number by adding an extra electrical phase. Using two or more teeth per pole as an alternative to this strategy for expanding the no. of steps is also an option, if we do so the desired motor will have 42 steps, resulting in an 8.57 degrees step angle which naturally has higher resolution that the one with fifteen degree of step angle.

2.6.3 Hybrid Stepper Motors

The features and characteristics of permanent magnet and variable reluctance kinds of stepping motors are merged in a hybrid stepper motor, or in plain terms, it's a VR and permanent magnet types of step motors combination. Hence, the word *"hybrid"* is used which means mixture. Although the hybrid stepping motor cost more compared to permanent magnet and variable reluctance types, it has high torque, high speed and high angular resolution.

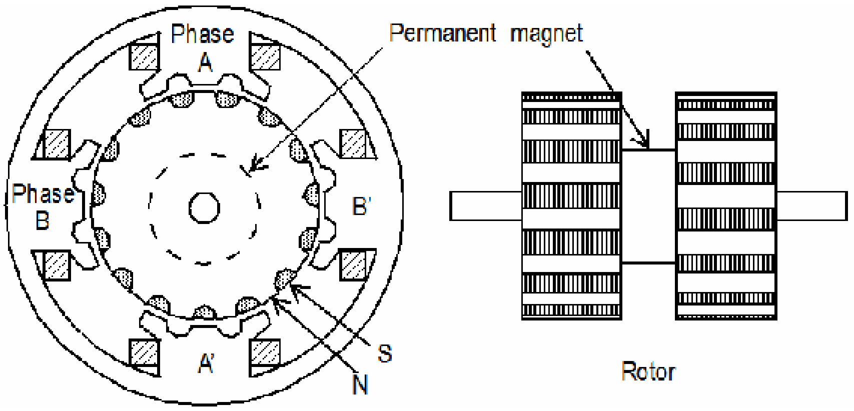


Figure 2.6 Hybrid Stepping Motor Structure [27]

The operating principle of permanent magnet & hybrid step motors are mostly similar. The motor shown above is consisted of a toothed rotor, four poles, and 2 phases. When the phase AA' is stimulated by DC current, and the phase BB' is kept inactive to excite. As a result, the rotor's poles will rotate in a new direction generated by the phase AA' electromagnetic filed path. Similarly, when the BB' phase is energized, AA' is switched off, altering the pole positions. As a result, the motor's rotor will be rotated counter-clockwise. If the BB' is energized in the opposite way; lower pole moves in the direction of the north and the upper pole moves toward south, then the rotor of the motor rotates clockwise.

To drive the rotor of motor in a chosen direction, the stator windings should receive an appropriate sequence of pulses. As a result, this will be protected in a different position upon each excitation. If stator coils are deactivated, this motor will retain its locked condition due to the permanent magnet excitation. This motor's step angle may be specified as 30 degrees. Furthermore, by using a high number of rotor poles, these motors can achieve excellent angular resolutions.

2.7 Comparison of Hybrid, Variable Reluctance & PM Types of Step Motors

i. **Cost:** The first consideration is from the cost point of view. Permanent magnet stepping motors are less expensive due to the production process. Stators are cast in molds that receive molten iron. variable reluctance and hybrid stepping motors need a more complex manufacturing procedure. This is because of the design of gearing on the rotor. To attain the appropriate thickness, the rotor is constructed from thin laminates of soft iron. Reducing eddy currents is the objective of this procedure.

ii. **Angular Resolution:** when it comes to step angle resolution, Variable Reluctance and hybrid step motors may attain very fine resolutions owing to the rotor's geared structure. However, physically the permanent magnet rotors are confined by the pole pairs number they can have.

iii. **Speed:** Generally, in stepping motors increasing the rotational speed of the rotor results in a noticeable drop in the motor's total torque. The torque of a variable reluctance motor is maintained for a longer period of time than that of a permanent magnet or hybrid step motors.

iv. **Noise:** The sound which the step motor generates can be an effecting factor in their application in a project or usage. Generally, variable reluctance step motors generate more noise and are louder compared to hybrid and permanent magnet stepping motors types.

v. **Micro-stepping:** Apart from variable reluctance type, both PM & hybrid step motor types possess the capability of performing micro step leading to higher resolution and accuracy in them.

2.8 Stepper Motors Types Based on the Stator Windings Configuration

The stator part of the stepper motor has a large number of windings tied around it. Electrically, the stator windings configuration can be an important aspect that distinguishes distinct stepping motors types. Thereby, step motors can be coiled or wound utilizing unipolar or bipolar winding configurations in the following manner.

2.8.1 Unipolar Stepping Motors

Two windings are used in these stepping motors, one of which contains a central tap. The center taps may be connected as two separate wires outside the motor, or they can be connected internally and subsequently connected as one wire outside the motor. Unipolar motors often contain five or six wires as a consequence. Unipolar motors are driven the same manner regardless of the number of wires. The coil ends are alternatively grounded and the power supply is connected to the center tap wire (or wires).

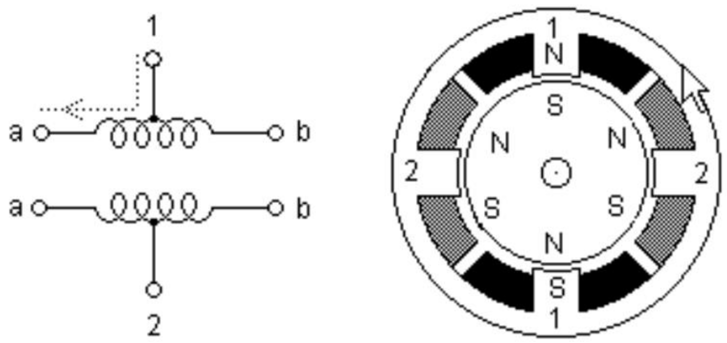


Figure 2.7 Unipolar Stepper Motor [28]

These motors function by attracting the permanent magnetic rotor's north or south poles to the stator poles. Consequently, the direction of the current flowing through the windings of the stator dictates that which one of the stator poles should attract the rotor south or north pole in these motors. Current direction is determined by which half of a winding is activated in unipolar motors. The windings' halves are physically parallel to one another. Thus, depending on which half is driven, one winding works as a north or south pole [28].

2.8.2 Bipolar Stepper Motors

These motors contain four connections and two windings and four connections considering their internal structure and in contrast to unipolar motors, lack center taps. Due to the inexistence of the center tab in them the current can flow through the full winding at once, rather than only half of it. As a consequence, bipolar motors of comparable size generate higher torque than unipolar motors. The shortcoming of bipolar stepper motors over the unipolar type is that bipolar motors need more complicated control circuitry.

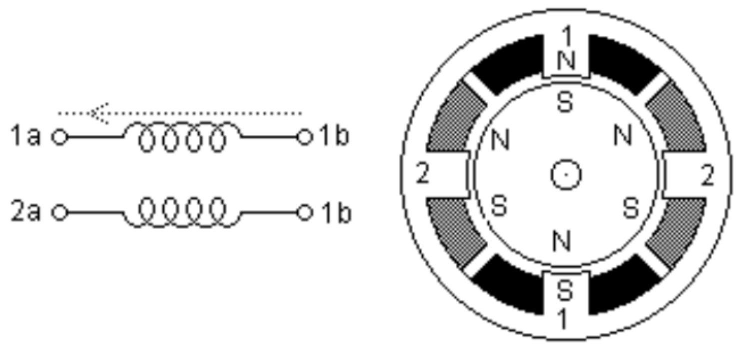


Figure 2.8 Bipolar Stepper Motor [28]

The current which flows through the winding of the bipolar motor is bi-directional and demands reversing every end of windings polarity, show in the illustration above, when position *one b* is negative and *one a* is positive, the current flows from left direction towards the right direction and vice versa. When the polarity of either end is switched, current flows in the reverse direction. To inverse the polarity on the ends of a winding, it’s done using the control circuit named H-bridge and a pair of these control circuit is required because of the existence of two windings in bipolar motor constructional design.

2.9 Unipolar and Bipolar Stepper Motors Comparison

Criteria	Unipolar	Bipolar
Wiring	Unipolar stepping motors have five or six wire connections.	Bipolar stepper motors are consisted of four wire connections.
Direction Control	The unipolar motors are quite simple and they don’t need a voltage reversal to change the direction of the motor rotor.	Bipolar counterparts are complex and they need voltage reversal to change the direction.
Speed	Unipolar motors have higher maximum speed.	Bipolar stepper motors have slower max speed.
Controller	They need very simple controller.	Bipolar motors which need very advanced controllers.
Torque	Lower torque	Higher torque (approx. 30% higher than unipolar motors)

Table 2.3 Unipolar and Bipolar Stepper Motors Comparison

According to the design and internal structure of these motor, bipolar stepper motors are consisted of 4 wire connections whereas unipolar stepping motors are comprised of 5 or 6 wire connections. The unipolar motors are quite simple and they don’t need a voltage reversal whereas the bipolar counterparts are complex and they need voltage reversal to change the direction of the rotation mostly using a H-bridge. Furthermore, the unipolar motors have higher speed than the bipolar stepper motors and they need very simple controller compared to the bipolar motors which need very advanced controllers. However, bipolar motors due to their internal stator winding structure have higher torque about thirty percent higher than the unipolar stepper motor. In general, bipolar motors outperform unipolar motors. They provide increased torque and efficiency. Afterall, the choice a stepper motor may also depend on the need and requirement of a specific project.

2.10 Stepper Motor Drive (Excitation) Modes

Stepper motor driving modes regulate the operation of stepper motors; mainly, there are 3 modes of excitation in step motors: micro-stepping, half step sequence & full step drive. These kinds of excitation modes have an influence on the motor's operating characteristics and torque output. These 3 excitation modes are as followings:

2.10.1 Mode of Excitation for a Single Coil

As seen in figure below, the wave stepping excitation technique energizes just one phase winding at a time and given instructions are numbered (1-4). Following step no.4, the order is repeated from step no.1; reversing the order of the steps from four to one causes the motor to rotate in opposite direction.

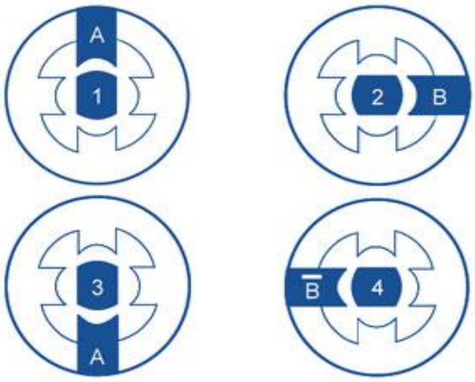


Figure 2.9 Single Coil Excitation Mode [29]

In *one phase on* mode (wave drive), just one stator winding is powered at a time. When the A phase is energized at the south pole, it draws the rotor's north pole and whenever the winding B is on and the winding A is deactivated the rotor turns ninety degrees to the right-hand side, continuation of giving pulses in an orderly manner will cause the rotation of the rotor. Only one phase is active at a time in this mode of excitation. This type of stepping mode results in smooth rotations and the least amount of power consumption, but producing less torque than the other stepping methods. At higher speeds, it is the most unstable.

2.10.2 Full-Step Drive

Two stator windings are simultaneously activated in this mode of excitation. Full step excitation may be divided into two types: 1-phase and 2-phase. One-phase full step mode is when just one phase is activated at a time to turn the rotor, and two-phase full step mode is when two phases are activated to rotate the rotor. Of all the excitation modes, the one phase excitation mode uses the least amount of power from the driver. Reversing the sequence causes it to rotate in a different direction, much as in single-phase mode.

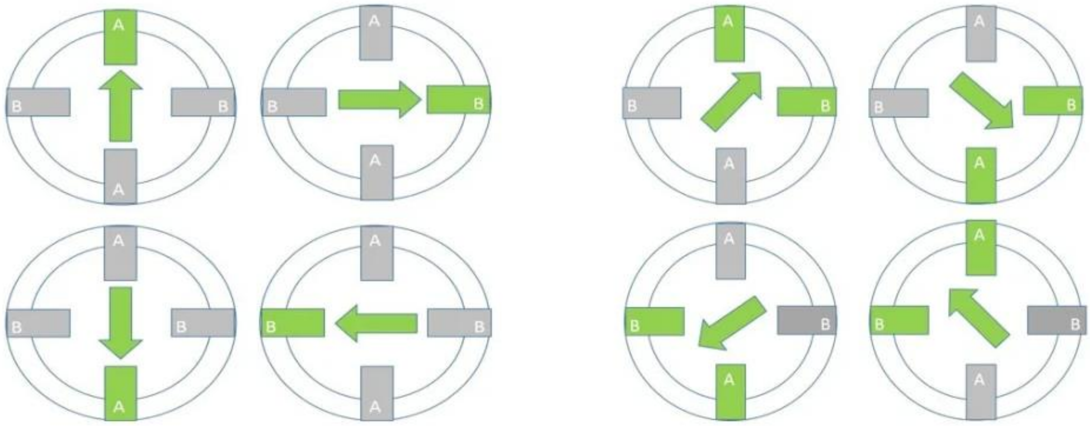


Figure 2.10 Full Step Drive [30]

As per illustrated in the illustration above, the left side diagram shows full step 1 phase mode in which just one stator coil is activated to move the motor rotor from the rest position. Then then another stator coil is activated to move the rotor to another position and so on which will cause the complete rotation of the motor in 360 degrees, each step moving about 90 degrees clockwise considering the example shown above. On the right side, the full step with two stator windings phases on is shown in the figure above in which operates the motor with both phases electrified simultaneously. This setting optimizes speed and torque. Moreover, *two phase on* offers greater torque compared to *single phase on* because it activates two stator windings, but it needs twice the driving power.

2.10.3 Half Stepping Mode

This kind of excitation mode switches in between the single phase and double phase, in the way that first it activates the single excitation mode to rotate the rotor and then it activates two stator windings to move the rotor in between the both stator windings, this is due to the fact that when two phases are one the rotor is attracted to both equally and this causes the rotor to locate itself in between the two activated stator windings causing the half step movement of the rotor from the previous position. And then the following single stator windings is energized to rotate the rotor in another half step and so on, till it completes one full cycle or more as shown in the figure below. The step motor driven on this mode of excitation will have smaller step angles and higher angular resolution compared to excitation modes discussed earlier.

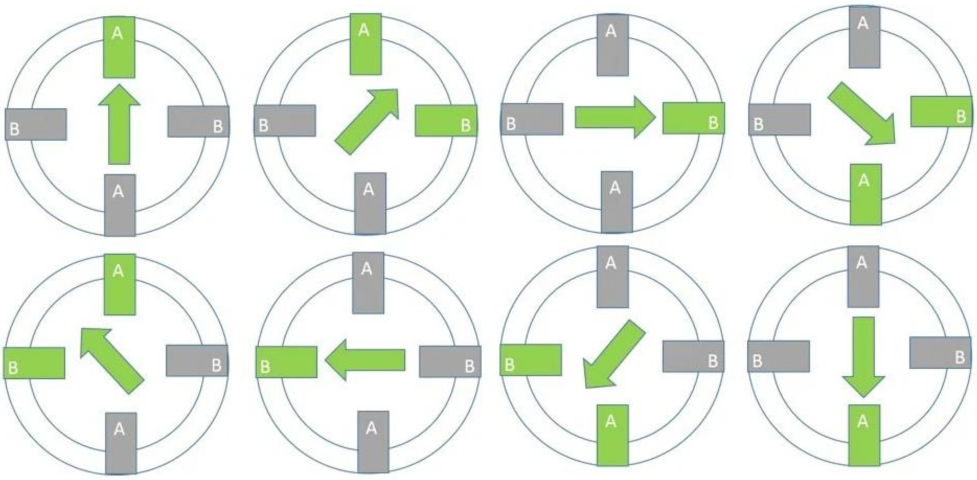


Figure 2.11 Half Step Mode [30]

The half stepping mode has greater resolution than the other two stepping modes discussed above; hence, it is recommended over the two phases on stepping mode. Moreover, this stepping mode produces the maximum torque and in the higher speed maintains a highest level of stability.

2.10.4 Micro-stepping Drive

In comparison to other kind of stepping motors excitation modes discussed the microstepping excitation mode can improve the motor performance at a reduced cost. The noise and resonance issues found in stepper motors are eliminated by this kind of driving mode, also the step angle resolution and precision level of the motor can be enhanced in a large extent by implementing the microstepping excitation mode. In addition, the step angles in this kind of step drive mode can be reduced to a large extent and it has higher accuracy and resolution than other excitation modes.

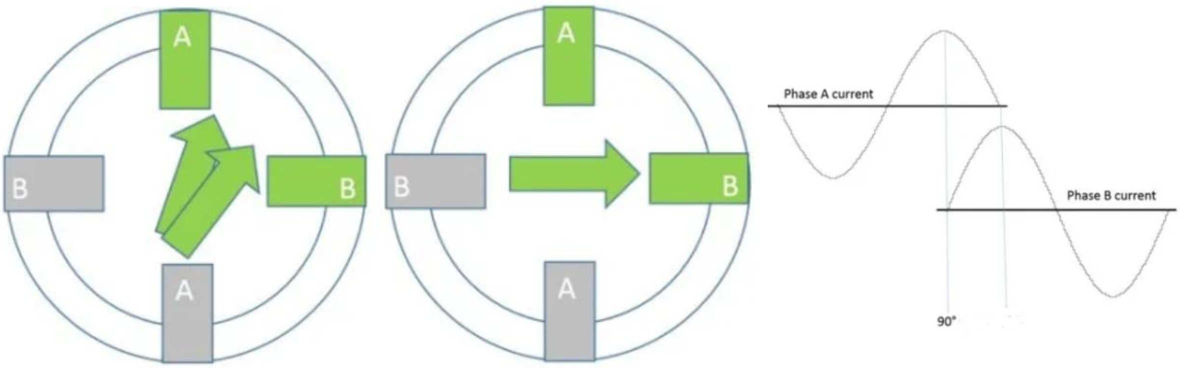


Figure 2.12 Micro Stepping Mode [30]

When stator winding A is energized and it has its max power the stator windings in position B is inactive, in this situation there will be a electomagnetic field generated due to the flow of curent in winding A and the rotor of the motor come with an alignment with it. when there is a gradual decrease in the current of winding A, and gradual increase in the winding B, accordingly the motor rotor will also follow up and gradually rotate in the direction of the winding B, till it reaches its to its max current level and the winding A current level decrease to zero, here the rotor will be in a new position of phase B as shown in the figure above. The same procedure is followed with other windings to cause the motor rotoate in a very small step, hence the name micro-stepping.

2.11 This Project Employed Apparatuses

2.11.1 Unipolar stepping motor

A 28BYJ-48 Unipolar Step Motor is utilized in this project work that has five pins and runs by a direct current voltage of five volts, with four phases and a stepping angle of 5.625 degrees and speed range of 10 to 15 RPM. This motor gives exceptional control of speed during rotation and provides accurate positioning and control. Due of this reason beside its wide application, it’s mostly utilized robotics and other automation applications.

Figure 2.13 28BYJ-48 Unipolar Step Motor

2.11.2 ULN2003 driver

ULN2003 contains the arrangement of 7 Darlington transistor pairings, one of these pairings has ability of driving loads of fifty volts and 500 milliamperes. It can be simply connected to the motor and Arduino. It has 4 control inputs and current supply connections. The Four LEDs show the board's 4 control input lines operational activities and give an incredible visual effect when stepper motor is operating and the its rotor is rotating [31].

Figure 2.14 ULN2003 Driver

2.11.3 Arduino UNO

"*The Arduino Uno is an open-source microcontroller board*" developed by Arduino.cc and based on the Microchip ATmega328P microprocessor, Wikipedia [32]. It is consisted of digital & analogue pins of output/input for connecting to stepper motor driver, power supply, personal computer, other circuitries and etc. It contains fourteen output and input pins, 6 can configured as outputs and 6 configurable analogue inputs. The USB port of the laptop or desktop computer can be used to charge it or it can also be charged by an external nine volts battery.

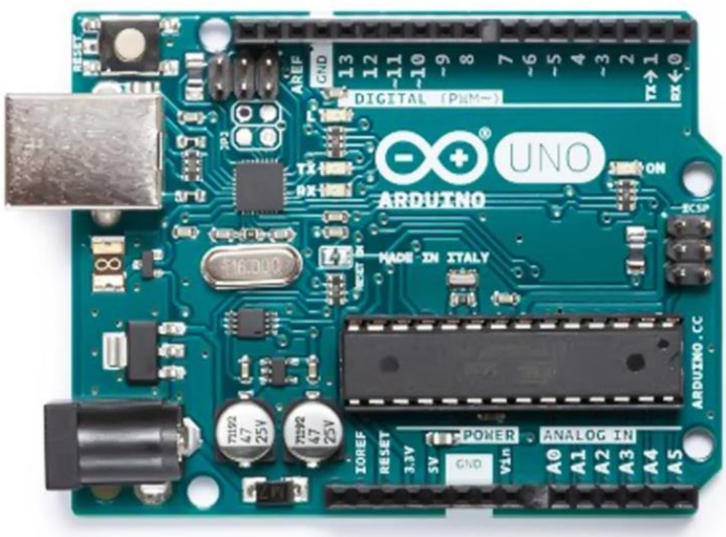


Figure 2.15 Arduino UNO

Chapter 3

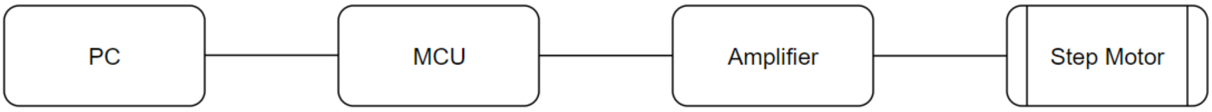
EXPERIMENTAL DESIGN

3.1 Introduction

Design, programming, implementation, and the complete experimental build process of stepper motor direction & speed control system via a graphical user interface using personal computer is discussed in details in this chapter. The overall experimental setup is consisted of two aspects: i) Software aspect ii) Hardware aspect. In the hardware aspect of the experimental design a microprocessor Arduino UNO, a ULN 2003 stepper motor driver, and a unipolar 28BYJ-48 model stepper motor is used, discussed in the literature review chapter. The software aspect includes the use of Visual Studio software to design the desired speed and directional control mechanism graphical user interface in simplest and most efficient way possible.

3.2 Block Diagram of the project

To precisely control the direction & speed of step motor via a PC designed graphical interface the below block diagram is followed up to achieve this objective of the thesis.



The designed User Interface in PC features a collection of motion control commands. These commands by the UI direct the microcontroller to produce the motion signals. The microcontroller (MCU) used is an Arduino Uno generating signals of the direction and step pluses for the motor driver is a subsystem that has the ability to understand high-level motion instructions received form the PC. The directional signals and step pluses received through MCU are translated via driver (Amplifier) to appropriate current levels to activate the motor windings. The stepper motor alters the waveforms received from the amplifier into mechanical rotor rotation.

3.3 Designed Graphical User Interface (GUI)

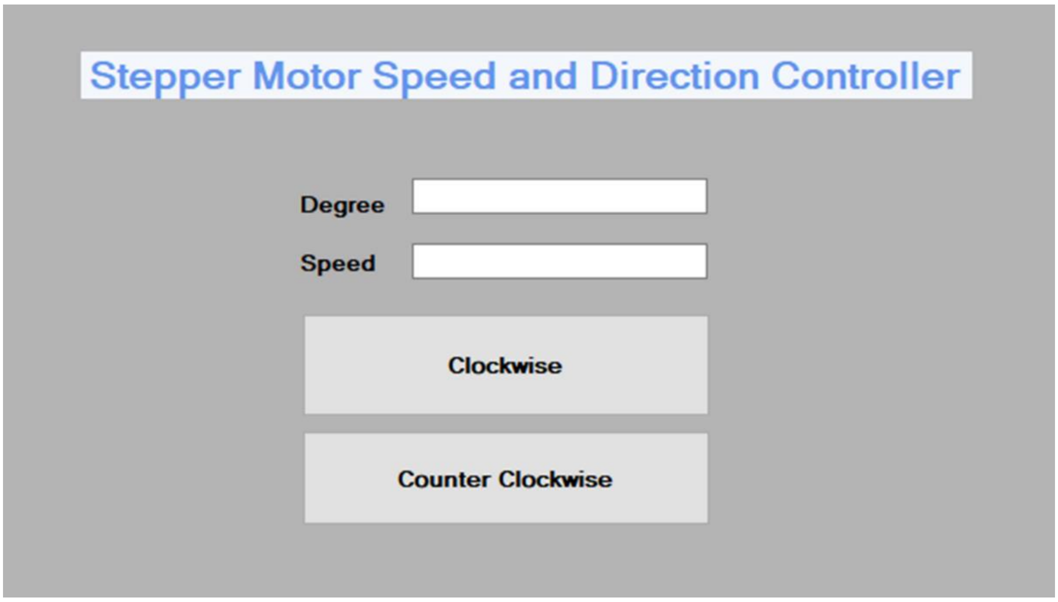


Figure 3.1 Designed Graphical User Interface (GUI)

The PC sends the control commands to the MCU, hence the design of this easy to use and efficient user interface to control the direction and speed of stepping motor so that it can be utilized by everyone very easily. Based on one of the main objectives of this thesis, which is to control the direction and speed of the step motor using GUI, the above shown user inface is coded and designed which is consists of main functions to achieve the objective of the project, such as the *Degree* function which controls the precise angular rotation of the motor's rotor, followed up by another very main and important function of *Speed* which controls the speed of the motor using revolutions per minute as a measurement unit, and lastly the two main functions of *Clockwise* and *Counter Clockwise* which controls the rotation of the motor in either directions of clockwise and anticlockwise.

The Visual Studio programming language is used to design and code this graphical user interface using very simple and easy code. In order to make this GUI we have used the programming language Visual Basic. As visible in code below, first of a serial port is added to connect the designed user interface with the Arduino board through USB port of the PC.

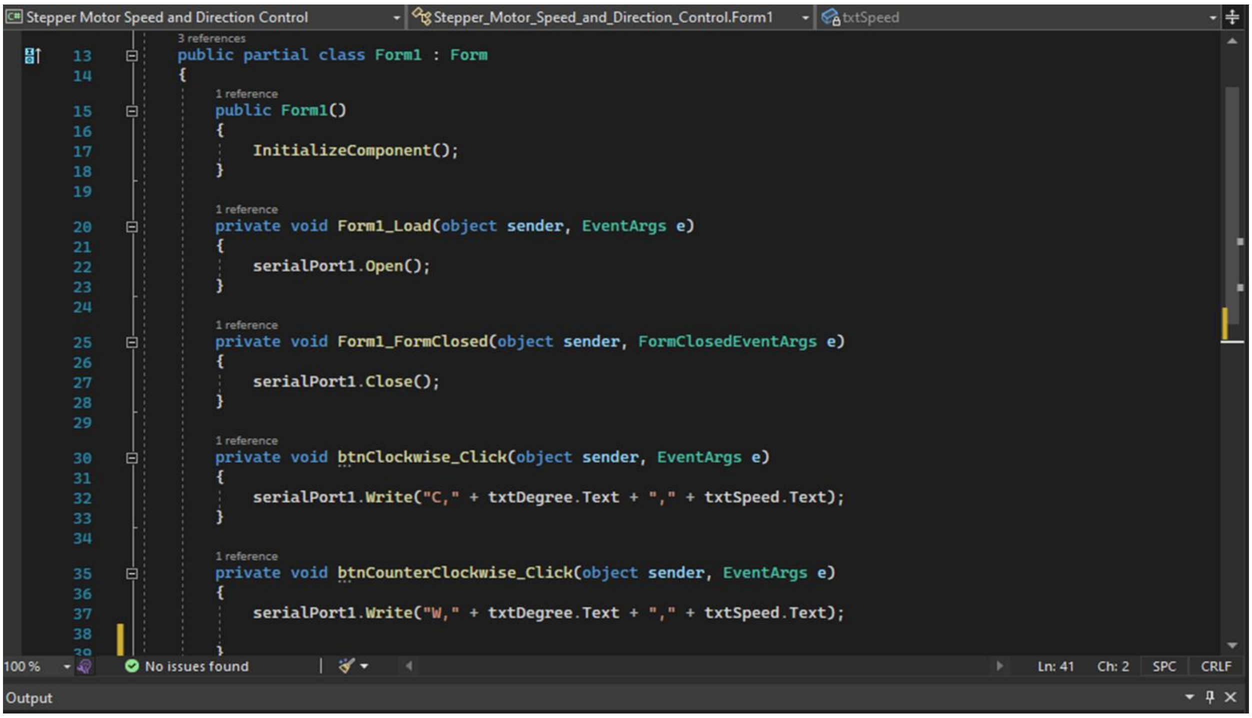


Figure 3.2 The written code in Visual Studio to run the GUI

In Visual studio software after designing the user interface, then using serial port function for the designed form to open the connection for serial port used in COM3 and also the form closed function in which its job is to close the serial port once the user interface is closed, as shown in the image above code number 22 and 27. This is important because while we are using the application the serial port connection will active and operating and once we close the application of user interface it will automatically close the serial port for the Arduino to not further receive any command using the PC designed interface application. Then the following code number 32 and 37 are written to take input values and control the direction, speed, and angular rotation degrees. The code number 32 in the code illustration controls the clockwise direction of the motor, followed up by the taking the input value for angular rotation degrees and the speed in RPM. Similarly, the code shown in line number 37 indicates the same functionality but in anticlockwise direction.

3.4 Project Schematic Diagram

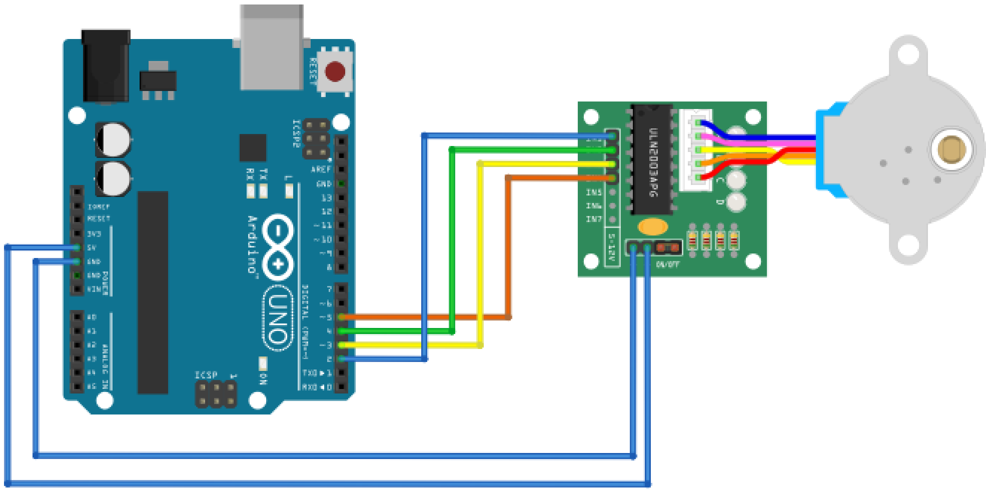


Figure 3.3 Schematic diagram of the project

The designed user interface shown in figure above is connected to Arduino board using its USB port, to provide the high-level control commands to the Arduino. As illustrated in the figure above the ULN 2003 motor driver is connected with the Arduino in such a manner that input number one of the driver is linked with the pin number 2 of the Arduino board, followed up by the input two of the drive with pin number four, input three with pin three, and input four of the amplifier with the pin number five of the Arduino board. This arrangement is necessary for better and precise control of direction and speed of the motor. And stepper motor is connected via the provided motor driver jack. The driver receiving commands of control and changing it to current level necessary to power the windings of step motor. Moreover, the power source which powers all the system is provided by the computer. The implemented circuit shown above experimentally is illustrated in the image below.

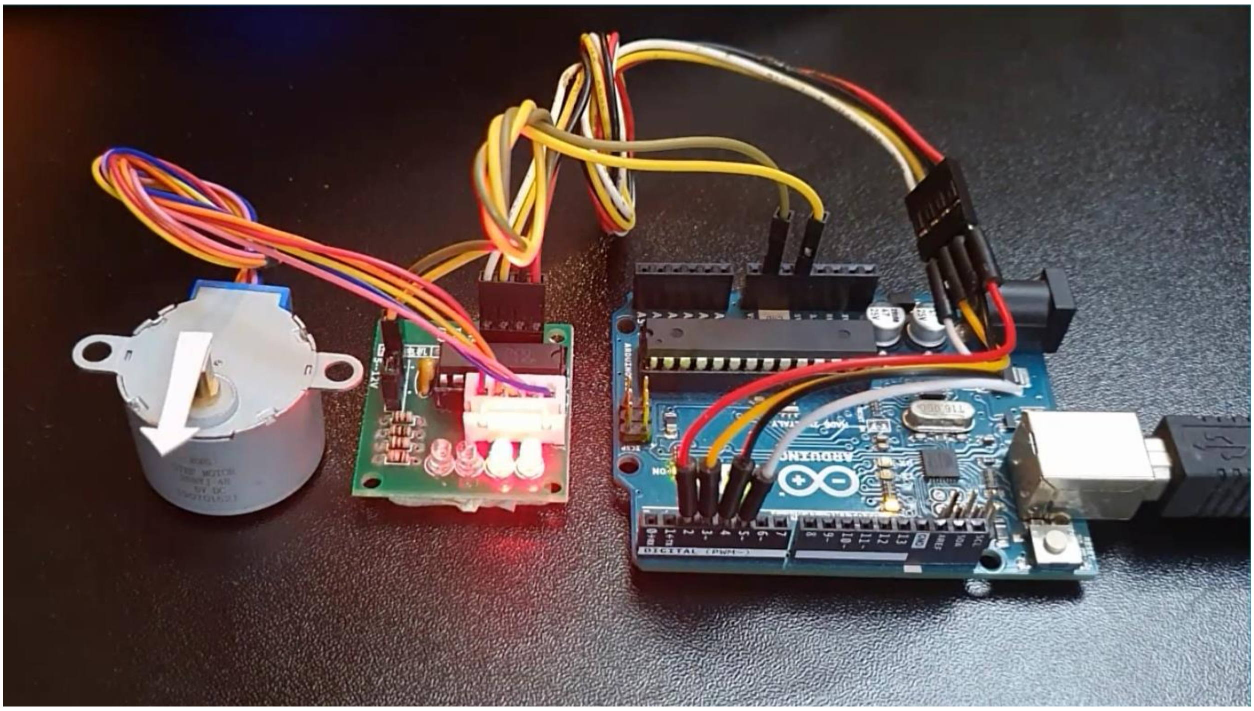


Figure 3.4 Experimental Set up

Concluding, using the designed graphical user interface and the constructed hardware set up shown above the step motor direction and speed can be accurately controlled.

Chapter 4

ANALYSIS AND DISCUSSION

4.1 Introduction

The thesis is primarily designed to achieve the three specific objectives of exploring the historical background and recent advancements of stepping motors technology, to compare the step motor with other kinds of stepper motors such as servomotors, DC motors both with the brushless & brushed types, and comparison of stepping motors types among each other. As well as, the design and build of a control system which controls the direction and speed of the step motor in an easy, efficient and with high level of accuracy via the use of a GUI. In regard to the first objective of this thesis; there has been done a lot of researches, studies and projects to improve the efficiency, accuracy, costing, angular resolution, control systems, and other aspects of different types step motors design to make them easily available to all with a very low cost and high levels of precision, accuracy, angular resolutions and a very wide range of applicability in various fields from its first known forms in early 1920s until the present day.

4.2 Evaluation of Step Motors Comparison with other Electric Motors

Stepping motors in comparison with servomotors have simpler design structure which is usually applied in applications which require low speed under 2000 RPM with high torque, and the stepwise rotation of the motor's rotor for precise control of object in an angular motion. Whereas the servomotors have a complex design structure due to the use of closed loop system in them, they operate in applications which require low torque and the continuous smooth rotation of the motor rotor under five thousand RPM speed range and they cost more than the stepping motors.

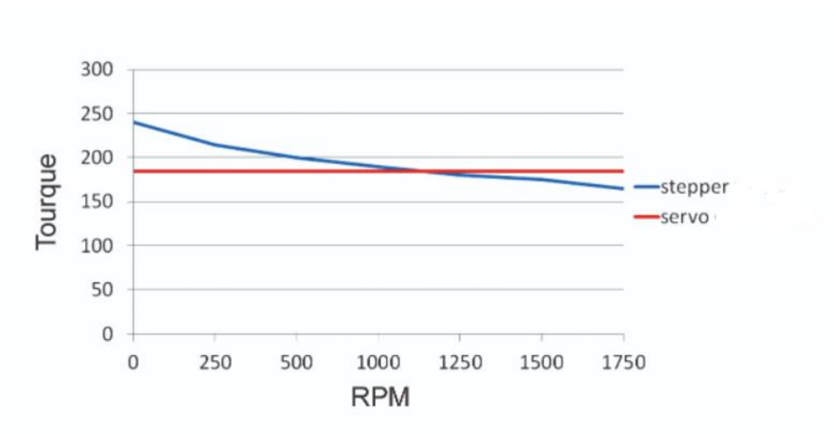


Figure 4.1 Stepper and Servo Motors Torque Comparison

As seen in the illustration above the initial torque of stepper motors are higher than the servomotors as their RPM increases their torque begin to fall, on other hand, the servo motors have constant torque with a continuous rotation of the rotor. Moreover, because servo motors can sustain dynamic loads, they may react with peak torque if the projected load rises. Whereas this is not a characteristic of stepper motors. Furthermore, to program a stepper motor is very easier than the servomotors. The servo motor is more efficient compared to step motor in terms of operation. The chief cause being the servo motor's closed-loop architecture, which uses error signals to deliver high accuracy and rotational motion.

In stepper motors comparison to DC motors, generally the step motors are applied in applications which demands accurate positioning and control of direction and speed and of rotor angular motion. While DC motors are used in application which demands the continuous movement of the motor's rotor with constant torque in contrast to the varying torque of step motors. We have two kinds of DC motors; brushed and brushless. Stepping motors in comparison to brushed DC motors have lower efficiency and speed range in which the brushed DC motor has a speed range of under ten thousand RPM which the speed range of step motors is below two thousand RPM. Moreover, the control system of brushed dc motor is through application of voltage and operating the motor while the step motor requires more complex control system in which to control the operations in it, they need a controller and motor driver. Overall, the choice of where to choose step or brushless dc motor depends on the need the requirement of each application and project. Highlighting the differences and comparisons between these motors help in choosing the best kind of required motor required by a specific project.

On other hand, the alternating power source supplied by the Hall element's sensor positioning controls the DC brushless motor. Whereas the pulse voltage operates the stepper motor directly, eliminating the need for positioning of Hall element sensors.

Brushless DC motors and stepper motors have certain commonalities. Both are powered by direct current. By activating the coils, they both cause the rotor to revolve. They change the sequence of the drive circuit's excitation phases to regulate forward and backward rotation. They both need electronic commuting and the ability to drive to work. They are both powered by the interaction of permanent magnets on the rotor with the magnetic field created by the winding of stator to provide the necessary working torque for operation. At low speeds, the motor produces a lot of torque, which diminishes as the speed increases.

The difference between these two motors include: Step motors provide considerable torque, particularly at low speeds. Brushless DC motors have a high beginning torque, which is proportional to the current in armature of the motor, which is substantial from moderate to high speeds. Stepper motors are typically available in industry-standard mounting sizes, which are simpler to come by and provide more options. Brushless DC motors, on the other hand, are often tailored for particular industrial applications and lack industry standard sizes. When especially in comparison versus brushless DC motors, stepper motors produce greater vibration and noise, particularly at low speeds. Because stepper motors do not need a feedback sensor, they are less costly than brushless DC motors. Brushless motors, on the other hand, require a sensor for positioning. In summary, Brushless DC motors are often utilized in applications requiring low control precision. When control precision is important, stepping motors are employed. A comparison of the features and performance of brushless DC and step motors may be used as a point of reference for selecting the appropriate motor for a specific application. The analysis throughout this section can be useful for gaining knowledge about different specifications and characteristics of each motor mentioned above since the same classification of motors covers a range of parameters. The final selection must be supported by the complete information included in each motor's technical specifications.

4.3 Evaluation of Various Step Motor Types Comparisons

Based on the rotor shape and design of the stepper motors have 3 classifications which are discussed in detail in chapter two of this thesis. Among the three types; the hybrid kind of stepping motor is very much popular on the market since it provides the highest-level performance. On other hand, Permanent magnet and variable reluctance types are just limited to some few applications while the hybrid type is utilized in wide variety of applications. Due to technical advancements in functionalities, distributed control, and simplicity of programming, stepper motor drivers have become cleverer in recent years. Moreover, by adding gearheads and closed-loop feedback, the stepper motor's range of applications can be broadened.

Type	Pros	Cons
PM	• They have detent torque. • Improved damping • A holding torque which is higher.	• Step angle which is large • Torque at constant rate • Power output & size limitations
VR	• Sturdy—no magnet required. • No cogging torque means smooth movement. • High-speed stepping and slewing capabilities.	• Control circuit that is complex • There are no smaller step angles. • There is no detent torque.
Hybrid	• No position inaccuracy in the aggregate	• They have Vibration and Resonance issues.

	• Step angle is 1.8 degrees & smaller • Function in an open loop	

Table 4.1 Comparison of Stepping Motor Types According to their Pros and Cons

Due to the geared structure of the rotor, Variable Reluctance and hybrid types of step motors are capable of producing very fine resolutions. Whereas the permanent magnet type is limited by the rotor made of permanent magnets quantity of pole pairs it may have. The permanent magnet type has a resolution range of three to thirty degrees per step, while the other two types of VR and hybrid have 1.8 and smaller degree per step. Moreover, the variable reluctance type operates only in full step sequence and is noisy while the hybrid and permanent magnet type make very insignificant noise and function in micro, half, and full step sequences which results in having better angular resolutions in them.

As is the case with any stepper motor, increasing the rotor rotation speed results in a reduction in the motor's total torque.

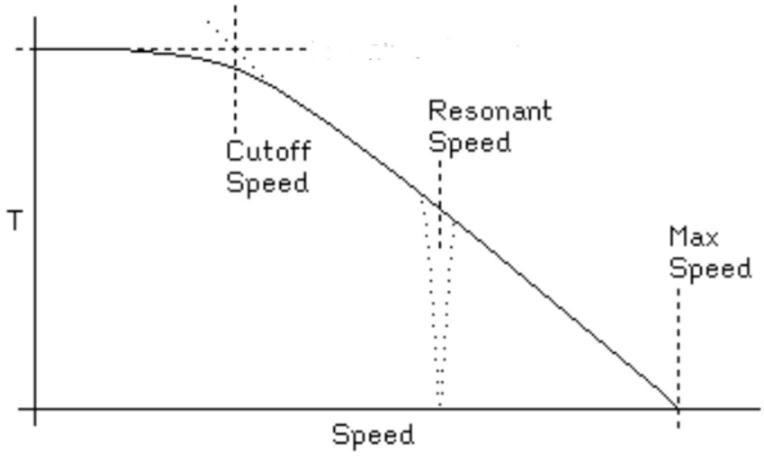


Figure 4.2 Torque and Speed Curve of Step Motors

In comparison to PM and hybrid stepping motors, variable reluctance motors torque is maintained for a longer period of time, and though their dynamic torque generation is minimal, they have a lower torque drop-off when the motor runs speeds which are higher, making them a better option for applications which require moderate to high speeds.

The other important classification of stepping motors is according to stator windings: in this regard the types include unipolar and bipolar stepping motors.

Bipolar step motors are composed of a complex control system due to their need for a device to reverse the voltage applied in order to change the direction of motor rotor rotation, while unipolar counterparts are not subject to such concerns. However, the way the stator coils are wound have an impact on overall performance of the motor. Unipolar type generally has five to six connections whereas the bipolar type has four connections.

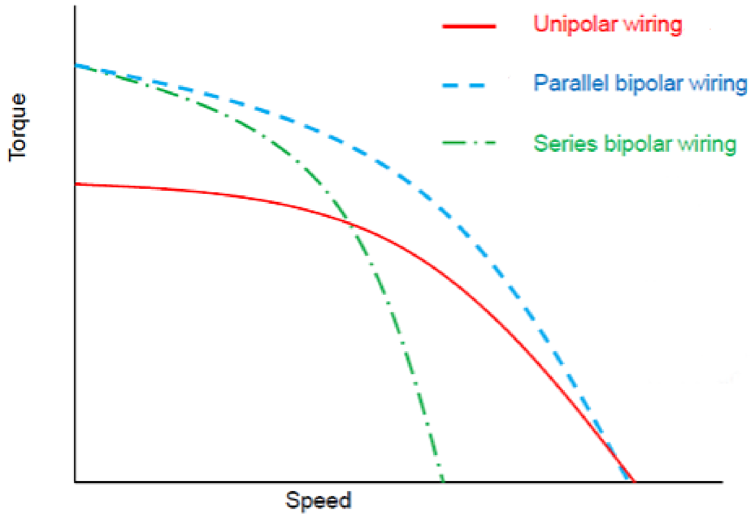


Figure 4.3 Bipolar and Unipolar Wiring

In general, bipolar motors outperform unipolar motors because they provide increased torque and efficiency. Moreover, As seen in the figure above, the way the bipolar type of step motors wires are wired have an impact on overall torque and performance of the motor. If the wires of the bipolar motors are linked in parallel, they can have higher torque compared to wiring them in series and better performance and efficiency.

4.4 Graphical User Interface Design and implementation

The third objective of the thesis included the direction and speed control of step motor using GUI. The achievement of this objective was based on three aspects: i) Software aspect meaning the design, programming, and coding of the user interface in Visual Studio software; ii) Hardware aspect in which the unipolar stepping motor, motor driver, and an Arduino Uno were used physically to experiment and test the performance of designed simple and efficient graphical user interface in a practical manner; and iii) the connectivity of hardware components in which the PC is connected to the Arduino board using its USB port to provide the high levels commands to it via the designed user interface, and then the Arduino is connected to the motor driver ULN 2003 to transmit the received directional signals and speed pluses commands to the it. And lastly the driver is connected to stepping motor. The reason behind the usage a driver is that the Arduino can't directly send the commands received from the computer to the stepper motor, hence there is the role of a motor driver to receive the commands from the Arduino and translate in to appropriate current levels required to power the stator windings of the motor causing the motor rotor to rotate. If the speed give in the user interface is higher than the specified speed of the motor, the motor simply will not rotor, it just vibrates continuously. Thereby, the speed range should always be given within the range provided by the manufacturer described specifications.

Chapter 5

CONCLUSION AND RECOMMENDATION

Stepper motors are an optimum choice and advantageous in areas where there is a need for a simple-to-control, low-cost, rotational accuracy and positioning at low speeds with high torques solution is required; however, the stepping motor do not perform the best when they are applied in applications which demand high torques at higher speeds of more than 2000 RPM. This is due to the fact that the step motors torque decreases as their speed increases. Stepper motors in spite of being very useful and used in so many areas like medical, military, industry and other applications they have their drawbacks also which are discussed in this chapter one of this study. There have been conducted numerous researches on stepper motors and improving their efficiency, minimization and elimination of their drawbacks from starting from their early forms in 1920s to the present day. There are a lot of devices which are used to control the rotary motion of an object such as DC motors, servomotors, induction motors, step motors, and etc. The focus of this thesis work being on stepping motors; these electric motors have variety of types and classifications, for one to choose the correct type required for a specific project or application there should be a comparison of different stepping motor types specifications, advantages and drawbacks so that the choice of stepper motor type can be easy and convenient and help in choosing the right kind of step motor for a specific application through different comparisons of its types provided. The same concept is applied to comparison of stepper motors with other electric motors. Hence, in this thesis a complete comparison of stepper motor types and its comparison with other electric motors have been provided. Moreover, the control of stepper motor which includes the control of its directional rotation either in clockwise or counter clockwise and the speed of it is another main objective of this project. Hence, the findings of this thesis work can be summarized in following points:

- There has been done a lot of researches, studies and projects to improve the efficiency, accuracy, costing, angular resolution, control systems, and other aspects of different types step motors design to make them easily available to all with a very low cost and high levels of precision, accuracy, angular resolutions and a very wide range of applicability in various fields from its first known forms in early 1920s until the present day.
- Stepper motors in comparison to servo and DC motors are less efficient and are not the optimum choice when efficiency is of concern.
- Hybrid Stepper motors have the best performance characteristics, combining the features of permeant magnate and VR stepping motors and an ideal choice to be applied in most of the applications.

- Bipolar type of step motors due to their high torque & efficiency are generally better compared to unipolar type.
- The design and coding of the Graphical User Interface (GUI) employed in this thesis is done in Visual Studio Version 2022 software.
- The GUI used in this thesis work to take the speed, degree and directional commands of clockwise and counterclockwise is designed simple, easy to operate and very efficient.
- Utilizing the designed GUI and the hardware components (Arduino, Amplifier, & step motor) the direction (clockwise & counter clockwise) and speed of stepper motor is accurately and precisely controlled based on the control system described and successfully implemented in this thesis.

This study can be further improved and carried out by; conducting a more in dept research on the stepping motors recent advancements covering a wide range of literature and numerous studies, researches, projects, and other resources to provide a compressive overview of step motors technology and preparing the ground for further improvements and research on eliminating the drawbacks of stepper motors and improving their efficiency and widening their range of applications. Another study which can be done to improve the findings of this thesis work is to compare the stepper motor different specifications, benefits and drawbacks with other electric motors which are used in field of control motion for providing a bigger picture of stepping motors comparison with other electrical motors to provide ease and simplicity of choice in choosing and electric motor for a specific application. Further, in the aspect of stepping motor control, the designed GUI in this study can be further improved and made more professional by adding more buttons of control in the GUI such as stop\start, reset, exit, and the display of current position of the motor rotor, as well as the control of several step motors and different kinds of them to be further integrated in much more complex systems and applications to achieve bigger objectives.

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