VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

Laboratory Servo Drive Stand With a DC Motor

Laboratorní stanoviště servopohonu malého výkonu se stejnosměrným motorem

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Bachelor Thesis

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Description:

1. Make a theoretical analysis for DC motors, their power supply methods and their control.
2. For a given DC motor and power supply, analyse the control and management options in terms of available user interface so that demonstrations can be made to students.
3. In consultation with the supervisor, implement a servo drive laboratory station with DC motor.
4. Perform sample verification and measurements on the given station.
5. Based on the results obtained, set up a sample laboratory problem to familiarize the students with the function and behavior of a DC servodrive.

References:

Jens Weidauer, Richard Messer: Electrical Drives
Manufacturer literature of used motors and inverters.

Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

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Abstrakt

Hlavní cíl této práce je zaměřen na dvě části, kterými jsou představení teoretické analýzy pro každý typ krokového motoru, jeho napájení, metody řízení a vytvoření laboratorního stanoviště krokového servopohonu k určení přesné cílové polohy každého písmene v abecedě určené integrovaným pravítkem na laboratorním stojanu vybraného krokovém motoru spolu s měničem a programem Ezi-Motion. Na základě získaných výsledků demonstračních měření jsou vytvořeny laboratorní úlohy, které mají studentům pomoci při získávání znalostí.

Klíčová slova

krokový motor, servopohon, servosystém, laboratorní stanoviště, lineární vedení.

Abstract

The main goal of this thesis focuses on two main parts, which is to present theoretical analysis for each type of DC motor, their power source, control method and establish a servomotor laboratory to determine the speed, position and torque control and increase or decrease the speed of the unit with an analogue button based on the selected DC motor, to program the DC motor it is necessary to use the Motion Manager 6.0 software manufactured by Faulhaber. Lab tasks are created and based on demonstration results for the purpose of supporting students to continue their practice.

Keywords

DC motor, Motion Controller, Motion Manager ,laboratory site.

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Contents

List of symbols and abbreviations

DC	–	Direct Current
AC	–	Alternative Current
GND	–	Ground
LED	–	Led Emitting Diode
I/O	–	Input/Output
PP	–	Profile Position
PV	–	Profile Velocity
CSP	–	Cyclic Synchronous Position
CSV	–	Cyclic Synchronous Velocity
CST	–	Cyclic Synchronous Torque
APC	–	Analogue Position Control
APV	–	Analogue Velocity Control
APT	–	Analogue Torque Control
AnIn	–	Analogue In
Digin	–	Digital In
Digout	–	Digital Out
Nm	–	Newton/metermeter

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Chapter 1

Introduction

Direct current is used to operate DC motors. The motor uses the energy to begin rotating. This causes the motor to deliver power to various applications in multiple domains. The DC motor has a feature that can modify its speed. It is possible to vary the speed of the motor according to the specifications and can operate the motor in the desired manner by adjusting the speed of the motor. In many cases, speed control mechanisms can be applied to motor movements, such as in the case of control of robotic vehicles, motor movements in paper mills, and motor movements in elevators with different types of DC motors [1].

We operate many DC motors in our everyday lives, and it's no exaggeration to say that they're everywhere. There are many applications for DC motors, and they're used in a variety of ways. You can find examples of these devices in your home like Electric tooth brushes , Computer ,Washing machine ,Vacuum cleaner, Smartphone, Electric toothbrush, Electric fan.. In your office, DC motors can be found inside POS (Point of Sale) and printer . In addition to these examples, motors are also used in furnaces and other home appliances and medical devices. Considering the great volume of DC motors found in modern appliances, and their contribution to noise and energy efficiency, they play an important role both in the determination of living conditions and in global climate change [2].

Currently, although alternating current (AC) is widely used, DC motors still exist. In industry, DC motors are used where large machine openings are required or where wide and flat speed regulation is required. Since DC motors have very good working characteristics on speed control faces (wide adjustment range, even from zero speed). But the reliability when using d.c. motor is lower than that of asynchronous motor due to brush contact system.

In fact, the mechanical characteristics of the independent and parallel excited motors are almost the same, but when large capacity is needed, people often use independent excitation electric motors to adjust the excitation current more conveniently and economically. more economical although this type of motor requires an additional external power source. In addition, unlike the case of series excited generators, series electric motors are used a lot, mainly in the electric load traction industry.

Chapter 2

DC Motor Fundamental Theory

2.1 History Introduction

The basic principle of electromagnetic induction was discovered in the 1800s by Oersted, Gauss, and Faraday. Electric motors convert electrical energy into mechanical energy based on electromagnetic induction. Until 1820, Hans Christian Oersted and Andre Marie Ampere were the first to discover that electric currents create magnetic fields. Over the next 15 years, multiple experiments and innovations led to the production of the first DC motor.

During Michael Faraday's tenure as an experimenter, the findings of Oersted and Ampere's experiments were either confirmed or disproven. In October 1821, Faraday first proved that a magnetic field would surround a current-carrying wire, and it wasn't until the end of the year that he had done so. It was Faraday who invented the electric motor because his free part rotated around the fixed part when the battery was connected to form an electric circuit. Reversing this action, the free part again rotates around the magnet.

It took Joseph Henry 10 years to refine Faraday's experimental motor improvement in the summer of 1831. A horizontal electromagnet that Henry built moved on an axis horizontally in a simple device. Due to its movement, polarity is automatically reversed, as wireless connections are made between the two electrochemical cells by the wires at its ends. This electromagnet swings back and forth at a rate of 75 cycles per minute due to the effect of two vertical permanent magnets that alternately attract and repel each other [3].

Since the beginning of the century, DC motors have been developing. In 1832, British scientist William Sturgeon invented the first DC motor, which could operate machines. For creating the first DC motor in history, he is renowned. This invention was patented in 1837 and brought recognition to the world. Although he was the world's first DC motor, the motor still had problems consuming power while running on battery power. This affects the reliability of the motors over the long term. The DC motor was modified by American scientist Thomas Davenport.

Science has begun to discover new concepts about the DC motor that were originally invented by William Sturgeon. Moritz von Jacobi, a Russian engineer, invented the first rotating DC motor in 1834 to improve its power, which is later recorded as a world record. He then went on to develop a DC motor with an even greater level of power. Moritz von Jacobi, however, did not stop there. Engineers have benefited from this work, as he inspired others to pursue and produce DC motors of similar capacity.

It was in 1864 when engineer Antonio Pacinotti developed the ring armature which gave the DC motor a new twist. DC motors, in general, rely heavily on this component. As the current passes through the grouped coils, the ring armature carries it.

This was perhaps the most important aspect of making the DC motor commercially available during the development of the DC motor in the 19th century. With the invention of the Julian Sprague engine, the speed could be maintained under diverse loads. Early electric trolleys and elevators would benefit from this. As a result, motors became more popular, both for commercial and residential purposes. People use DC motors in many aspects of their lives and in many industries today. These motors are known for their increased performance and productivity [4].

2.2 Basic of DC motor

Electric motors convert electrical energy into mechanical energy by means of direct current (DC). Electric motors use direct current power to generate magnetic fields that drive a rotor fixed within the output shaft. DC motors use magnetic fields that are generated by the electrical current. It is both the design of the motor and the electrical input that determine the output torque and speed [5]. The direction of the electric current in DC motors is controlled by internal electromechanical or electronic mechanisms within the motor [6].

2.3 The structure of a DC motor

The stator and armature are the key components of DC motors. Motors consist of a stator and an armature, which are stationary parts. As the armature rotates, a rotating magnetic field is created by the stator of a DC motor. The stator of a DC motor consists of magnets that are stationary, and a coil of wire that is driven by a current that aligns the magnetic field with its center.

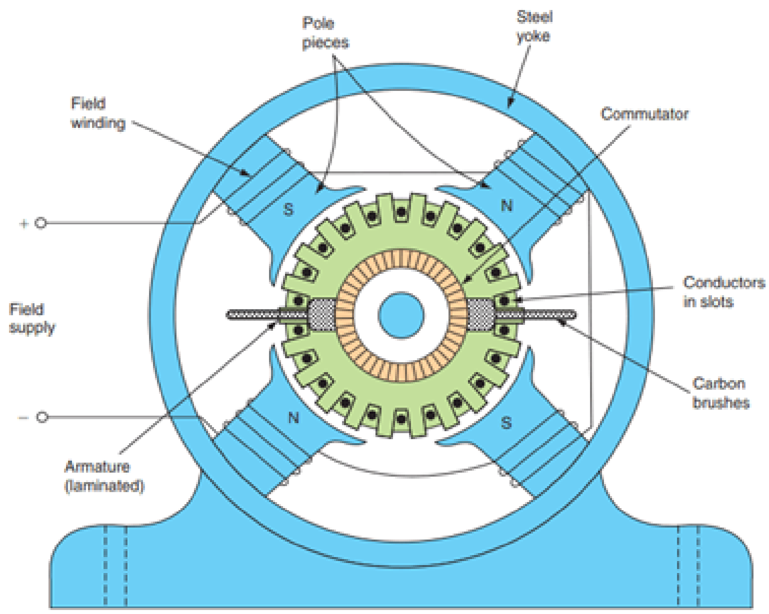


Figure 2.1: A cross-section of a DC motor [7].

All the other components of a DC motor are placed inside a cylindrical steel yoke, which may be referred to as a stator. Stators have a vertical shaft that emerges from one face of them, along with two terminals for plugging in a DC power supply.

The stator of a DC motor is made up of two stationary permanent magnets. A horizontal magnetic field is created across their surfaces, forming their north and south poles.

Armature is an electrical engineering term used to refer to a rotating coil structure that is influenced by electromagnetic forces. The rotor is placed between the two magnets of a DC motor's armature. There are several discs laminated together that are wrapped around a coil of conducting field. Along with the axis of the armature, the shaft pointing out of the motor rotates.

As the permanent magnets on the inside walls of the stator are replaced by a copper winding, the field coil is the field winding of the motor. With a polarity-controlled electromagnet, DC can be passed through this coil to set up any desired magnetic field.

In DC motors, the electromagnetic armature coil inside is wound around a hollow cylinder segmented at many points to reverse polarity. Powering a motor with a DC supply is a critical component. This power supply goes around the shaft of the motor. All the parts except the brushes, except the ends of the armature coil, are electrically isolated from the commutator.

Connecting the static terminals to the rotating parts of the motor are the brushes in a DC motor. They are often made of graphite since it conducts electricity well and makes for excellent lubricants. In addition to the commutator and brushes, the motor is also equipped with the motor's terminals, which completes the circuit with the DC power source [7].

2.4 Principle of operation

Current-carrying conductors and magnetic flux are essential to DC motors. For example, consider a DC motor that has a coil for DC current and brushes for magnetic flux. During the rotation of these segments, magnetic flux is generated. In the commutator, the portion of the segment which contacts the left brush has polarity positive and the portion of the segment located on the right has polarity negative. These two characteristics cause a current to flow through the coil.

Electrical energy is converted into mechanical energy by DC motors. An electric motor is based upon the principle that, whenever a conductor carrying a current is placed in a magnetic field, the conductor experiences mechanical force as a result. DC motors use the Lorentz equation to calculate the force transmitted.

2.4.1 Scalar Multiplication with Vectors

In mathematics, vectors are quantities that can be described both by magnitudes as well as by directions Many vectors have more than one component since they are related to a set of coordinates.

Scalar quantities can be referred to as quantities that are completely described by a magnitude (or numerical value). These quantities can often be made up of only one number, which is called a scalar. Scalars are simply fancy words for real numbers and they can be used in many situations. The scale of a vector is changed when using a scalar [8].

As a result of multiplying a vector by a scalar, a new vector appears.

To multiply a vector, follow these steps:

$$v =< x, y > \tag{2.1}$$

by the scalar k:

$$kv = k < x, y >=< kx, ky >$$

where x,y are components of the vector v

The following results are achieved through scalar multiplication from a geometric point of view:

- Scalar multiplication by a positive number other than 1 changes the magnitude of the vector but not its direction.
- By multiplying a scalar by -1, its magnitude remains the same but its direction is reversed
- Any negative number multiplied by the scalar changes the magnitude and the direction of the vector

Multiplication of a scalar can either increase or decrease the magnitude of a vector :

- The magnitude of a vector is increased by multiplying the scalar by a number greater than 1 or less than -1.

- The magnitude of the vector decreases when the scalar is multiplied by a fraction between –1 and 1.

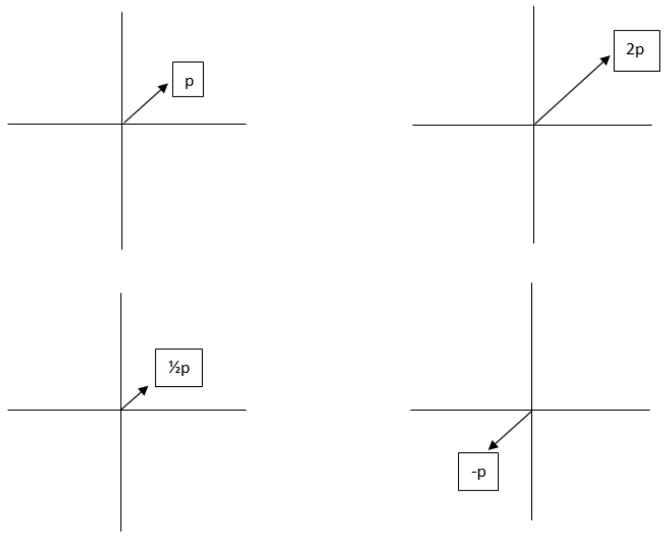


Figure 2.2: Scalar multiplication of a vector changes its magnitude and/or its direction

As you can see, the vector 2p is twice as long as p, the vector 1/2p is half as long as p, and the vector p extends in the opposite direction to p while also being the same length as p [8] .

2.4.2 Fleming's left-hand

Fleming's left-hand rule tells us the direction and magnitude of this force:

$$F = BIL$$

Where B = magnetic flux density, I = current, L = length of the conductor within the magnetic field.

Magnetic field direction is represented by the first finger of our left hand, current direction by the second finger, then force experienced by the current carrying conductor is represented by the thumb of our left hand[9].

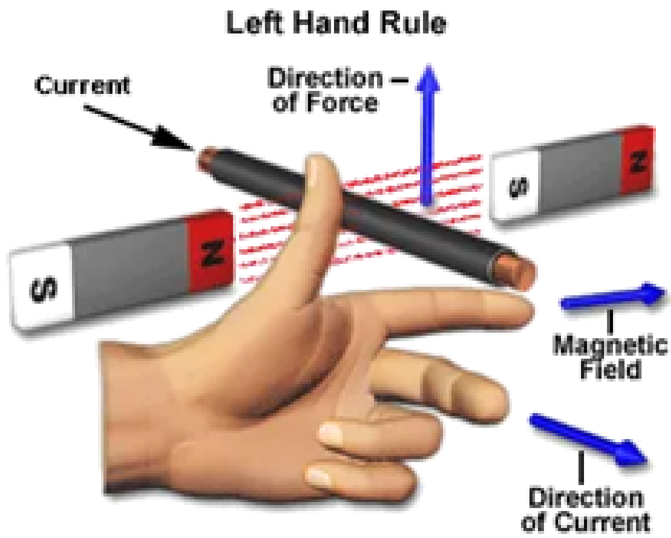


Figure 2.3: Left Hand Rule [10].

At the point of the armature's initial location, angle α = 0, the armature is in its starting position.

$$\tau = BIL\omega \times Cos0^0 = BIL\omega$$

Where τ = Torque, ω = width of the armature turn Therefore, since $\alpha = 0$, $Cos\alpha = 1$, or the maximum value, so at this position the torque is all about τ = BIL which equals the maximum torque. In order to get the armature to rotate, a high starting torque is needed to overcome the inertia of the rest.

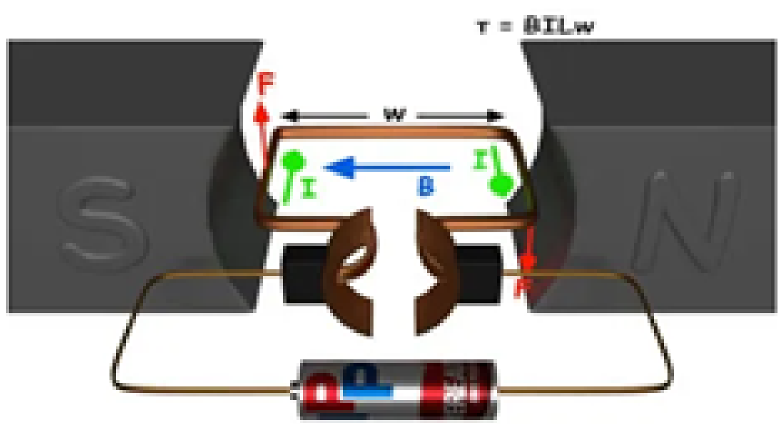


Figure 2.4: Starting position at angle $\alpha = 0$ [10].

After the arm moves into motion, it increases its angle α as it rotates until it becomes 90^0 from the initial reference position. As a result, the value of torque decreases and $cos\alpha$ decreases. When α is greater than 0^0, the torque is given by τ = BILcosα, which is less than $BIL\omega$.

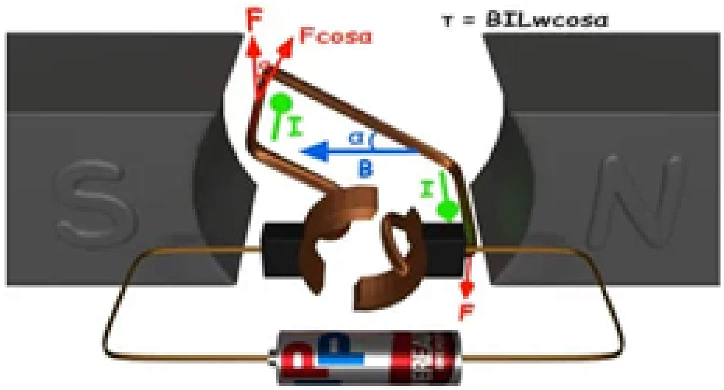


Figure 2.5: Rotate with angle α [10].

The actual position of the rotor is reached at a point in the armature rotation path where it is perpendicular to its starting position, such that $\alpha = 90^0$, therefore the term $Cos\alpha = 0$. When the conductor is in this position, the torque acting on it is given by.

$$\tau = BIL\omega \times Cos90^0 = 0$$

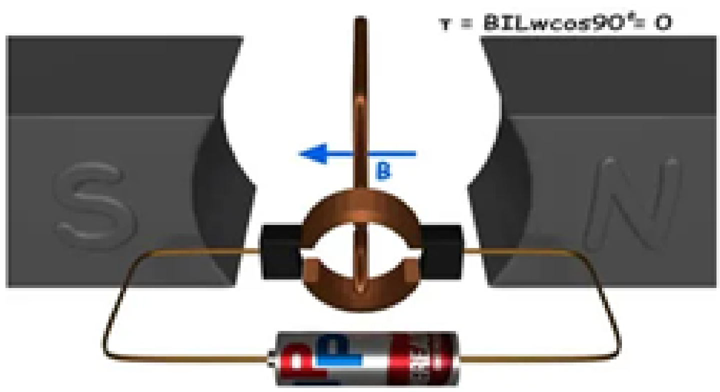


Figure 2.6: Rotate with angle $\alpha = 90^0$ [10]

2.5 Back-EMF

The armature of a motor is driven by a voltage (an electro-motive force) that creates a magnetic force that causes it to rotate. An armature rotating in a magnetic field generates eddy currents that generate a counter force. Back Electro-motive Force (BEMF) is the name of this counter force. It is a force that is produced whenever one turns the armature too fast. As a result, the eddy currents oppose the flow of the current through the winding. Therefore, the BEMF limits the speed at which the motor or generator can turn because of the BEMF.

$$V_m = c \times \Phi \times \omega$$

where

c machine constants : constants which are defined by the motor construction.

Φ air-gap flux : determined by the strength of the permanent magnets or the exciation current I_{exc}

ω mechanical angular speed : the mechanical rotational speed n given by $\omega/2\pi$

When a rotating machine (a generator or an electric motor) operates, it generates a back electromotive force. The strength of the BEMF increases as the speed increases. The motor is limited by the BEMF counterforce. An electric motor's armature rotation is induced by its magnetic field when its conductors move through it under the influence of the driving torque, just as a generator generates emf. Known as Back EMF or Counter EMF (Eb), this induced EMF is the opposite of the applied voltage V (Lenz's law) [11].

2.6 Advantages and Disadvangtage of DC motor:

2.6.1 Advantages of DC motor

These are some of the advantages of DC motors, including the following ones:

- DC motors are more easily installed .
- DC motors are typically more efficient and make better use of their input energy.
- Their starting power is high.
- Compared to normal operating torque, the starting torque of these motors is as high as 500
- These motors have an incredibly fast response time when they are started, stopped, and accelerated.
- Several standard voltage options are available.
- Speeds above and below the rated speeds can be controlled by the device.
- Motor shaft torque is constant over a range of speeds with constant torque drives.
- Reactive power consumption is not a problem.
- DC motors can be used in electronic devices since they run on DC power.
- Traction systems can be powered by DC motors [12].

2.6.2 Disadvantages of DC motor

The DC motor is associated with several disadvantages, including the following:

- Initial costs are high
- A commutator and brush gear greatly increase the maintenance and operation costs of this machine.
- Sparking at the brush can cause commutation failure, so it cannot function in explosive or hazardous conditions [12].

2.7 Applications of DC motor

DC motors are available in a wide variety of types, and they have a wide range of applications. DC motors were previously discussed in relation to some of the various applications and circumstances for which they are used, and their benefits.

Different types of DC motors have different advantages, but DC motors are generally used for various purposes. Tools, toys, and a variety of household appliances use small DC motors. DC motors can be used for both retail and industrial applications, since they can be used for turntables, and braking/reversing.

DC motors can be used:

- Toys powered by DC motors
- Bikes powered by DC motors

2.8 DC Motor Types and Applications

DC motors can be categorized into three types: series, shunt, and compound. Field windings are connected to the armature circuit based on their connection type

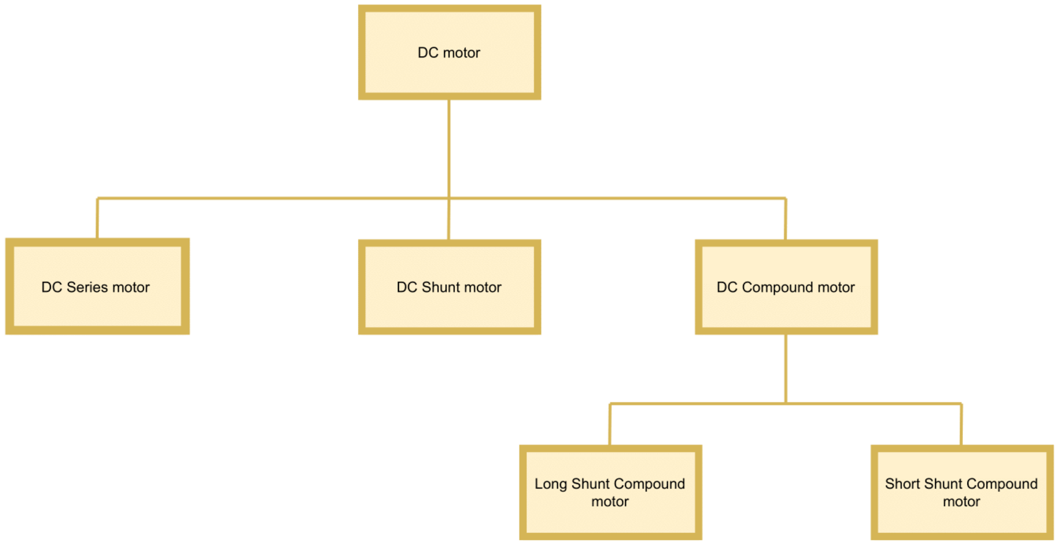


Figure 2.7: Types of DC motors

2.8.1 DC shunt motor

There is also a type of self-excited DC motor known as a shunt wound DC motor that uses a shunt winding arrangement over the armature coil, or where the field windings are connected parallel to or with the armature coil. With the armature and field windings being connected in parallel, the same supply voltage will be applied to both of them. Even so, it is evident from the diagram below that the flow of armature currents and the flow of field currents are divided based on the branches.

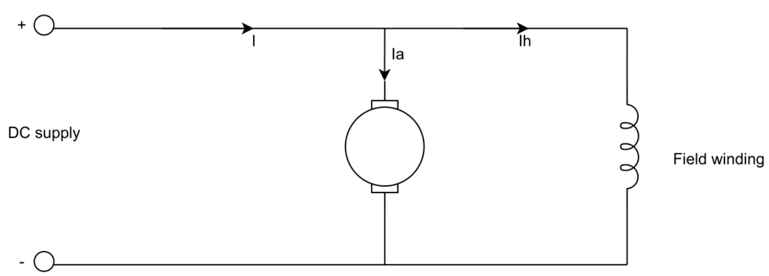


Figure 2.8: DC Shunt motor

An electric motor is generated a direct current when it is switched on. This direct current flows in the field windings and armature conductors. Current flowing in these windings and conductors produce the pole field and armature field. Between the field shoes and the armature, there are now two magnetic fields. The armature rotates when these two fields interact. As a result, the pole field repels the armature field at regular intervals as the commutator reverses the armature current directions. The armature turns in the same direction due to continuous repulsion from the field poles [13].

2.8.2 DC series motor

An electric motor, known as a series DC motor, is basically a self-excited motor in which the armature coil is connected in series with the field coil, allowing a higher current to flow through it.

Adapted to electromagnetic laws, a series DC motor converts electrical energy into mechanical energy. In this process, a rotating motion on an output shaft is generated by the interaction of an outside magnetic field with a current carrying conductor

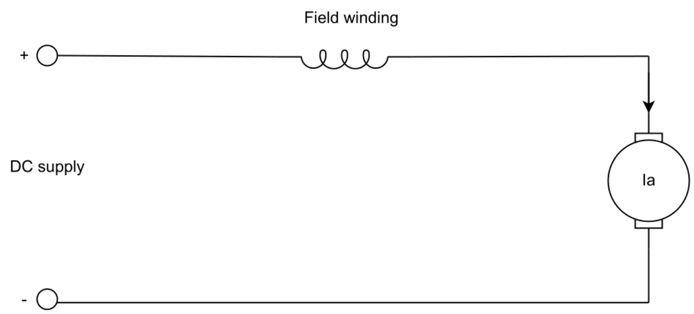


Figure 2.9: DC series motor

DC series motors work by converting electrical energy into mechanical energy. The armature and field coils of this DC motor are both powered. Voltage is applied to these terminals via the armature and field windings.

The massive conductors in this winding offer low resistance. The terminals provide an incredible amount of power to the motor. Because of the immense torque produced by the massive current running between the armature and field coils, a magnetic field is created. This powerful drive spins the armature, generating the desired mechanical energy [14].

2.8.3 DC compound motor

Compound DC motors are a mix of shunt and series motors. These are DC compound motors. The armature winding connects to series and shunt field coils. This causes magnetic flux to be generated which in turn produces torque to allow rotation of the armature at the correct speed. The field is wound for a shunt field and has several series windings at the top.

This structure amalgamation is done for the purpose of gaining the best properties of both types. A series motor provides high starting torque and a very efficient speed regulation. A shunt motor has a very low starting torque but a very high-speed regulation. As a result, compound DC motors have a great deal of compromise [15]. On the basis of how its field winding is connected to the armature winding, the compound wound DC motor can be further divided into two major types:

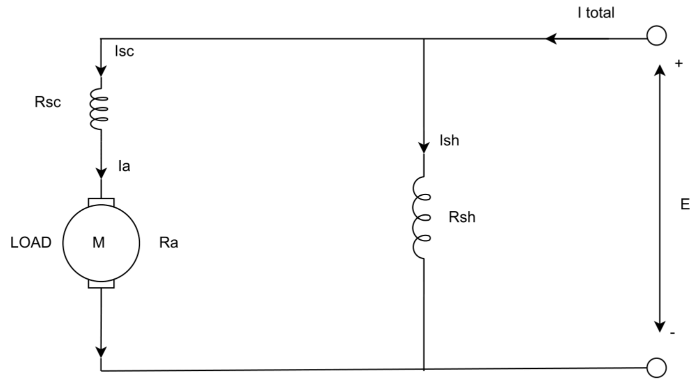


Figure 2.10: Long Shunt Compound DC Motor

Motors with a long shunt compound winding are arranged with the shunt coil in parallel with both the armature and the series coil of the series field winding [16].

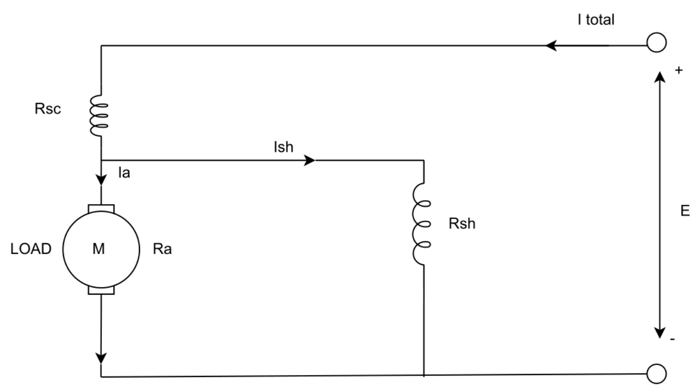


Figure 2.11: Short shunt compound DC motor

The armature winding is only connected across the shunt field winding in a short shunt wound DC motor. This means that the entire supply current flows through it [16].

2.9 Their application of three types of DC motor

We have three types of the DC motor and their applications:

- DC Series motor : Traction system , Air compressors , Vaccum cleaners , Sewing machines , Trolly cars.
- Dc Shunt motor : Lathe machines , Fans , Blowers, Spinning machines , Milling machines, Printing machines , Paper machines , Centrifugal and reciprocating pumps.
- DC compound motor : Pressers , Shears , Rolling mills machines , Reciprocating machines , Planers , Air compressor machine.

Chapter 3

DC Drivers

3.1 Outline of DC drives

In this case, the drive is operated by means of direct current (DC) which is the reason for the name of the drive group. In spite of the fact that direct current may have a certain ripple in it, the term direct current is still used. There are still many industrial applications that rely on DC drives; however, AC drives are steadily dislodging them in favor of them [17]. Figure 3.1 shows the DC motor at the center of a DC drive.

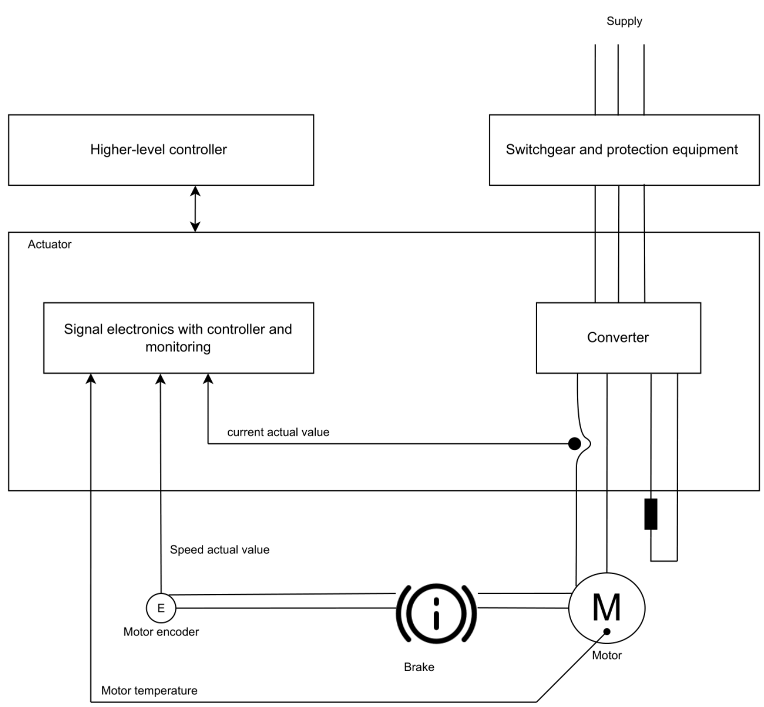


Figure 3.1: The DC Drive

Almost all machines and industrial equipment have access to an AC 24 V power supply in the lower power range (< 500 W). In terms of cost-effectiveness and ease of implementation, small drives can be realized by using permanently excited motors and very simple controllers.

Comparing cost and size of AC drive controllers with that of controllable DC drives is still worthwhile when dealing with higher powers (> 100 kW). Despite all this, DC drives remain in use today for rolling mills, cranes, elevators, and many other applications. Despite their size and simplicity, DC drives still offer reliable and efficient control functions. As a result, DC motors, which are separately excited, are often used in high power applications [17].

3.1.1 Controllability

Motor speed can be adjusted with variable-speed electrical drives. According to the characteristics of speed-torque, it is possible to vary the speed of the motor in the following manner:

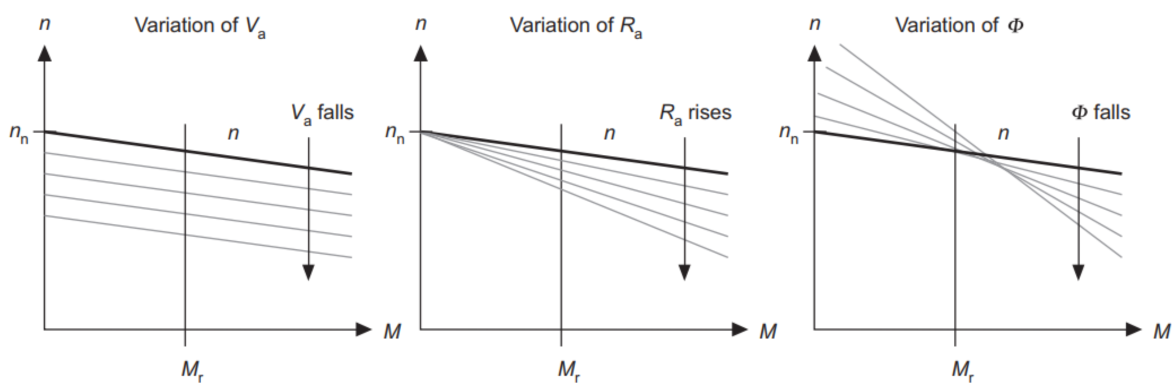


Figure 3.2: Variable speed capabilities of a DC motor [17].

Armature voltage: It is possible to shift the speed-torque characteristic by varying the armature voltage, Va, of a motor in parallel with the armature current. While the characteristic gradient remains unchanged, it is often difficult to observe. Consequently, the armature voltage tends to be the preferred input variable for variable-speed DC drives, as it generally results in the lowest load current. By adjusting the armature voltage to its maximum value, the maximum speed can be achieved [17].

Armature resistance: The gradient of the characteristic increases as the motor resistance increases. The working speed remains constant at the M = 0 operating point despite no loads. The result is that a motor with a lightly loaded shaft is almost impossible to control. Increased armature resistance leads to an increased speed reduction due to load-dependent behavior. It is therefore only appropriate to change the resistance of the armature when adjusting the speed under constant load conditions and when controlling the starting of the motor [17].

Air-gap flux/excitation current: It may be possible to reduce the air-gap flux by altering the excitation current in motors equipped with an excitation winding. In addition to the load-dependent speed reduction growing as the excitation is lowered, the no-load speed also grows. Thus, in order to reduce the speed of a light-load motor one must increase the excitation current substantially in order to achieve this goal. Increasing the excitation current of the motor would not result in the expected increase in air-gap flux as the iron in the magnetic circuit would quickly reach saturation. Using a variable of the system input, therefore, to control the speed of an air gap may only be effective for ranges below the recommended value [17].

Field weakening: In the field weakening process, armature voltage and air-gap flux are controlled together with excitation current. In order for the motor to reach the maximum speed, the armature voltage must reach the maximum value before any further speed increase can take place. After the voltage maximum has been reached, the flux/excitation current can be reduced in order to overcome this limitation. Now that the field of the motor has weakened, it can achieve higher speeds. It is not possible to determine the motor's rated torque within this range [17].

3.2 Fixed-speed drives using DC motors

In fixed-speed drives, the speed is not variable, as they are powered by a constant supply. A DC motor, except for possible starting circuits, is connected directly to a DC power supply in the case of DC drives. The DC power supply networks used by most industrial facilities are almost nonexistent nowadays, so fixed-speed drives with DC motors in the higher power range are of little interest. The 24 V DC control voltage, which is commonly available, can be utilized in the lower power range. There are also low power DC voltage sources with voltage ratings from 6 V to 12 V available for vehicle electronics (windshield wipers), appliances (fans), and model building [17].

3.2.1 Shunt-wound characteristic

Shunt-wound motors are used for constant gap flux motors, in which the air gap is uniform throughout the motor. As a result, the speed of the motor decreases slightly when it is loaded. Either a constant excitation current is generated, or a permanent magnet is used to produce the steady air gap flux [17].

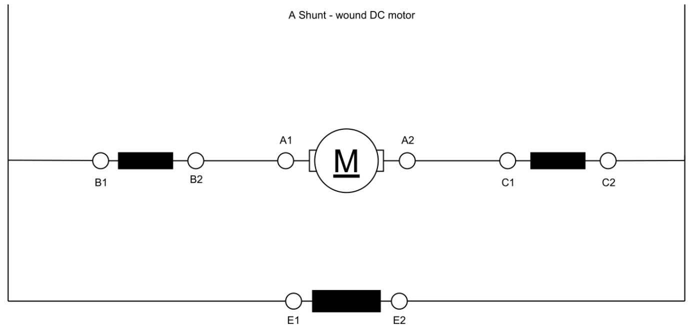


Figure 3.3: Circuit configurations for a DC motor with shunt-wound characteristic

In the case of V_a = constant, the following speed-torque characteristic will be found. This characteristic has a gradient that depends on the resistance of the armature. A DC motor that has shunt-wound characteristics will decrease slightly in speed as its load also increases, however.

A fixed-speed drive's starting behavior is just as significant as its operational behavior. The starting behavior describes what happens when a motor is initially operated at zero speed with an armature voltage Va [17].

There is no motor voltage V_m (EMF) at zero speed because there is no motor rotation. Consequently, there is a large inrush current I_a created as a result of the process. It is true that very small motors can be charged with relatively large inrush currents. However, in the case of large motors, countermeasures must be taken to suppress the inrush current. During start-up, current inrush is limited by the use of technical solutions [17].

As part of the armature circuit of the DC motor, ohmic resistors are connected in series with each other. This resistor increases the armature resistance R_a of the DC motor which limits the inrush current I_a and therefore changes the speed-torque characteristic of the motor in a steeper way. As the speed increases, the resistances are bridged one by one until the armature's effective resistance becomes equal to R_a. Motor speed-torque characteristics "jump" from one switching operation to the next until they finally return to their original values. As the motor reaches its operating point, it moves along this characteristic [17].

Soft Stater :

An alternative to starting resistors, soft starters are used today. A soft starter is an electronic device which increases the voltage of the armature starting at 0 volts. Increasing speed results in an increase in motor voltage (emf), which is ramped up along with it. By doing so, you are limiting the inrush current and counteracting the armature voltage.

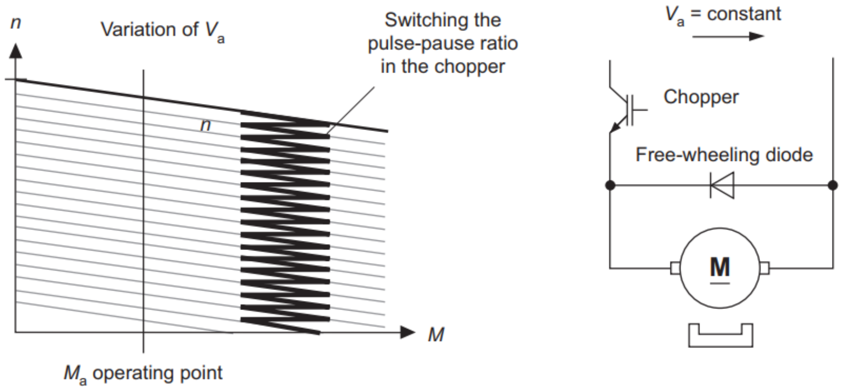


Figure 3.4: Starting characteristic of a DC motor with soft starter [17].

An electrical motor starts automatically and continuously by switching the armature voltage on and off periodically, in a process referred to as a soft starter. If the motor terminals are switched on, the motor voltage V_m is a function of DC supply voltage applied at the motor terminals. When it is turned off, it is a function of motor speed applied at the motor terminals. In order to calculate an average motor armature voltage V_a, one must divide the intensity of pulses by the duration of pulses (pulse-pause ratio). This voltage then correlates with the speed and torque characteristics of the motor. The armature voltage V_a also increases gradually when the switch-on duration is gradually increased, and the motor speed "jumps" with very small steps between characteristics. When the motor is switched on for 100 % of its switch-on time, it begins to follow its original characteristics until its operating point is reached [17].

3.2.2 Series-wound characteristic

DC motors can also have their excitation windings switched in series with their armature windings. Series-wound characteristic motors are known by this circuit configuration [17].

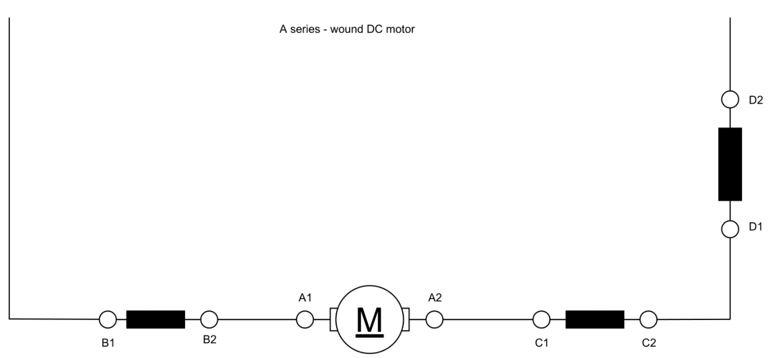


Figure 3.5: Circuit configuration of a DC motor with series-wound characteristic

An interesting feature is the current flowing in the armature's excitation winding. Due to the load on the motor, the resulting magnetic field is not constant. A series-wound motor is characterized by its characteristic operation.

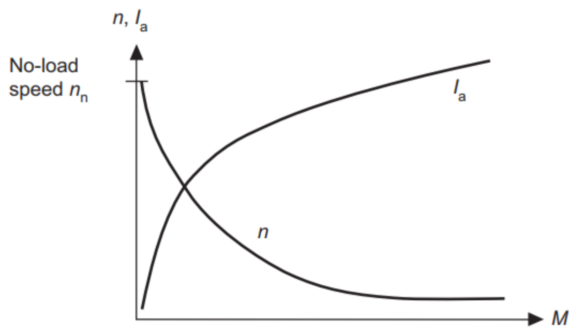


Figure 3.6: Steady-state operating characteristic of a DC motor with series-wound characteristic [17].

The speed-torque characteristic shows a steep decline when the no-load speed is reached, and it closes out almost to a constant value for high torques. With a series-wound motor, load changes are very softly impacted.

It should be noted that the motor has no active flux when it is not operating under load. As long as the motor speed is very high, the air-gap flux produces a very small motor voltage V_m that compensates for the armature voltage V_a. The motor may therefore be destroyed if it is accelerated to a high speed. No-load operations must never be performed with series-wound motors [17].

3.3 PWM (Pulse Width Modulation)

Signal amplitude is represented by generating variable-width pulses as a result of pulse width modulation (PWM). High-amplitude signals are more likely to turn on the output switching transistor, and low-amplitude signals are more likely to turn it off. Unlike an analog circuit that drifts over time, the PWM circuit has a digital nature (full on/off).

This kind of pulse width modulation can be used in a wide range of applications, ranging from simple circuitry to highly sophisticated systems. Because pulse width modulation can be applied to both analog and digital applications, it can be used to achieve a variety of results. By varying how long the signal stays high, we can achieve a variety of results. We can change the proportion of time the signal is high over a significant period of time compared to when it is low, even though the signal can only be high (usually 5V) or low (ground) at any one time [18].

3.3.1 Duty Cycle

The duty or power cycle is the fraction of the time period for which the signal or system is operating. Duty cycle is usually expressed as a percentage or a percentage. Duration is the time it takes for a signal to complete one cycle on and off. The duty cycle of the system is the time the system is active. To be able to calculate it, we have the following formula:

$$D = \frac{P * W}{T} * 100\% \tag{3.1}$$

where
D is the duty cycle
PW is the pulse width (pulse on or active time)
T is the total period of the signal

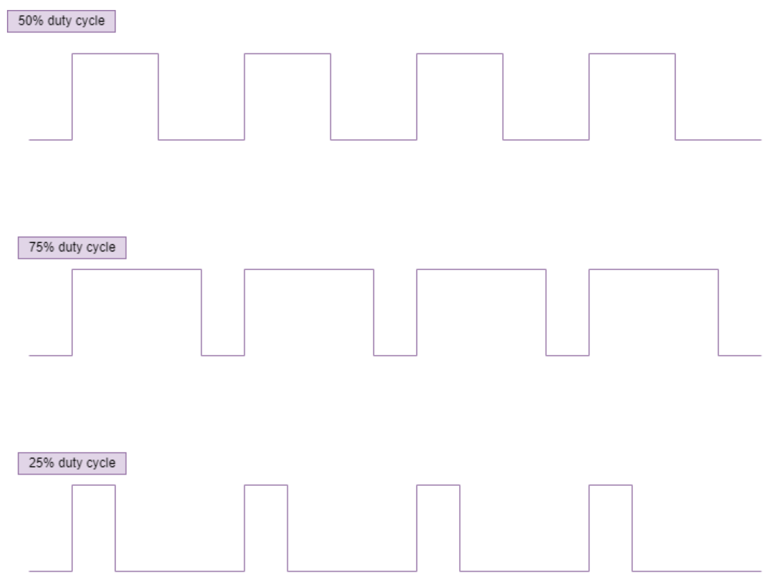


Figure 3.7: 50%, 75%, and 25% Duty Cycle

Digital signals with a duty cycle of 50% resemble an ideal square wave and are said to have a 50% duty cycle. Using a duty cycle over 50% will focus more time on the high-state digital signal, while a duty cycle under 50% will focus more time on the low-state digital signal. Let's look at three different scenarios in a graph: If the voltage were 5 Volts (high), the duty cycle would be 100%. If the duty cycle was zero, the signal would take on the same characteristics as if it was ground [18].

3.3.2 Four-quadrant operation

In DC/DC converters, four-quadrant converters are used to control semiconductor devices to adjust the direction of voltage source. Consequently, you can separate the control into many different methods.

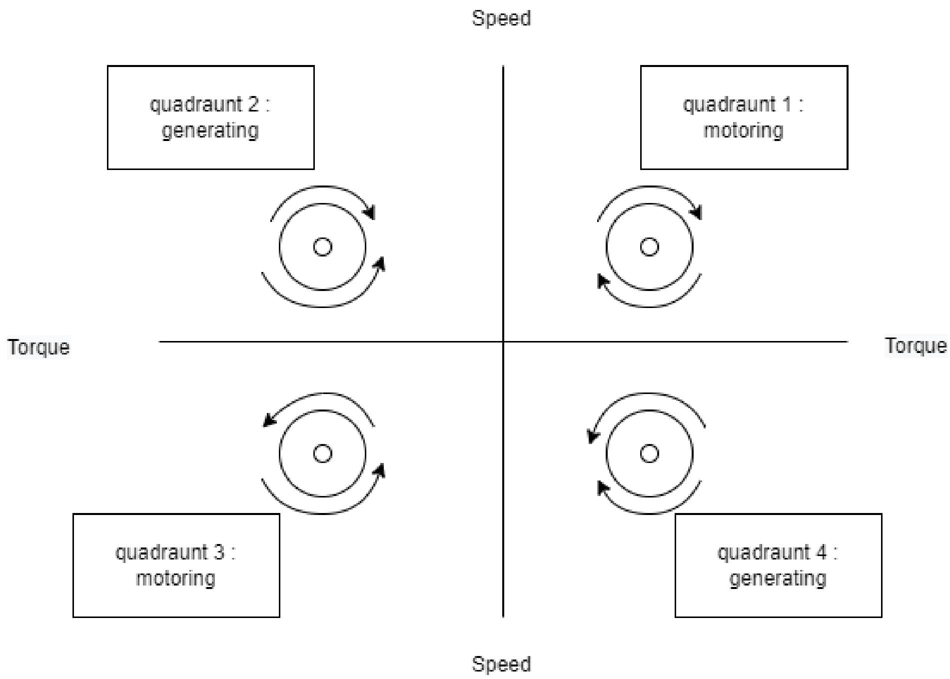


Figure 3.8: The four-quadrant operation of drives

The machine is working as a motor in the I quadrant while generating positive power and even supplying mechanical energy. Forward motoring is an operation that operates in the I quadrant. Braking is an operation that operates in the II (second) quadrant. The machine operates as a generator in this quadrant, and the torque is negative, so it opposes movement while rotating in a positive direction.

It is possible to supply back to the grid the kinetic energy of the rotating parts. The resistance dissipates the energy in dynamic braking. The reverse motoring is an Operation of the III (third) quadrant. Motors work by reversing direction. Motors' negative values are found in both torque and speed, whereas the positive values are found in power.

Torque is negative and speed is positive in the IV quadrant (fourth). The brakes are applied in this quadrant when driving in reverse [17].

3.4 Variable-speed drives using DC motors

3.4.1 Converter

The converter is a controllable rectifier based on thyristors. The supply network's AC voltage is converted to an adjustable DC voltage through one stage of this process.

Among the most important elements of power electronics are AC to DC converters. Real-life applications rely on these conversions since there is a great deal of data that can be converted [17].

The control of the flow of power through a thyristor switch can be achieved by varying the rms value of the AC voltage applied to the load connected by the thyristor switch. An AC voltage controller is a type of power circuit that controls the voltage of an AC current. During the conversion process, the AC/DC converter provides the DC motor with the AC voltage of the armature (rotor winding), while the DC current of the field winding (stator) is regulated.

Rectification is the process of converting AC current into DC current so that you can use them with your electrical equipment. In order to supply the load at the load end of the circuit, the rectifier has to convert the AC supply into DC power. Likewise, transformers are typically used to reduce the voltage level of an electric supply source and, as a result, have a better range of DC use [17].

3.4.2 Firing angle delay α

By adjusting the point in time of firing, one can adjust an armature voltage Va produced by a thyristor bridge. It is possible for the firing angle delay α to be used as a process variable to influence the firing point. Each thyristor's firing angle delay α indicates the commutation time used to send a firing pulse. Natural commutation occurs when the thyristor is first able to fire because of the line supply voltage waveform. Diode bridges also undergo natural commutation at a particular point. Delay of thyristor T1 with firing angle α on Figure 3.9.

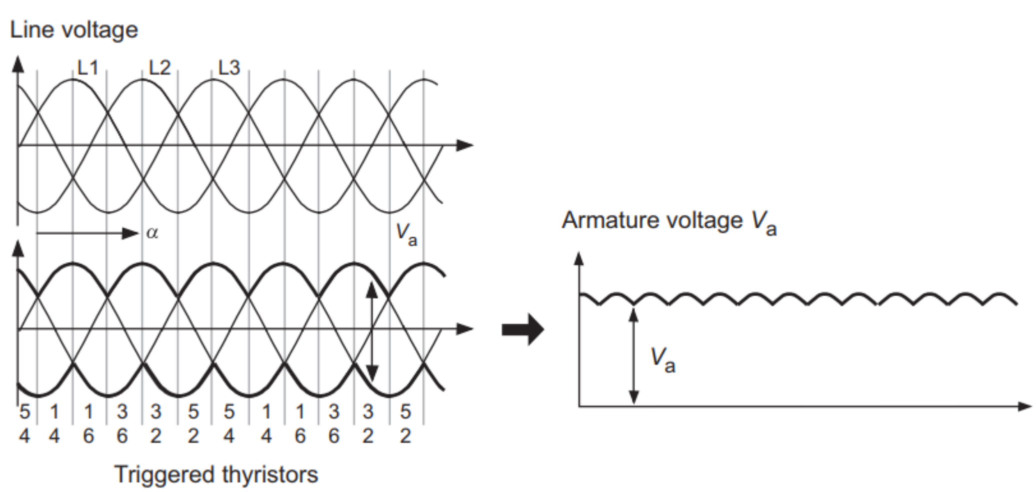


Figure 3.9: $\alpha = 0$ firing angle delay voltage waveform [17].

Degrees are used to measure firing angle delays. There are a total of 180^0 between 0^0 and 180^0. With a firing angle delay of 180^0, the lowest average armature voltage is obtained and the highest with a delay of 0^0. Based on the Figure 3.10, we see that there is a possible negative value for the armature voltage. As soon as the maximum value of 180^0 is exceeded, there is already a potential difference between the anode of the thyristor to be fired and the anode of the thyristor that is active, so you cannot convert the voltage of the active thyristor into your system [17].

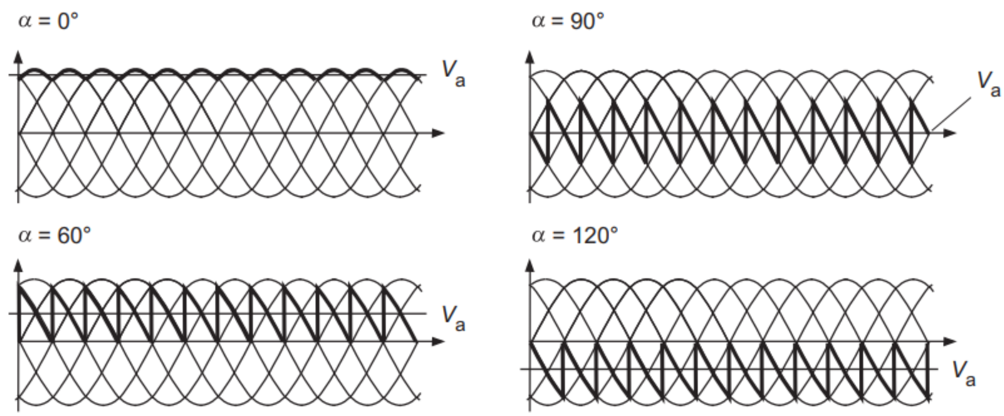


Figure 3.10: The firing angle delays are included in the voltage waveforms $\alpha \neq 0$ [17].

3.4.3 Inverter commutation failure

The reason behind this failure is that the phases will be short circuited if a thyristor is fired with an angular delay α of 180^0 (or more) as a result of the commutation angle delay. Providing the signal electronics with sufficient protection against bridges commutation failures is one of the ways that they can prevent thyristor bridges from operating in an undesired state. Fire angle delays are usually limited by signal electronics to 150^0 maximum [17].

3.5 Speed encoders for DC drives

Analog speed controllers are frequently included as part of variable-speed DC drives. Analog speed measurements must be provided to the controller to function. The term tachometer or tach generator refers to encoders that display an analog speed value. An analog voltage signal is an output at the terminals through an induction process. A connection is made between the encoder and the motor shaft [17].

3.5.1 DC tachometer

Accordingly, the voltage signal obtained by measuring the voltage across the motor shaft is proportional to its speed. A voltage induced in the winding segments is generated in accordance with the direction of rotation and the rotary speed. The voltage is passed through the brushes and commutator to the converter signal electronics [17].

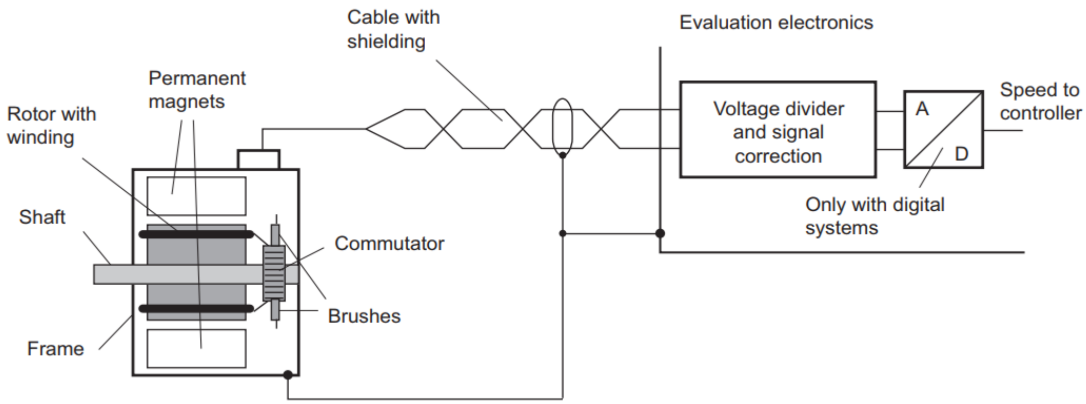


Figure 3.11: Components of a DC tachometer [17].

Figure 3.11 shows the two-conductor shielded cable used for the DC tachometer signal cable since it is not powered. If the motor runs away, it is important to ensure that the signal cable is connected correctly.

According to the encoder, the speed and direction of rotation are determined by the voltage signals at the encoder's terminals. Voltage output and speed are linearly related. A finite number of part-windings and commutator laminations, however, result in a less than ideal output voltage. The output voltage can fluctuate on a regular basis [17].

The digitally controlled converters used in recent DC drives are state-of-the-art. For speed measurement, incremental encoders can be used together with these.

3.5.2 Control structure

Closed-loop speed control drives are usually used with converter-fed drives. The open-loop speed control of such motors can also be used in principle by using a voltage value of the armature's voltage Va as the absolute value implement open-loop speed-controlled drives.

There is a horizontal relationship between speed and torque. Speed is independent of the load on a particular axle. Speed and current are managed by the same speed controller in controlled DC drives. It has been successfully applied for many years. Each controller can be optimized step-by-step using this transparent process [17]. Each controller has a specific function:

- In order to detect deviations in speed from the setpoint, the motor speed control system varies the torque setpoint if necessary, in response to the deviations in speed. A substitute variable is used with respect to torque measurement, that is, the armature current I_a, since torque cannot be measured directly. It is prudent for a speed controller to output an appropriate setting for the armature current I_a when high torque is necessary due to a high load. After the drive loses loads, the speed controller detects that there are a lot of high speeds and the driver speeds up. As a result, the setpoint for the I_a is reduced [17].

- Adjusting the armature voltage V_a allows the current controller to determine the necessary armature voltage Va. The firing angle delay α which a converter uses to calculate the firing angle is varied. Thus, the motor voltage V_m (emf) must be compensated by the current controller[17].

In a motor with an unloaded shaft, a positive excitation current and positive armature current result in a positive torque and acceleration. An unloaded motor can accelerate in the positive direction if it runs on a negative excitation current and a negative armature current. A motor will accelerate in the opposite direction if its armature and excitation currents are polarized differently. [17].

Chapter 4

Stand of a DC Servo drives

4.1 DC motor and Motion Controllers

4.1.1 The specification and dimension of DC-Micromotors

Table 4.1 shows all the necessary information about the DC-Micromotors Series 2342 024 CR. The number 024 tells us that the rated voltage of this motor is 24V. All necessary information and data of the product is identified with all the data below . Refer to the DC-Micromotors Series 2342 024 CR datasheet and manual for further reference information, as well as the communication functions and motion program.

Table 4.1: The specification of DC-Micromotors Series 2342 024 CR

Model		**Unit**	**024CR**
Nominal voltage		V	24
Terminal resistance		Ω	7.1
No-load speed		min^{-1}	8500
No-load current		A	0.038
Back-EMF constant		mV/min^{-1}	2.73
Stall torque		mNm	85.4
Friction torque		mNm	0.99
Speed constant		min^{-1}/V	366
Rotor inductance		ms	265
Rotor inertia		gcm^2	5.8
Angular acceleration		$10^3 rad/s^2$	150
Speed up to		min^{-1}	11000
Operating temperature range	**motor**	°C	-30to+1000
	winding		+125
Number of pole pairs		-	1
Magnet material		-	NdFeB
Housing material		-	Steel,Black coated
Mass		g	88

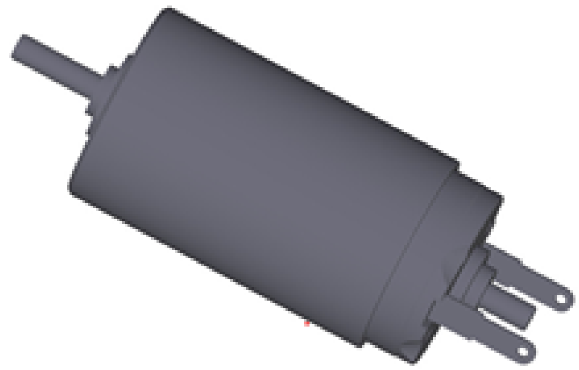


Figure 4.1: DC-Micromotors Series 2342 024 CR

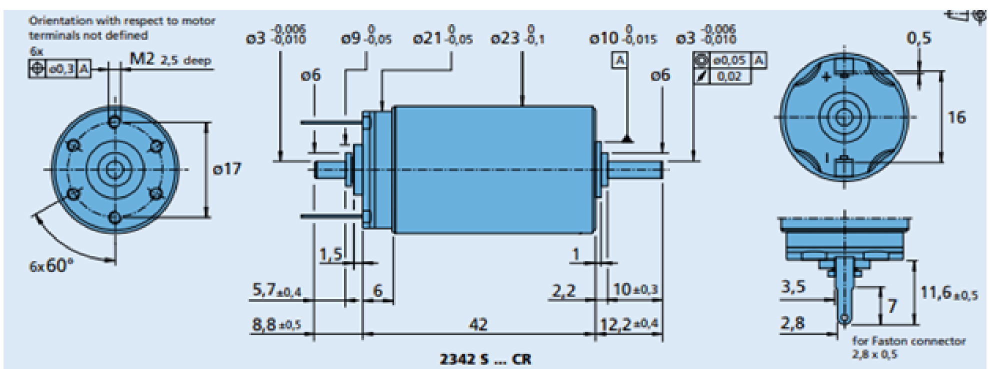


Figure 4.2: The Sizes of DC-Micromotors Series 2342 024 CR

4.1.2 The specification and demension of Motion Controllers

Table 4.2: The specification of Motion Controllers Series MC 5005 SRS.

Type of Drive		-	**MC5005 SRS**
Mass		g	RS/CO:230 ET:0.07
PWM switching frequency		100kHz	
Efficiency electronic		97A	
Max peak output current		15A	
Operating temperature range		-40∼+85°C	
Housing material		Aluminium , powder-coated	
Max continuous ouput current		5A	
Power supply electronic		12∼50VDC	
Power supply motor		0∼50VDC	
Interfaces	**Configuration from Motion Manager 6.0**	RS232/USB	
	Fieldbus	RS232	
Basic features		Control of brushless, DC – and linear motors Supported sensor systems: absolute encoders (AES or SSI), incremental encoders (optical or magnetic), Hall sensors (digital or analog), techno meters. Positioning resolution when using analog Hall sensors as position encoders: 4096 increments per revolution. 3 digitals input, 2 digitals outputs, 2 analog inputs, flexible configuration. Setpoint specification via fieldbus, quadrature signal, pulse and direction or analog inputs. Optional stand-alone operation via application programs in all interface versions	
Function	**Motor types**	DC, BL and linear motor	
	Operating modes	Profile position mode (PP), Profile velocity mode (PV), Profile torque mode (PT), Cyclic Synchronous Position, Speed and Torque (CSP, CSV, CST) and homing acc.to IEC 61800-7-201 or to IEC 61800-7-301 as well as position, speed, torque control via analog setpoint or voltage controller.	
	Speed range for brushless motors with number of pole pairs 1	$0min^{-1}$ ∼$30000min^{-1}$ with sinusoidal commutation (optionally to $60000min^{-1}$ with block commutation).	
	Application programs	Max 8 application programs (BASIC), one of which is an AutoStart function	
	Additional functions	Touch-probe input, control of a holding brake , connection of a second incremental encoder	
	Indicaton	LEDs for displaying the operating state Trace as recorder (scope function) or logger	
X1		Configuration interface	USB
X2		Fieldbus	RS:RS232
X3		Input/Output	DigIn1, DigIn2, DigIn3, DigOut1, DigOut2, AnIn1, AnIn2, V_{out}/GND
X4		Electronic power supply	
X5		Motor power supply	
M1		Motor phase	A, B
M2		Hall Sensors	A, B,C,D,V_{out}/GND
M3		Encoder	

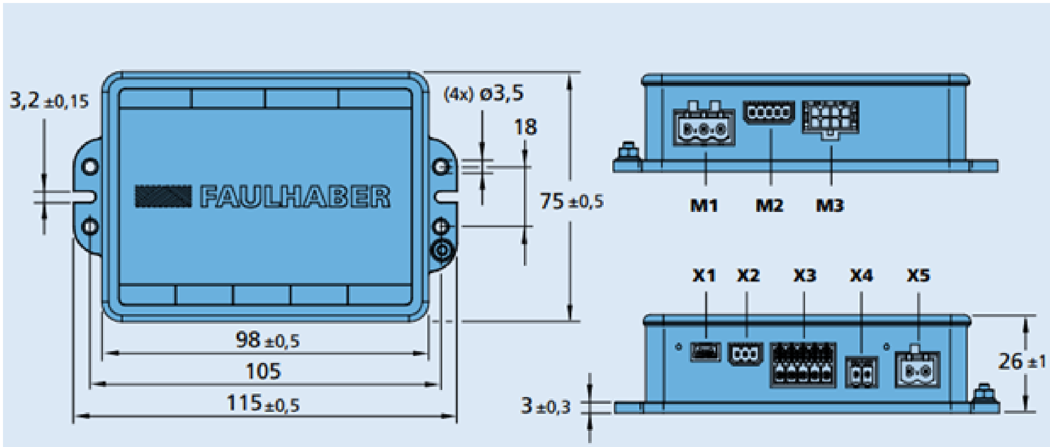


Figure 4.3: The sizes of Motion Controllers Series MC 5005 SRS

Figure 4.3 shows us that this is a motion controller MC5005SRS and table 4.2 presents the specification of MC where we can know the power supply, control method, current consumption and refer to The Motion Controllers MC5005 SRS datasheet and manual for further reference information, as well as the communication functions and motion program.. Other important information to know about the name of Motion Controller MC 5005SRS indicates 50 as max. supply voltage 50 V , 05 is max continuous output current 5 A , S is Housing with plugs/terminals , RS is Serial interface RSR232. More information about pin assignments can be found at Appendix A.

4.1.3 Controller System Configuration

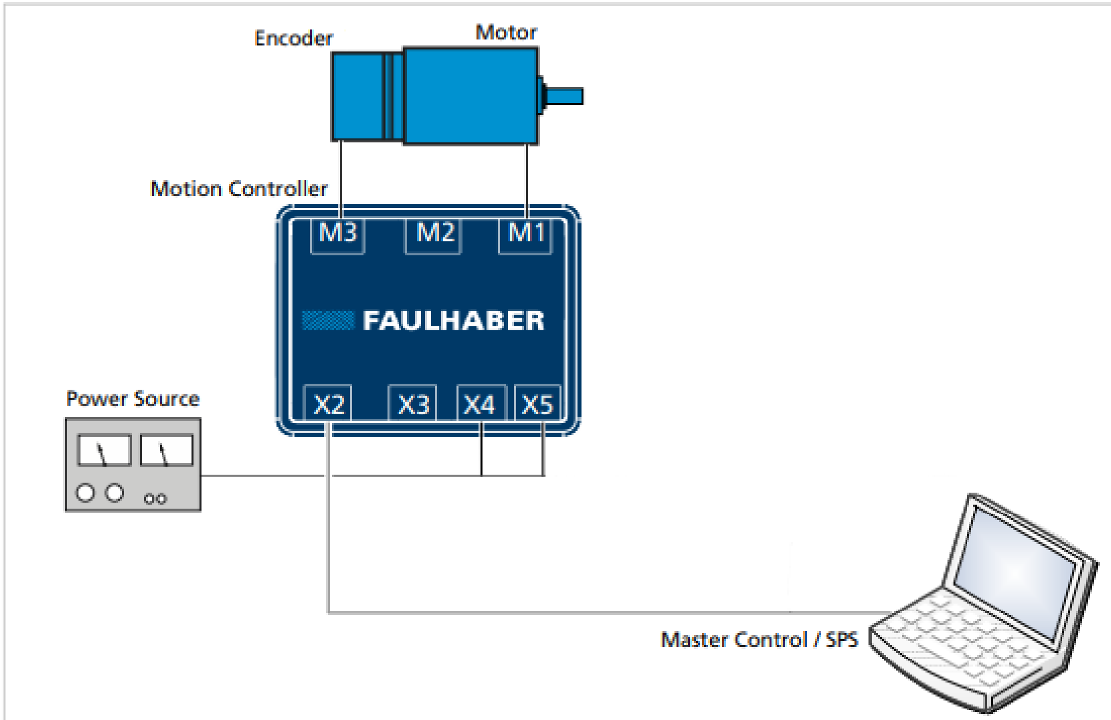


Figure 4.4: Controller configuration drive

4.1.4 Motion Controllers Series MC 5005 SRS is operating modes

Motor Control: With the cascade controller, you can control the current, speed, and position of the motor. The ability to control even the fastest movements reliably and reproducibly is made possible by the optional pilot paths. With a wide range of encoders and loads available, this filter can be adapted to a wide range of applications

Motion Profiles: Speed and positioning mode (PP) and profile velocity mode (PV) allow the user to set the acceleration ramp and brake ramp as well as the maximum speed.

Autonomous operation: There is the possibility of storing and executing on the controller up to eight sequential programs written in BASIC. The AutoStart application can be used to configure one of these programs. There is an option to enable or disable access protection.

Protection and diagnostics functions: Thermal models protect motors and electronics of FAULHABER Motion Controllers of generation V3.0 from overload. Regenerative operation can be performed by monitoring the supply voltage. This prevents overvoltage from damaging external devices.

Profile Position Mode (PP) / Profile Velocity Mode (PV) : If the movement target is the only parameter specified for the controller, then this is suited for applications. This is done through the integrated profile generator, which takes into account possible acceleration and brake ramps, as well as possible maximum speeds. Hence, profile-based movements can be combined with standard networks, such as RS232 and CANopen, in order to achieve the functionality described above

Cyclic Synchronous Position (CSP) / Cyclic Synchronous Velocity (CSV) / Cyclic Synchronous Torque (CST): The path planning can also be synchronised for multiple axes when a controller at a higher level performs the planning. Current and position setpoints are continually updated. Updating occurs every few milliseconds on average. In this way, EtherCAT is ideally suited for use with cyclic modes. Another option is CANopen [19].

Analogue Position Control (APC) / Analogue Velocity Control (AVC) / Analogue Torque Control (ATC) : In applications with analogue setpoint or, for example, with a direct encoder connection, the setpoint is specified. The characteristics of these operating modes make them particularly suitable for stand-alone operation without the need for a master at a higher level.

Voltage mode (VOLT) : Current limiting controllers are used only in the voltage mode. Higher-level control systems close all control loops. An analogue input can be used to set the setpoint, as can the communication system [19].

Interfaces – discrete I/O: Connect limit switches and reference encoders with three to eight digital inputs. Select from three to eight logic levels. It is possible to choose either the setpoint or actual value of the two analogue inputs ($\pm$10V). A digital output can be used to output error information, to directly actuate a holding brake, or to serve as a flexible diagnostic output.

Interfaces – position encoder : FAUHABER Motion Controllers of generation 3.0 in all of its designs can support virtually every sort of sensor system that is used in our industry today, including analog and digital Hall sensors, incremental encoders with and without Line Driver, or protocol-based encoders such as AES/SSI [19].

4.1.5 Benefits of Motion Controllers Series MC 5005 SRS

Position control:

- Using the interface to input setpoints
- Using analog signals
- In the gear mode
- Operate the stepper motor

Speed control:

- Using a setpoint input
- Analogous to a dial

Torque control:

- Using an interface to input the setpoint
- Using analog signals [19].

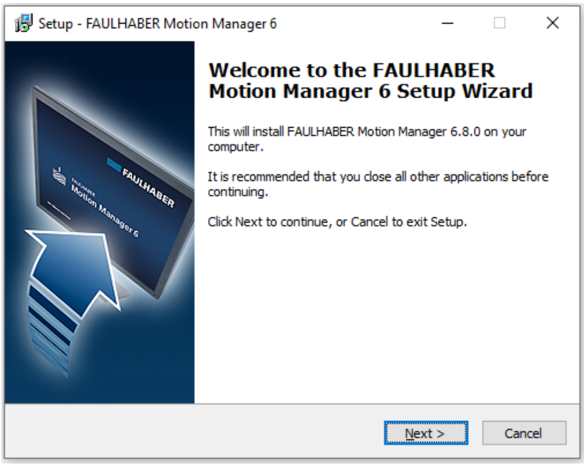
- Voltage controller mode as servo amplifier
- All motor and encoder types can be controlled by one controller
- Making the control process very dynamic
- It is perfectly matched to FAULHABER DC, BL, and LM motors
- Using a variety of setpoint and actual value interfaces
- All variants are capable of standalone operation
- Using simple plug-in connections
- Status LEDs provide quick feedback
- FAULHABER Motion Manager 6.0 is included as a free download
- A wide range of mounting accessories is offered [19].

4.2 Installation and Connection of Motion Manager 6

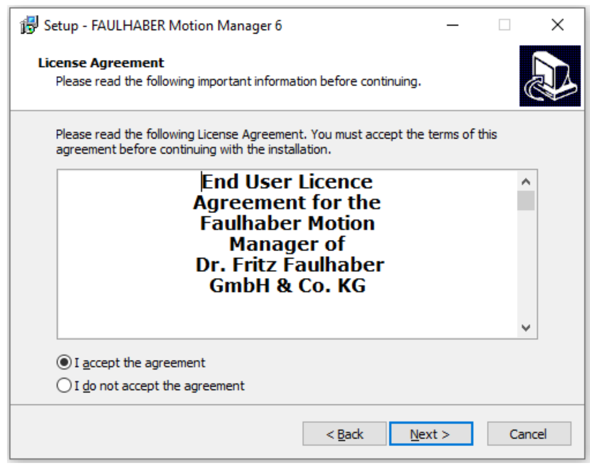
To be able to control all Motion controllers of the manufacturer Faulhaber, they have released Motion Manager 6.0 software which is the latest version released by the manufacturer to be able to control and adjust on the part. This software is very easy to use and connects to a single computer (personal computer or laptop).

How to connect between the computer and Motion Controllers with a cable (one USB end and the other end is a mini type B port), this program requires a personal computer with the operating system Win 7 or higher version and requires a machine The computer must be over 100MB in size. All motion conditions are set and saved in Flash ROM as a parameter via network. Because the software is completely free, we can go to the manufacturer's website to be able to download and use it. Motion manager 6 software free download provided by the manufacturer and link to download the software to your personal computer: The Motion Manager 6.0

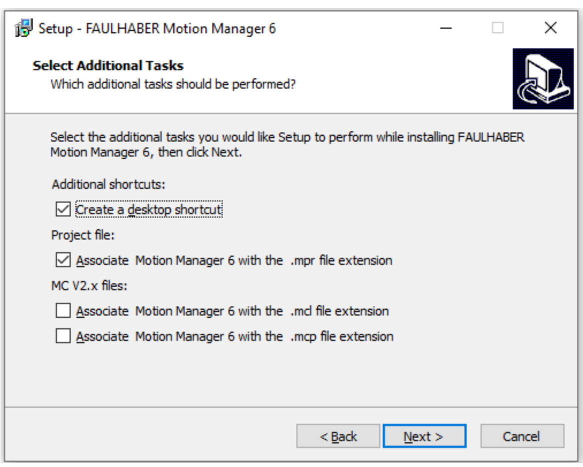
According to the above, we can find Motion Manager 6.0 software on the manufacturer's website. Please download the latest version of the program and extract it into a new folder. Run the program by selecting Open or Run as administrator from the right-click menu. Clicking Next and Finish launches Motion Manager 6.0 software, as shown below 4.5



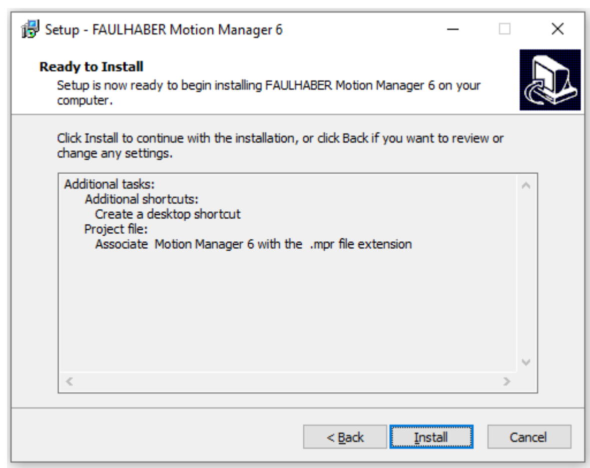
(a) Step 1 to install the program .



(b) Step 2 to install the program .



(c) Step 3 to install the program .



(d) Step 4 to install the program .

Figure 4.5: Motion Manager 6.0 program installation steps.

4.2.1 Motion Manager 6.0 User Interface

1. Menu Bar :

- File : Default functions for management of programme files and project files
- Edit : Default functions for editing files
- Terminal : Functions for management of interfaces and connected nodes
- Extras : Additional functions

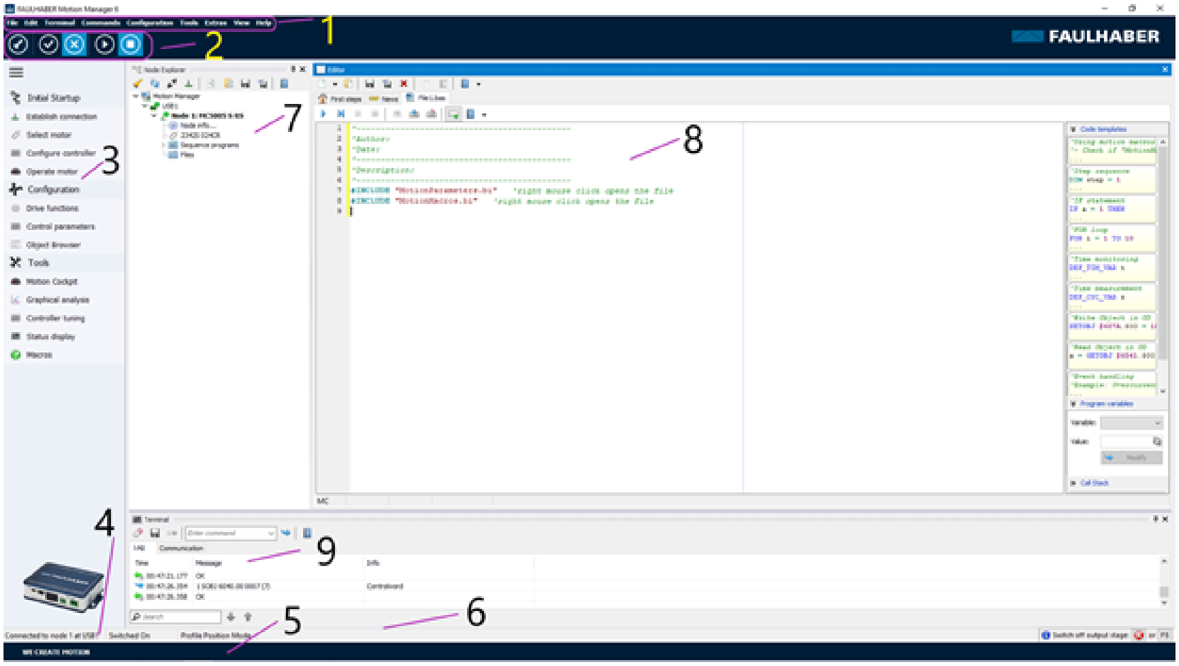


Figure 4.6: The Motion manager 6.0 program function

- View : Setting the window layout and the displayed windows
- Help : Access to online Help and other support facilities [20].

2. Toolbar buttons function:

Figure 4.7: The Toolbar buttons

- Node search Searches : the specified interfaces for connected drive nodes or network nodes
- Enable : Switches on the output stage of the control
- Disable : Switches off the output stage of the control
- Run Loads and starts : a sequence programme on the control
- Stop : Stops a running sequence programme on the control [20].

3. Quick access (fold away, fold out):

- Commissioning Wizards and dialogues for commissioning a drive control
- Configuration Dialogues for configuring and parametrising a drive unit to the respective drive task
- Tools Further tools for operating and analysing drives units [20].

4.Status Bar:

5.Footer:

6.Docking area :

7.Node explore : It displays all controls found to which a successful connection could be established by Motion Manager. Node Explorer also shows the structure of the project [20] .

8.Editor The built-in editor allows you to edit and execute various file formats :

Sequence programmers: On the control, you can save and execute programs:

- Motion Control file MC V3.x (*.bas)
- Motion Control file MC V2.x (*.mcl)

Parameters file :

The MC V2.x parameter file is used to transfer or save the parameter sets read from the control: Parameter file MC V2.x (*.mcp)

VB Script programmers:

PC-based motion management applications run within Motion Manager: VB Script file (*.vbs)

Text files:

Any type of document can be uploaded: Text file (*.txt).

Each newly opened or newly created file is displayed in a separate tab. Automatically, a comment header is generated for every new programme file. If you are using a VBS file then the body of the main function is inserted.

In the case of tabs with programme files, there is an additional toolbar that allows the user to start, stop, upload, download, or in other ways manipulate the programme. Described in the respective programming chapters as well as in the respective programming manual are the individual symbols in this toolbar, as well as the procedure for programming and debugging.

You can display additional functions like monitoring/changing code templates or variables by clicking the Extras button in the program files toolbar.

These templates consist of popular programming constructs and can be imported and customized within the programme code. As an alternative, a highlighted area of code can be dragged into the code templates toolbar from the Editor window, in order to create a new template. You can delete previously added templates by pressing the Del key on your keyboard [20].

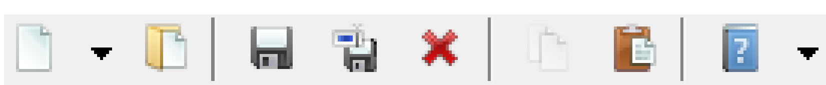


Figure 4.8: The buttons in the Editor

- Create new document
- Open saved document
- Save document
- Save document as
- Close the open document
- Copy selected content on to the clipboard

- Insert content from the clipboard
- Call up context-sensitive Help [20].

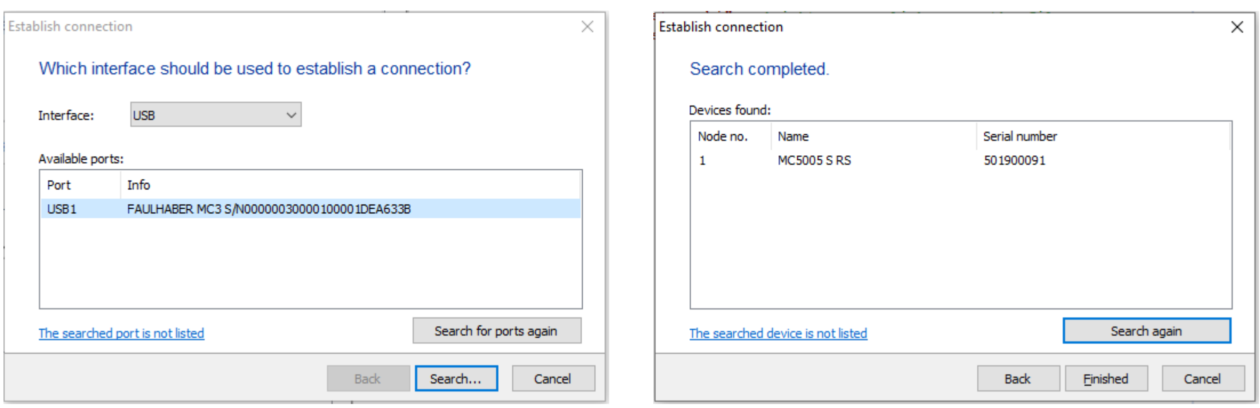
9. Terminal :

Manually entering commands is done on the terminal. Status messages, exchanged data, and actions are recorded [20].

4.2.2 Establish communication with the Motion Controller

Initial contact with the Motion Controller is made by using the connection wizard in the Motion Manager. In the commissioning category of the quick access bar, you can find the Create connection wizard.

Motion Manager searches the USB ports for the FAULHABER USB devices connected to that port.Motion Manager displays an overview of the FAULHABER USB devices that have been detected.



(a) Select the desired USB device and confirm with the Search button

(b) A device was found, accept the connection settings with Finish.

Figure 4.9: How to connect software to Motion Controller.

The correct motor data must be entered before the Motion Controller can be used. Motion Manager quickly guides you to the right motor type and sensor system by using a motor selection wizard.

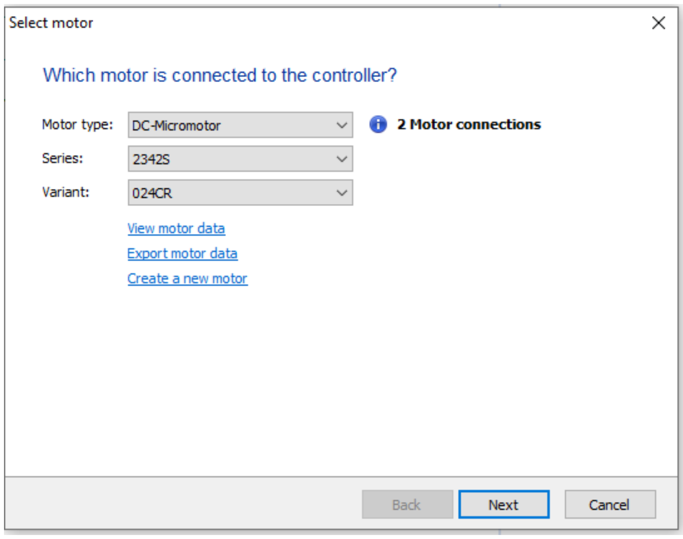
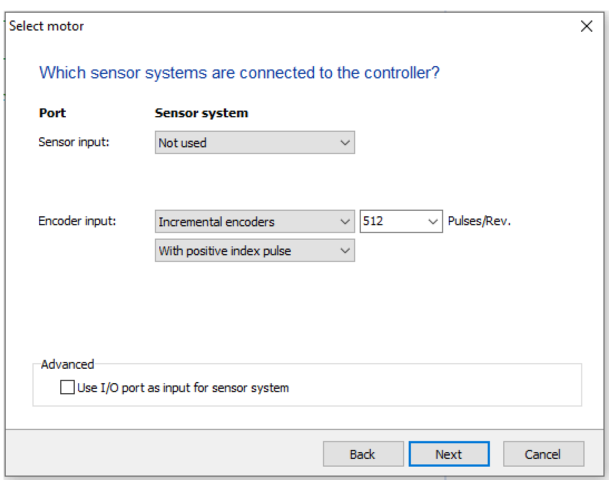


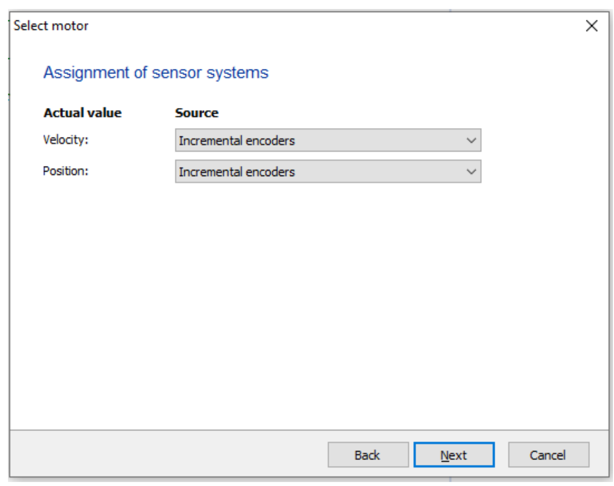
Figure 4.10: Select the motor type.

Select the motor type. The input required is:

- Type of the motor (BL, DC or linear BL)
- Dimensions of the motor
- Winding variant



(a) Select the Encoder connected to the system and click Next.



(b) Choose the purpose for which the sensor systems will be used .

Figure 4.11: Set a DC motor with incremental encoder.

Select the sensor type:
The correct motor data must be entered before the Motion Controller can be used. A motor selection wizard in Motion Manager has become a useful tool that guides us through selecting the right motor type and sensor system in just a few steps. In order for the FAULHABER Motion Controller to

run the motor in a controlled manner, it always requires the use of a suitable sensor system. It is possible to connect BL motors with analogue Hall signals to the sensor inputs (M2) of the device, but there are two ways of doing this. An encoder input (M3) is attached to DC motors equipped with IE encoders. BL motors can also be operated with Hall sensors + IE encoders or AES encoders [21].

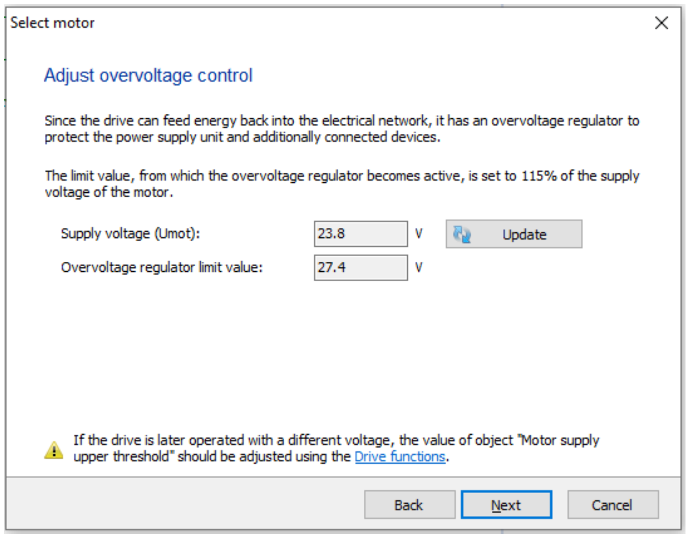


Figure 4.12: Adapting the overvoltage control to the motor supply voltage

The current supply voltage of the motor should be used to set the limit value of the overvoltage controller. Motor supply upper threshold should be adjusted if a different supply voltage is used later on. Configuration - Drive Functions in the Motion Manager can be used to perform this task [21].

To transfer the configuration to the Motion Controller, check the configuration and click on Transfer configuration [21].

To permanently store the transferred sensor data and basic motor information into the Motion Controller, click Yes at the end of the process. The communication has been established. Motion Manager contains a Node Explorer that displays the controller [21].

During the first commissioning of the controller, there will be no motor data set. The FAULHABER Motion Manager does not display motor types in its Node Explorer. The motor symbol is replaced by the Select Motor instruction instead of a connected motor [21].

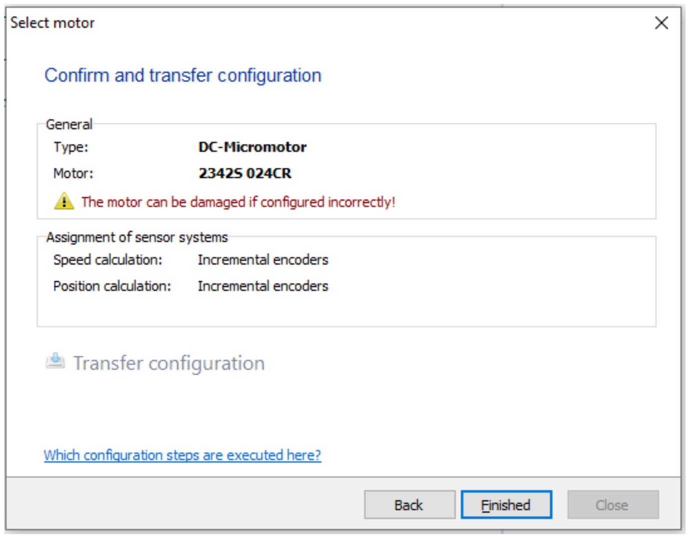


Figure 4.13: Adapting the overvoltage control to the motor supply voltage

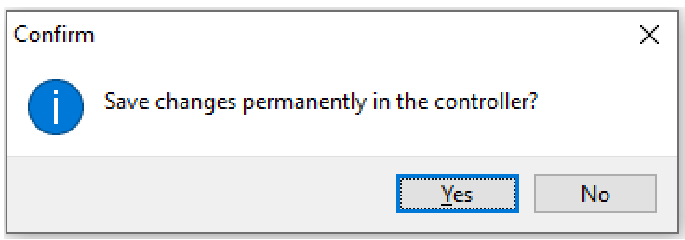


Figure 4.14: Adapting the overvoltage control to the motor supply voltage

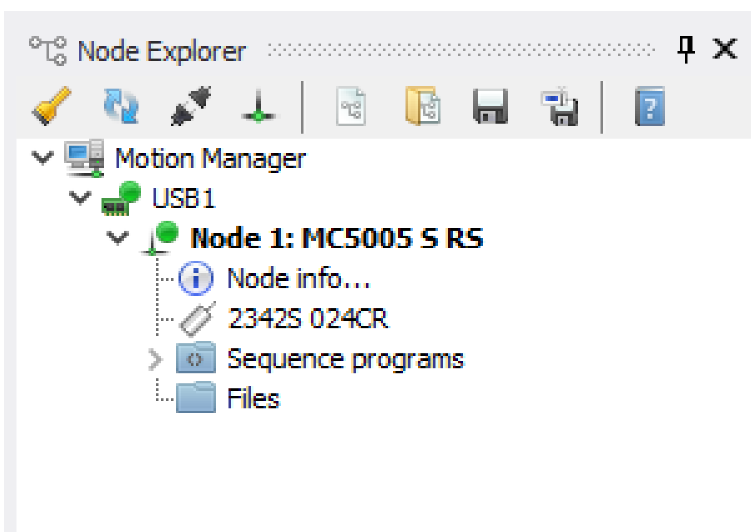


Figure 4.15: A Node Explorer that displays the controller

4.2.3 Operation Motor

Having successfully completed the wizards for attaching the motor, selecting it, and configuring the control system, the first commissioning of the drive system has already been carried out, which is bound to happen in due course. During the motor selection stage, the position of the Hall sensor signals can be adjusted by repeating the process several times. In the FAULHABER Motion Manager's Node Explorer you will be able to see the set motor. During the next part of our course, we will look at how a DC motor works in order to learn more about the DC motor. Operate motor is a quick access dialogue in the commissioning category that allows for easy control of the motor without diving too deeply into many configuration options [21].

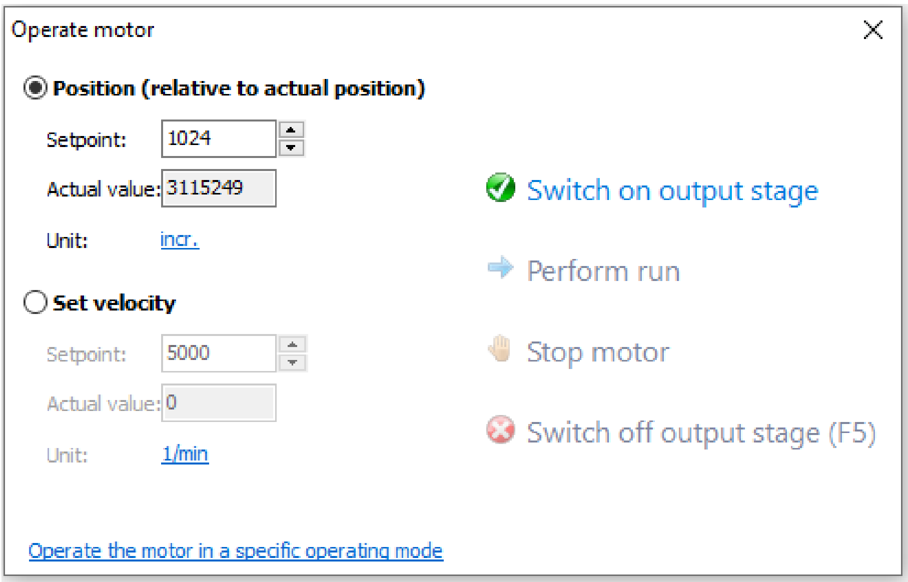


Figure 4.16: Operation Motor

On the motor operation table, we can see that there are two ways to adjust the motor. The first step is to adjust the position. One round corresponds to 4096 setpoints. Running 1/4 on a revolution corresponds to setting 1024 setpoints. In the second step, we adjust the motor's speed. The motor's speed unit displays the unit of rotation per minute, so this means, that if we set each setpoint to 5000, we will be able to determine that within a minute, the motor can rotate 5000 times around. Then we press the switch on the output stage to activate the motor, then we set the unit to the setpoint frames, then we press the Perform Run button to start the drive, and then we press the Stop motor to end the motor, but the control remains active. In order to switch off the output stage, the final button on the drive has to be pressed [21].

4.3 Laboratory Motion Control Assignments

Task Description: In this task, we will define the operation of the DC motor through the Motion controller. Control the DC motor with 3 different modes: position, speed and torque. How we can control understand all Digital buttons and Analogue buttons. We can operate it through the 2 tasks shown below

Task 1 :

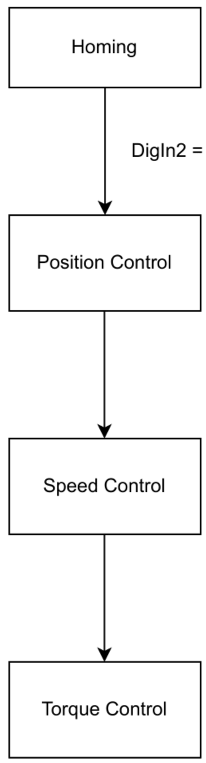


Figure 4.17: Flow chart of Task 1

For task 1, we will set digital button 2 to operate the DC motor with three moving parts: torque, position, and speed. We will set two different conditions for the position movement: the first setting will be to set the motor to rotate in the opposite direction with a reverse half-turn value, and the second setting will be to set the motor to rotate in the forward direction with a single revolution. A rotation of 4096 equals one round. This is repeated three times in a row.

The next step in the speed movement of the motor will be to start the motor to rotate the following way: the first step will set the motor to rotate at 40 rounds per second for three seconds. The second step involves rotating the motor in reverse for 3 seconds at 50 rounds per second twice in a row.

Lastly, the motor will be set to torque. The torque 30 Nm will rotate within 7 seconds and the torque 0 Nm will be set within 3 seconds to reduce the motor speed. For reverse rotation, set torque -6 Nm for 5 seconds, and for rotation, set torque 0 Nm for 2.5 seconds, until it stops

Task 2 :

As part of task 2, we will adjust the analogue dials to increase and decrease the speed.

Task 2a:

During this section, we will set the Digin 1 button which will act as a switch to turn the motor on and off and configure the Digin 1 button to binary 1 so that the Analog 1 button will open to control the DC motor. As the motor can run at maximum speed with 10000 rounds/s, we will set it to -5000, then the motor will recognize the position of analogue button 1 in the middle of the motor's idle state. By turning to the left, the motor will increase in the opposite direction, and by turning to the right, it will increase in the forward direction. At -5000 speed, the lowest and highest positions of the two directions rotate with the same force, but in the opposite direction.

Task 2b:

As with task 2a, this section will also be set up and Digin1 will be the switch for this operation. However, there will be a difference with task 2a in that the speed unit will be set to -7500 and the Analogue button 2 will be used to adjust the speed. The resting state will fall exactly at the 3/4 position of the Analogue 2 button because the set unit is -7500. Naturally, the reverse rotation speed at the end point will rotate faster than the forward position at the end. The max speed of the reverse side will be 7500 rounds/s and the forward direction will be 2500 rounds/s

4.4 Laboratory Tasks for Students

4.4.1 Here are some facts about DC motors and motion controllers:

- A description of the product
- These are their specifications
- The location of the motor and wiring is shown in the picture
- An image is attached between the Motion Controller and the computer
- Motion Controller allows you to set actions
- LED characteristics
- Motion controller benefits

4.4.2 Using Motion Manager 6.0, connect computer and Motion Controller:

- The type of cable used to connect the computer to the motion controller
- This section contains information about Motion Manager 6.0's functions
- Motion Manager 6.0 - How to install DC motors
- A step-by-step guide to setting the supply voltage

4.4.3 DC motor operation on Motion Manager 6.0:

- Position movement of DC motor with 1 turn corresponding to 4096 positions per revolution
- In Motion Manager 6.0, you can set the unit change on the Operation Motor section by selecting the round/s value for the DC motor position motion.
- DC motor on/off buttons.

4.4.4 Demonstration of motor movement with digital and analog buttons:

- In part 1, we will set the Digital 2 button to open for three movements of position, speed, and torque:
- Position movement with specified number of rotations
- You can set the number of revolutions and the speed of the movement
- Specify the number of rotations for torque motion
- The Digital 2 node should be installed in the active binary.
- Our next step is to install Digital 1 in order to control the speed of Analog 1 and Analog 2.
- Analog 1 screw speed should be set to -5000
- Analogue 2 screw speed should be set to -7500
- Add Digital 1 button to active binary

Chapter 5

Dicussion

After studying the DC motor's main movement, we can alter it in three ways: by using the three buttons on the control panel and the knob to increase or reduce the movement. If the motor has an encoder, it may be made to operate smoothly and meet the maximum standard. The control tasks in the demonstration can be extended to be controlled by the Motion Controller 5005 SRS's external input and output signals, according to laboratory tests. It is quite simple to demonstrate the control methods and behavior of the DC Motor by simply setting the Motion Manager 6.0 application to a fixed unit for the motor.

Failure Dicussion:

Analogue and buttons are not set:
The manufacturer does not provide clear instructions on how to set the Digital and Analogue buttons in the included documentation. If we open Digin 3 at binary 1, both Digin 1 and Digin 2 buttons will work. If Digin 3 is not opened, the other two Digin buttons will not work. Digin 2 has a set limit and does not behave as the Digin 1 button. Digin 2 only turns on and off when we set its value, but integrated with the Analogue button, it doesn't work.

There is a problem with Motion Manager 6.0-written .bi libraries:
The Motion Manager 6.0 program includes the MotionFunctions.bi library, according to the manufacturer. If you want to rewrite the error, you must declare the library in another folder and the file in the general folder it understands. It would be helpful if the manufacturer provided more concrete examples for customers to better understand and use it.

Failures associated with DC motors and controllers include:
Over time, we find that the data we enter into the controller doesn't work as we intended it to. When its power is cut off, the motor runs without stopping until 1 to 2 minutes have passed before it is plugged back in and it resumes normal operation.

Chapter 6

Conclusion

DC motors are able to be controlled in three different ways when it comes to adjusting their speed, position and torque. In these three ways of adjustment, a vital role has been played in the operation and effective use of machinery in industry. Because of the precision on which the adjustment is made, the operation is very convenient both in your day-to-day life and your professional life. The combination of DC motors with encoders as well as Motion Controllers are the perfect solution in the manufacturing industry. Motion Manager 6.0 is a software package that contributes to the quality and efficiency of the motor by monitoring and adjusting the absolute value based on the absolute value of the motor during operation.

In this thesis, the background has been discussed in detail and the important points of DC motors have been stated clearly. This will allow you to become familiar with the motor as well as the control system, in particular with regards to the control methods and control modes for the stepper motor, as well as for each type of motor. The DC motor lab meets the needs and presents the motion behavior of position, speed and torque in the DC motor lab. This is where the switch buttons are located so we can turn the engine on/off and knobs are placed so that we can increase or decrease the speed of the engine. In this set of values, students will be able to see clearly how to adjust the parameters and their ideas about the desired motor operation will be clearer. The students can follow the above instructions based on this set of values.

Future Work:

The interesting demonstration Section 4.2 , in the motor connection part controls only 1 motor . However, in Motion Manager 6.0 software, it is possible to integrate 2 or more other DC motors so that we can use it to install and operate it so that we can make an integrated series of motors used in the production line to can increase work efficiency.

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Appendix A

Connector PIN assignment

Pin assignment of the DC motor connection (M1)
M1(motor) : connection of the motor phases (Max 5/15A)

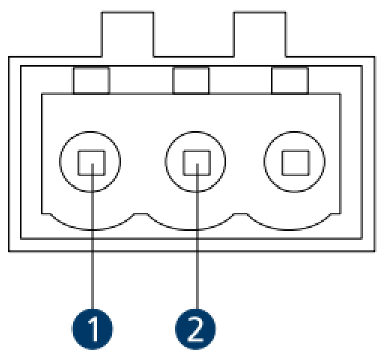

Figure A.1: Pin assignment of M1 [22]

1. Motor + : Connection of motor, positive pole
2. Motor – : Connection of the motor, negative pole[22].

Pin assignment of encoder connection (M3)
M3 (encoder) : connection of an incremental encoder with or without line driver . alternatively an absolutely an absolute encoder can be connected with or without line driver..

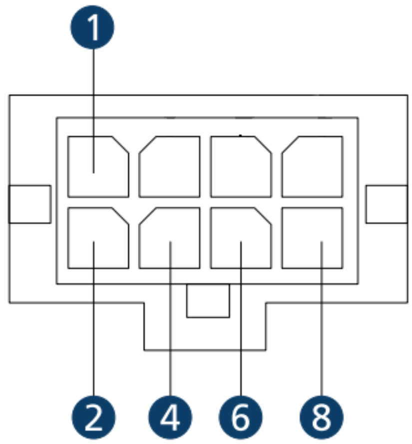

Figure A.2: Pin assignment of M3[22]

1. UDD : Power supply for incremental encoder
2. GND : Ground connection
4. Channel A : Encoder channel A
6. Channel B : Encoder channel B
8. Index : Encoder index

Pin assignment at the USB port (X1)

X1(USB) : connection of the usb communication

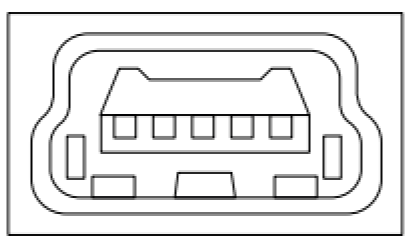

Figure A.3: Pin assignment of X1 [22]

1. USB : USB communication [22].

COM port (X2)

X2(COM) : RS232/CAN interface connection

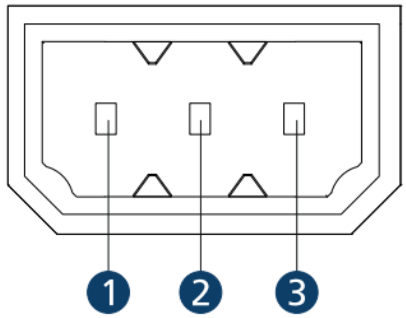

Figure A.4: in assignment of the COM port (X2) for RS232 [22]

1. TxD : RS232 interface transmit direction
2. RxD : RS232 interface receive direction
3. GND : Ground connection

Pin assignment of the I/O connection (X3)

X3 (I/O) : Inputs and Outputs for external circuits :

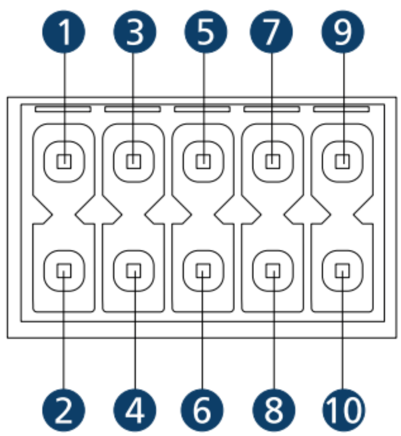

Figure A.5: The PIN of X3 [22]

1. V_{DD} Power supply for external consumer loads
2. GND Ground connection
3. DigOut 1 Digital output (open collector)
4. DigOut 2 Digital output (open collector)
5. DigIn 1 Digital input : The digin 1 node is set to the position of the binary number. Binary 0 is in the upper and middle positions, binary 1 is in the lower position. We can set it on Editor Motion Manager 6.0 software
6. DigIn 2 Digital input : Its operation like Digin 1

7. DigIn 3 Digital input : The Digin 3 button is used to enable digin1 and digin 2 operations. digin 3 button when in the middle position and up position corresponding to binary 0 will be off and when in the lower position corresponding to binary 1 it will be open for the other 2 digin buttons work
8. AnIn 1 Analogue input
9. AnIn 2 Analogue input
10. AGND Ground connection for analogue inputs [22].

Table A.1: Electrical data for the I/O connection (X3)

Description	**Value**
Power supply for external consumers	5 V $<$100 mA
DigOut	low = GND high = high resistance 47 k Max. 0.7 A TTL level: low $<$ 0.5 V, high $>$ 3.5 V PLC level: low $<$ 7 V, high $>$ 11.5 V
DigIn	T$<$50 V 47 k $<$1 MHz
AnIn	$\pm$10 V AGND

Voltage supply of the controller (X4)

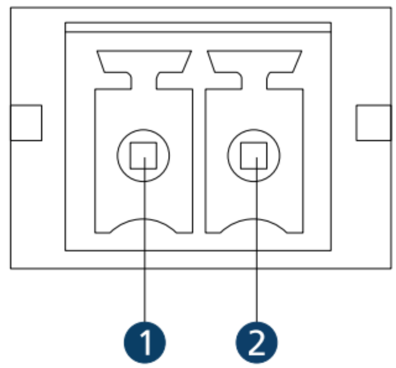

Figure A.6: Pin assignment of X4 [22]

1. GND Ground connection
2. V_P Power supply for controllers [22]

Power supply of the motor (X5)

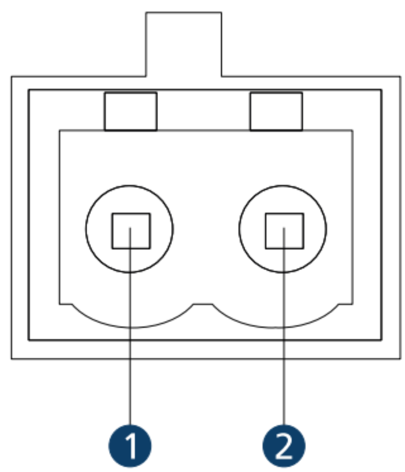

Figure A.7: Pin assignment of X5 [22]

1. GND Ground connection
2. V_{mot} Power supply for controllers [22]

LED overview :

- State LED : Green (continuous light): Device active.
- Green (flashing): Device active. However the state machine has not yet reached the Operation Enabled state.
- Red (continuously flashing): The drive has switched to a fault state. The output stage will be switched off or has already been switched off.
- Red (error code): Booting has failed. Please contact FAULHABER Support.
- Power LED : Green: Power supply within the permissible range.
- Off: Power supply out of the permissible range [22].

Appendix B

Identify the difference between a DC motor and a Stepper motor

A comparison of Stepper Motors and Direct Current (DC) Motors is given by taking into account factors such as the loop of operation, controlling, brushes, motion, and displacement of the motor. Motor response time and overloading effects[23].

Table B.1: Difference between Stepper Motor and DC Motor [23]

Characteristics	**DC motor**	**Stepper**
Nature of loop	DC motors are designed to work in closed loops.	Stepper motors are designed to work in open loops.
Controlling	Controlling DC motors is not an easy task	Microprocessors make microcontrolling easy.
Brushes	Brushes are part of DC motors.	Motors that run on brushless motors
Motion and displacement	They are characterized by continuous displacement and can be controlled very precisely.	A step's resolution and motion are limited by the size of the step
Response time	The control of a DC motor by feedback gives a faster response time than when the motor is controlled by a stepper motor.	Response times are slow
Effect of Overloading	It is possible to detect an overload if it occurs	If a stepper motor is overloaded, it may slip and the error can't be detected.

Appendix C

Long Source Code Listing

```
 '--------------------------------------------
'Author: HOANG
'Date: 18/03/2022
'--------------------------------------------
'Description: Program combining three control modes:
'Position-speed-torque
'--------------------------------------------
'loading libraries into the program
#INCLUDE "MotionParameters.bi" 'load the necessary parameters from library files
#INCLUDE "MotionMacros.bi"   'load macros files
#INCLUDE "MotionFunctions.bi" 'load functions like Enable (), WaitPos (), etc.
'allocation of symbolic variable names
#DEFINE DestinationSpeed $60FF.00
#DEFINE instant_position $6064.00
'*********************************************************************
'===== BEGIN THE PROGRAM =====
'allocation of variables
DIM position_before_strar ' variable allocation
DIM current_position      ' variable allocation
DIM positive_rotated = 4096 ' 4096 = rotate 1 round
DIM negative_rotated = -2048 ' negative rotate by a value
DIM Waiting = 1000         ' time 1000ms
DIM Position_cycles = 4    ' number of cycles in position control mode
DIM Speed_cycles = 3       ' number of cycles in speed control mode (velocity)
DIM Torque_cycles = 1      ' number of cycles in torque control mode
'*********************************************************************
```

```
DO WHILE (MC.DigIn2 = 0)   'will repeat the loop until (condition)
LOOP                       'end of loop / jump to beginning

Enable()                  'Switching on the inverter output stage (MotionFunctions
    .bi)
position_before_strar = GETOBJ instant_position 'load current position
'********************************************************************
' Position control Mode:
DO WHILE (Position_cycles > 0)            'Loop with check of the loop condition
    at the start of the loop
    SETOBJ ModesOfOperation = OpModePP     'Set position mode
    DIM Position_cycles = Position_cycles - 1 'countdown of position cycles
    MoveRel (negative_rotated, 0)          'rotate in a negative direction
    WaitPos ()                             'Waiting to reach the position
    DELAY Waiting                          'time pause
    MoveRel(positive_rotated, 0)           'rotate in a positive direction
    WaitPos ()                             'Waiting to reach the position
    DELAY Waiting                          'time pause
LOOP                                       'end of loop
'********************************************************************
' Speed (velocity) control Mode:
DO WHILE (Speed_cycles > 0)            'Loop with check of the loop condition at
    the start of the loop
    MC.SetOpmodePV                     'Set Speed mode
    DIM Speed_cycles = Speed_cycles - 1 'countdown of speed control cycles
    SETOBJ DestinationSpeed = 40       'setting of rotation speed 40 rpm in rpm (
        round/minute)
    DELAY 3000                         'Delay 30000ms
    SETOBJ DestinationSpeed = -50      'speed setting to -50 rpm
    DELAY 3000                         'Delay 3000ms
    SETOBJ DestinationSpeed = 0        'speed setting 0 rpm
LOOP                                   'end of loop
'********************************************************************
' Torque control Mode:
DO WHILE (Torque_cycles > 0)              'Loop with check of the loop condition
    at the start of the loop
    MC.SetOpmodeCST                       'torque setting. inverter mode
    DIM Torque_cycles = Torque_cycles - 1  'countdown of torque cycles
```

```
    SETOBJ TargetTorque = 30                'torque setting 30 Nm
    DELAY 7000                              'time pause 7000ms
    SETOBJ TargetTorque = 0                 'torque setting reduce the speed of
       torque setting 0Nm
    DELAY 3000                              'time pause 3000ms
    SETOBJ TargetTorque = -60               'torque setting -60 Nm
    DELAY 5000                              'time pause 5000ms
    SETOBJ TargetTorque = 0                 'torque setting reduce the speed of
       torque setting 0Nm
    DELAY 2500                              'time pause 2500ms
LOOP
Disable() 'turn off the output stage (MotionFunctions.bi library)
END      'end of program
```

Listing C.1: Set motion position , speed and torque with button Digital 2

```
  '--------------------------------------------
'Author:
'Date:
'--------------------------------------------
'Description:
'--------------------------------------------
#INCLUDE "MotionParameters.bi" 'load the necessary parameters from library files
#INCLUDE "MotionMacros.bi"   'load macros files
#INCLUDE "MotionFunctions.bi" 'load functions like Enable (), WaitPos (), etc.
'allocation of symbolic variable names
#DEFINE DestinationSpeed $60FF.00 'allocation of symbolic variable names

DIM Speed ' variable allocation
DIM Vol1 ' variable allocation
'**********************************************************************

Enable() 'Switching on the inverter output stage (MotionFunctions.bi)
DO
  IF (MC.DigIn1 = 1) THEN 'Programming a branch
    MC.SetOpmodePV 'Set Speed mode
    DO WHILE (MC.DigIn1 = 1) 'Loop with check of the loop condition at the start
        of the loop
      Vol1 = GETOBJ $2314.$07 ' set analogue 1
```

```
        Speed = Vol1 - 5000     'set the center analogouge position to rotate in
            the opposite direction and rotate in the right direction
        SETOBJ DestinationSpeed = Speed 'set speed FOR control analogue
    LOOP
    MC.SetOpmodePV 'Set Speed mode
    SETOBJ DestinationSpeed = 0 'setting Speed =0
  END IF
LOOP
  '--------------------------------------------
MC.SetOpmodePV
SETOBJ DestinationSpeed = 0
END    'end of program
```

Listing C.2: setting speed motion with Digital 1 trigger and 1/2 condition in Analogue 1

```
  '--------------------------------------------
'Author:
'Date:
'--------------------------------------------
'Description:
'--------------------------------------------
#INCLUDE "MotionParameters.bi" 'load the necessary parameters from library files
#INCLUDE "MotionMacros.bi"   'load macros files
#INCLUDE "MotionFunctions.bi" 'load functions like Enable (), WaitPos (), etc.
'allocation of symbolic variable names
#DEFINE DestinationSpeed $60FF.00
DIM Speed ' variable allocation
DIM Vol1 ' variable allocation
'**********************************************************************

Enable() 'Switching on the inverter output stage (MotionFunctions.bi)
DO
  IF (MC.DigIn1 = 1) THEN 'Programming a branch
    MC.SetOpmodePV 'Set Speed mode
    DO WHILE (MC.DigIn1 = 1) 'Loop with check of the loop condition at the start
         of the loop
        Vol1 = GETOBJ $2314.$08 ' set analogue 2
        Speed = Vol1 - 7500 'set the analog point position 3/4 to rotate in the
            opposite direction and 1/4 to rotate in the right direction
```

```
        SETOBJ DestinationSpeed = Speed 'set speed FOR control analogue
      LOOP
      MC.SetOpmodePV 'Set Speed mode
      SETOBJ DestinationSpeed = 0 'setting Speed =0
   END IF
LOOP
   '--------------------------------------------
MC.SetOpmodePV
SETOBJ DestinationSpeed = 0
END     'end of program
```

Listing C.3: setting speed motion with Digital 1 trigger and 3/4 condition in Analogue 2