

Course: Special Electrical Machines (BEE061)

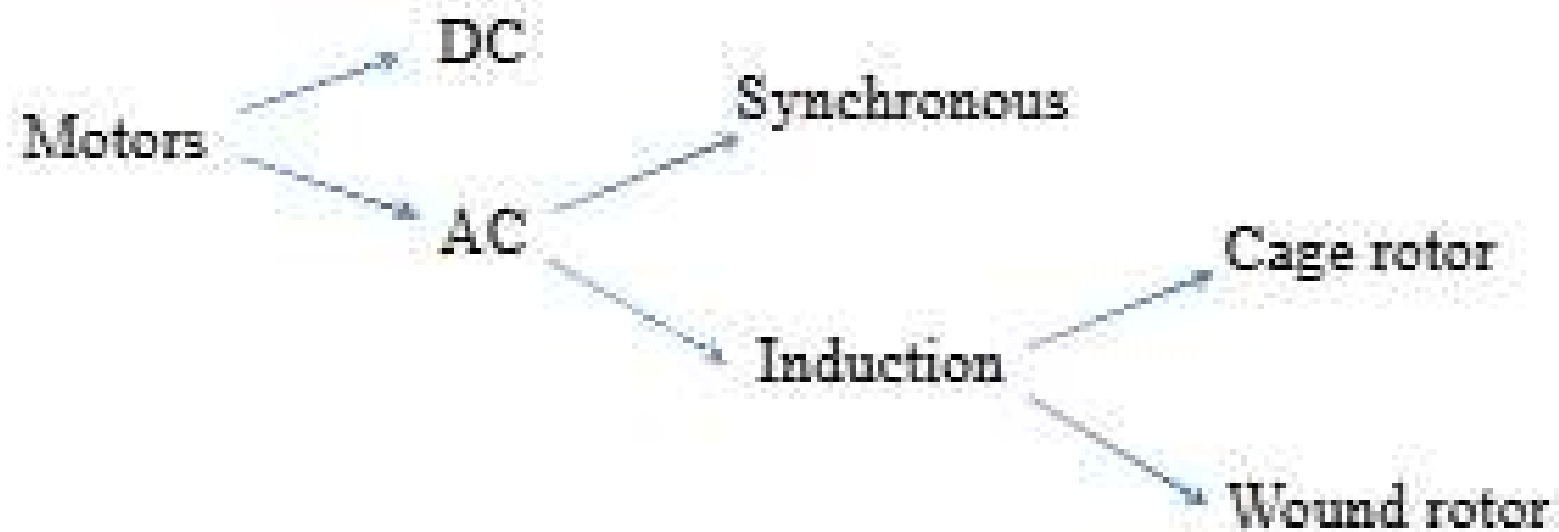
Unit 1
Induction machines

Electric Motors (A major power consumer in industries)



- Electromechanical device that converts electrical energy to mechanical energy.
- Motors in industry: 70% of electrical load.

General Classification of Motor



Why Induction Motor ?

(Major Advantages)

- Rugged structure
- Low maintenance
- Better reliability
- Ability to operate in dirty and explosive environment
- Higher efficiency
- Available in wide power range

Uses of Induction Motor

➤ Industrial Applications:

- Steel and cement mills
- Paper and textile mills etc.

➤ Domestic uses:

- Pumps
- Fans
- Other home appliances

➤ Fixed and variable speed applications

Constructional Details

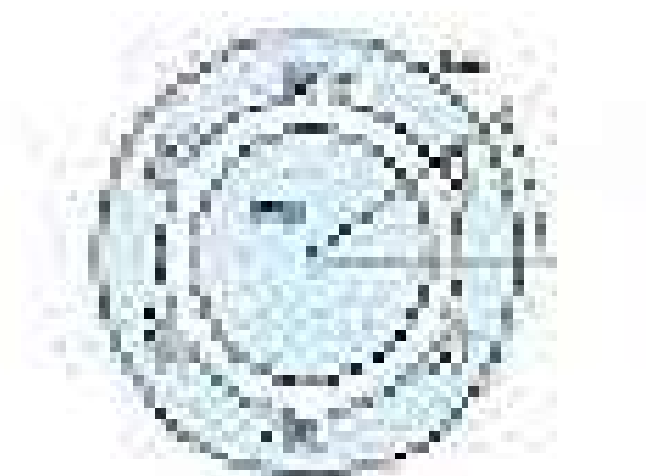
Major parts:

➤ Stator (stationary part)

Three phase armature winding is embedded.

➤ Rotor (rotating part)

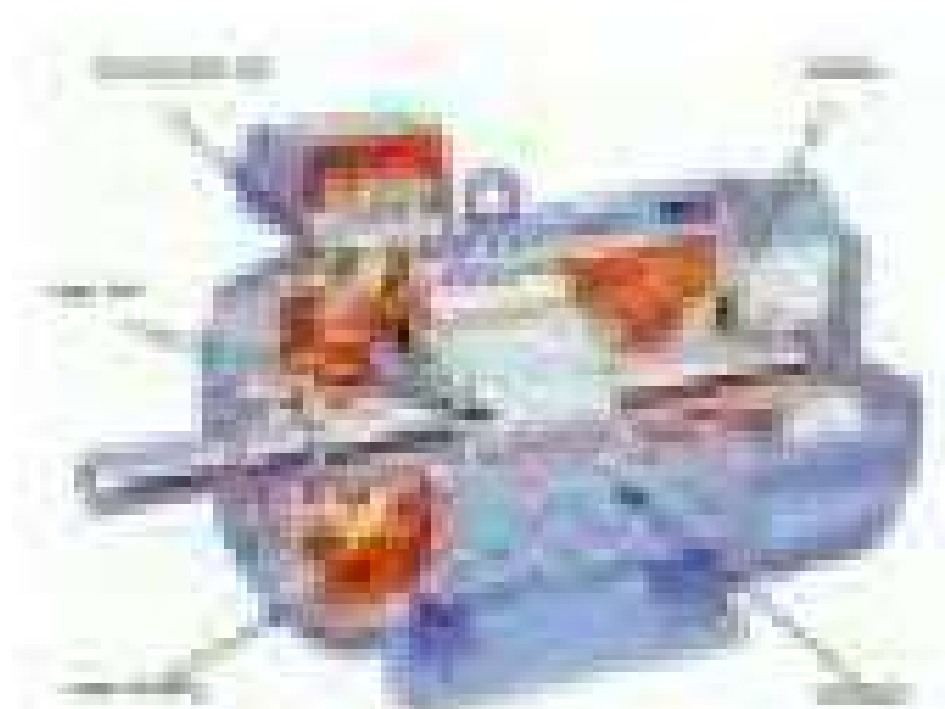
Types: - Squirrel cage
- Wound rotor



Cross sectional view of Induction motor



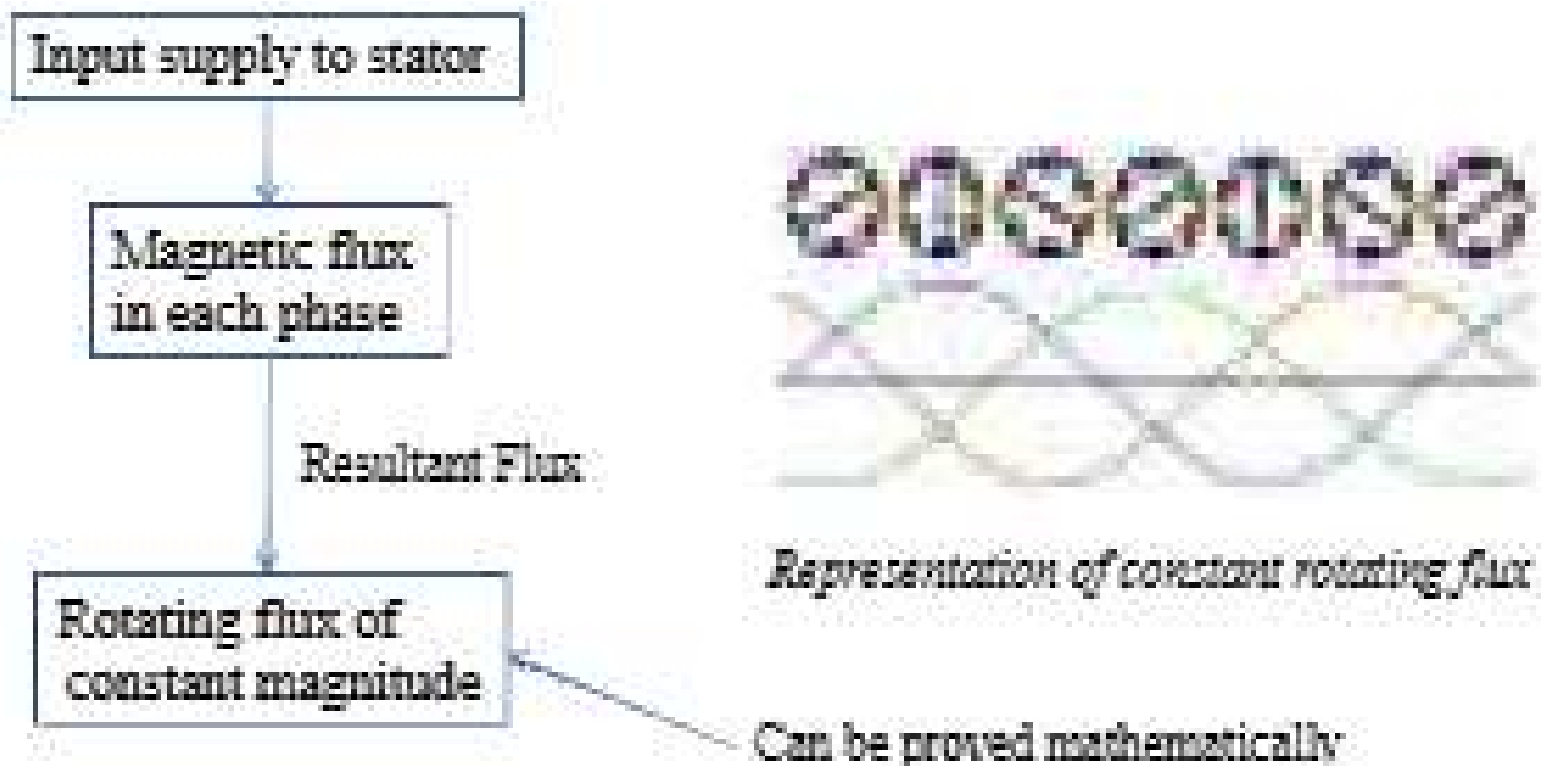
General view of stator and rotor



Complete view of Induction motor

Operating Principle of Induction Motor

- Rotating Magnetic Field



- Speed of rotating flux $\xrightarrow{\text{known as}}$ Synchronous Speed

How rotating torque is produced ?

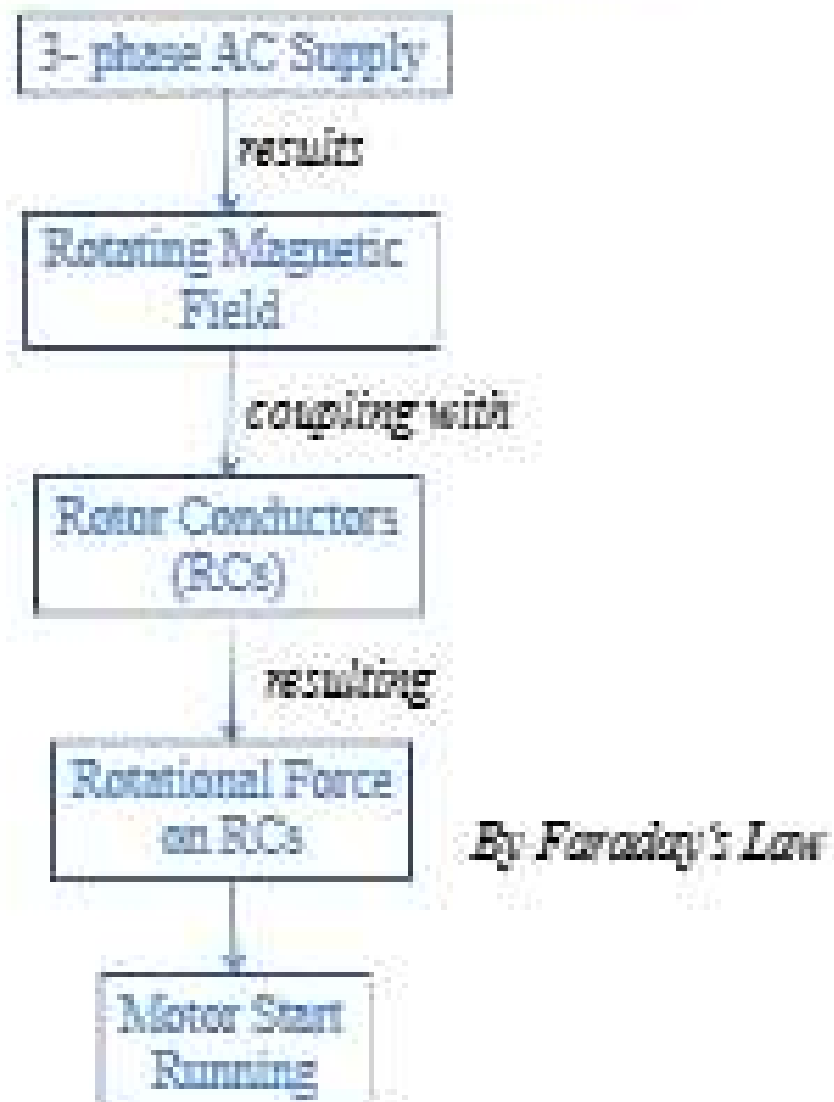
- Induced e.m.f. in rotor conductor (theory of electromagnetic induction).
- Flow of rotor current due to its closed circuit.
- Presence of current carrying rotor conductor in magnetic field produced force.

- Direction of force is governed by Faraday Left Hand Rule.

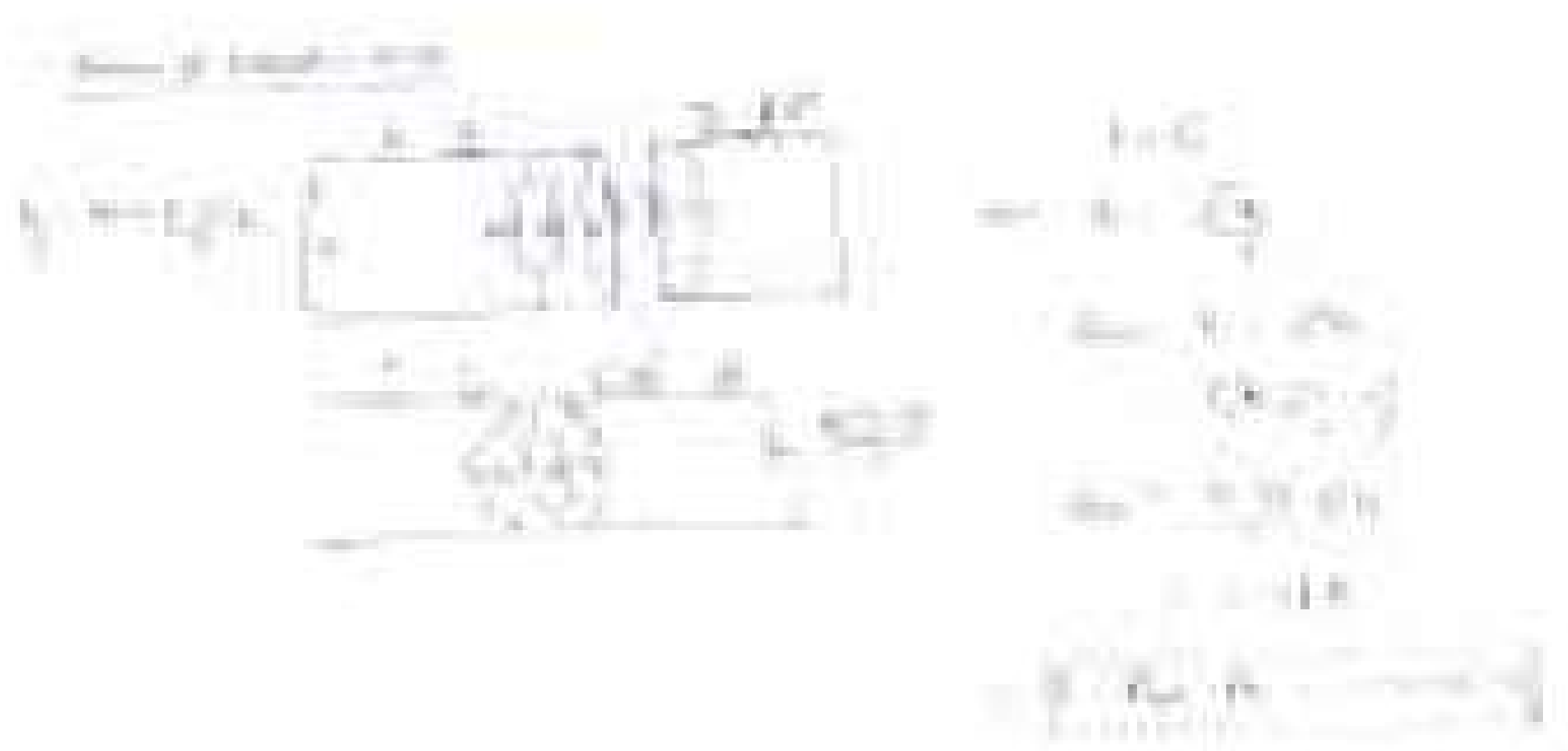


- Hence, induction motor is self starting.
- Speed of rotation is slightly less than synchronous speed.

Various Steps in motor operation



Review of Induction motor



Torque of induction motor

Figure 1: Induction motor equivalent circuit

Figure 2:

Figure 3:

Figure 4:

Figure 5:

Figure 6:

Figure 7:

Figure 8:

Figure 9:

Figure 10:

Figure 11:

Figure 12:

Figure 13:

Source: <http://www.fishbase.org>

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Classification of speed control of induction motor

Stator Side

1. Stator voltage Control
2. Stator Frequency Control (V/f control)
3. Pole changing

Rotor Side

1. Rotor circuit resistance variation
2. EMF injection in rotor circuit
3. Cascade connection method

Speed Control by Stator voltage Control

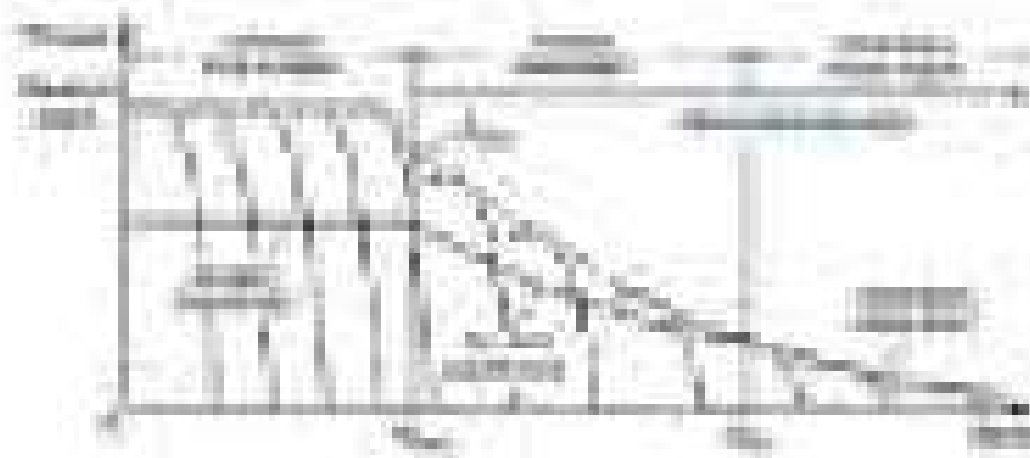
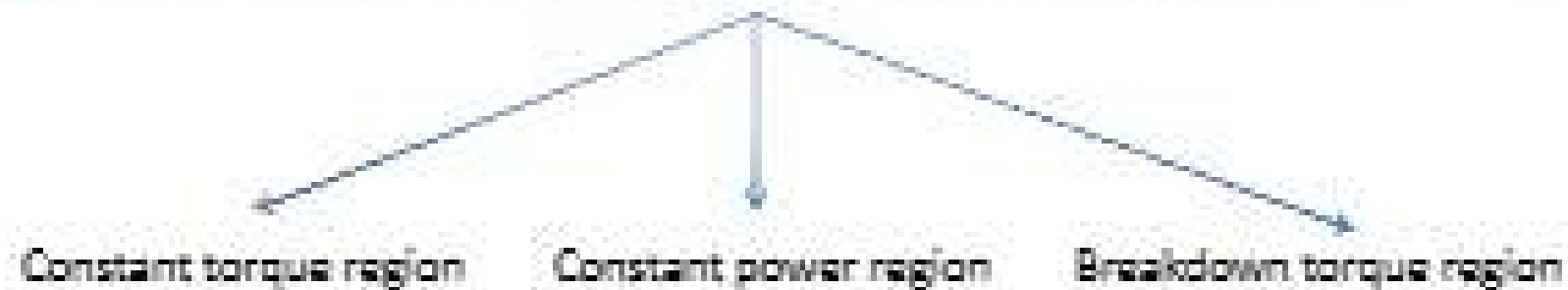


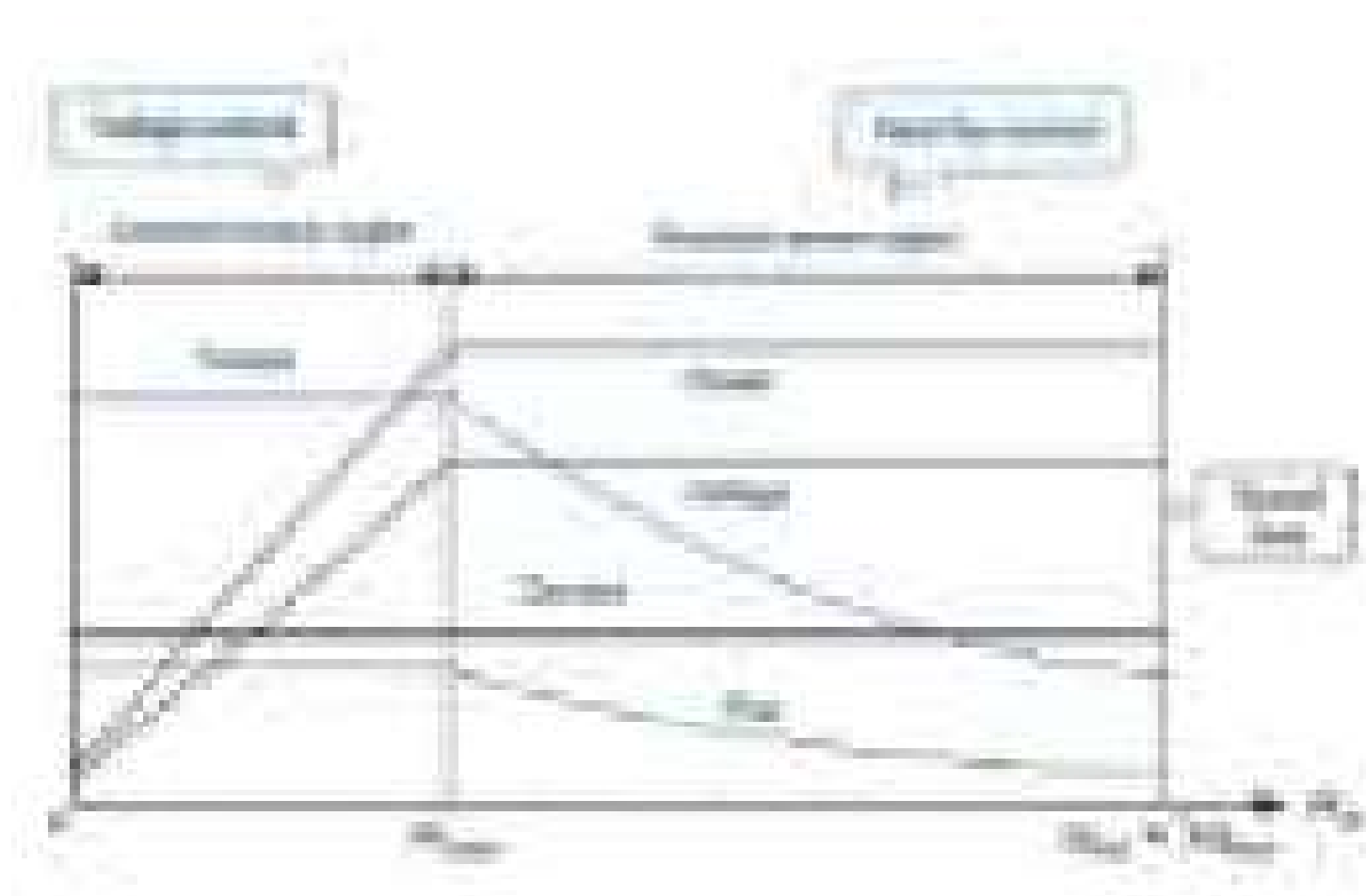
Speed Control by Stator Frequency Control (i.e. V/f control)

$f_3 < f_2 < f_1$



Operating region of Induction Motor

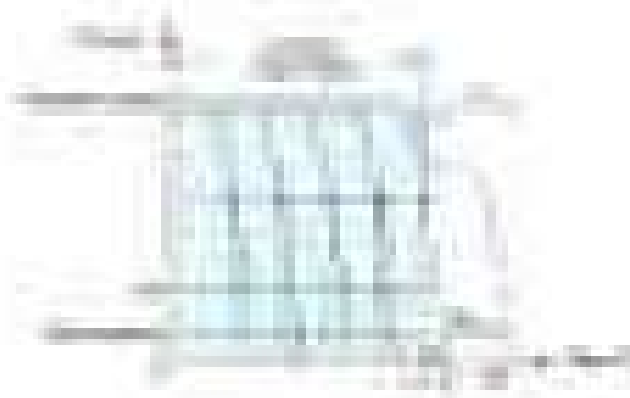




$$P = T\omega$$

A) Constant torque region

- Motor speed is increased by increasing the stator frequency maintaining constant flux (according to the linear V/f relationship)
- In this control method, since the output torque is proportional to the slip frequency, the output torque can be produced equally at any speed for the same slip frequency. How?



1. Introduction

2. Background
3. Methodology

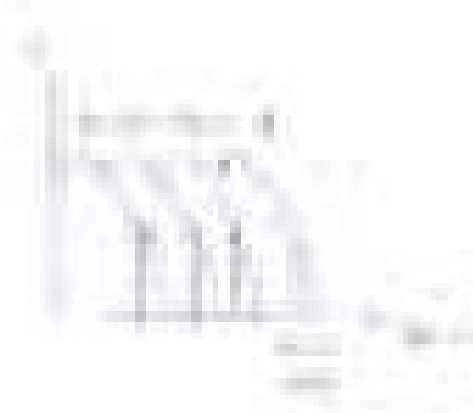
4. Results

5. Discussion
6. Conclusion

7. References
8. Appendix
9. Index
10. Table of Contents

11. Summary

12. Abstract
13. Keywords
14. Subject Headings
15. Notes



B) Constant power region

constant power region

in this region power is constant and $P = P_{max}$

if current is less than maximum

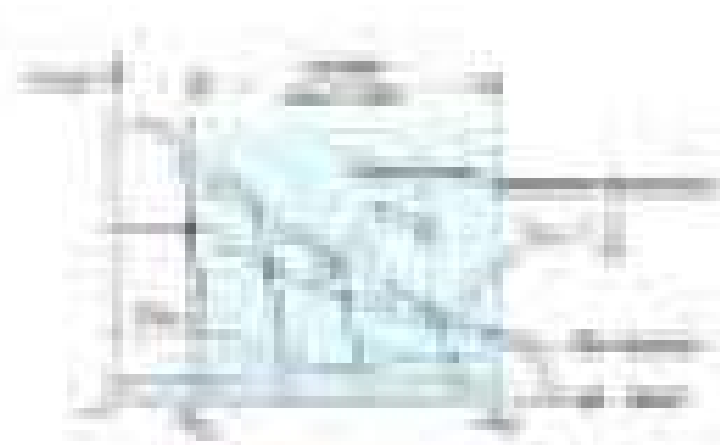
we can find maximum P by changing V and I

(with $P = P_{max}$ in constant power region)

$P = V \cdot I = P_{max}$ (in this region)

$$I = \frac{P_{max}}{V} \quad \text{for } V < V_{max} \quad \text{and } I < I_{max}$$

$$P_{max} = \frac{V_{max} \cdot I_{max}}{2}$$



The diagram shows a rectangular structure with internal components. The labels 'Top', 'Bottom', 'Left', and 'Right' indicate the orientation of the structure. The numerical values '100', '200', and '300' represent dimensions or specific parameters. The diagram is a technical drawing, likely used for engineering or scientific purposes.

Linear Induction Motor (LIM)

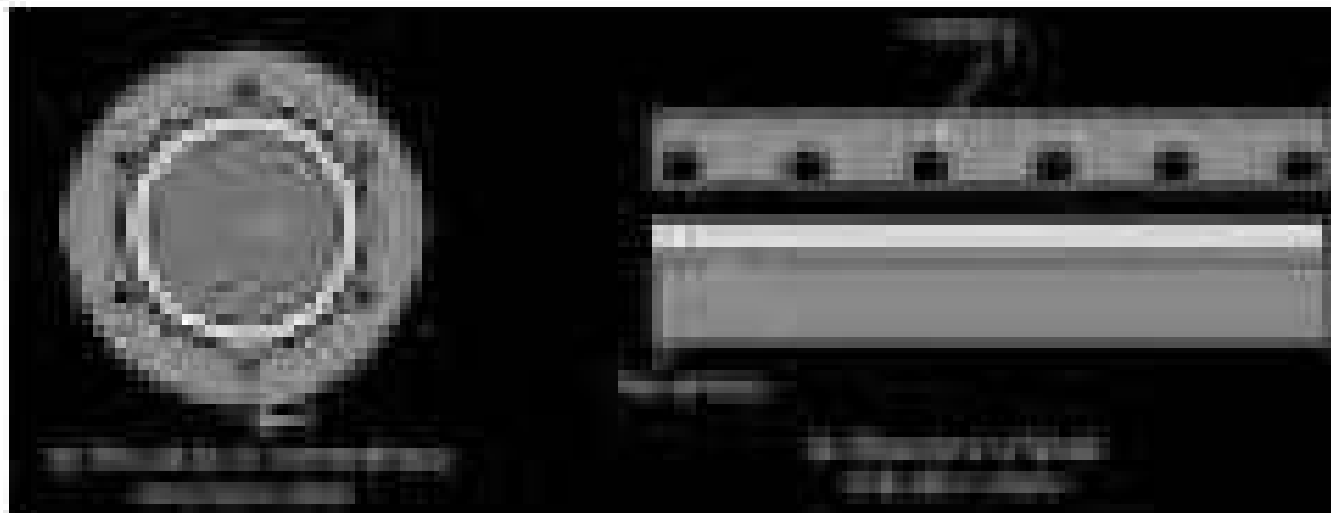
Linear induction motor (LIM)

is a motor which gives

a linear or translational motion

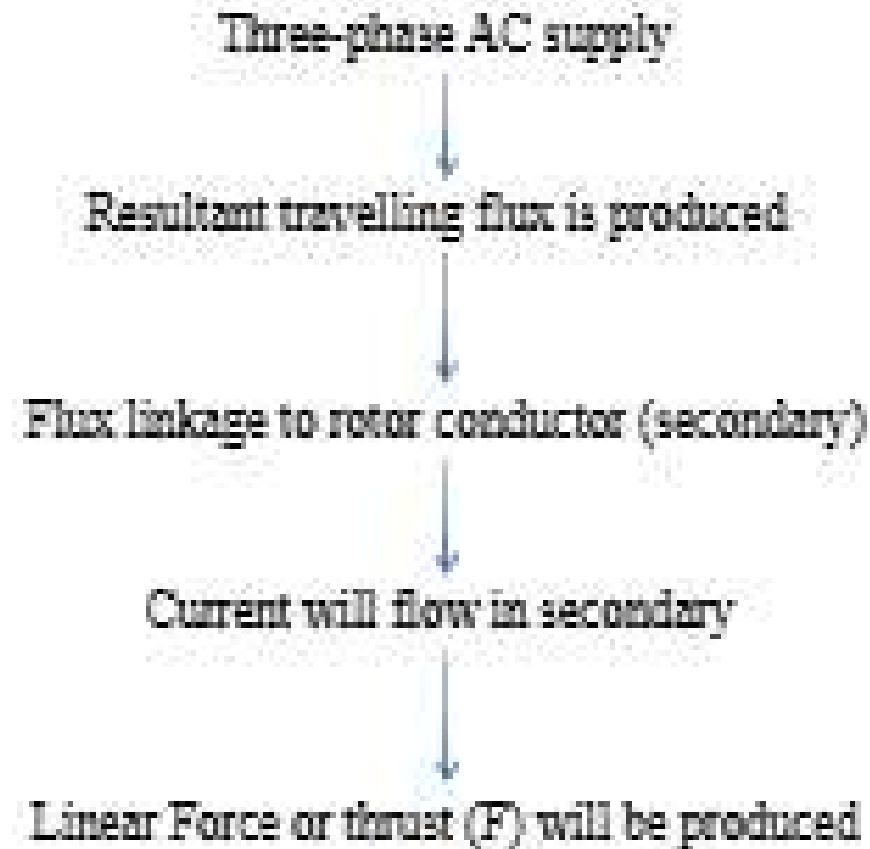
How and Why?

Construction of LIM



Constructional features of Linear induction motor

Operation of LIM



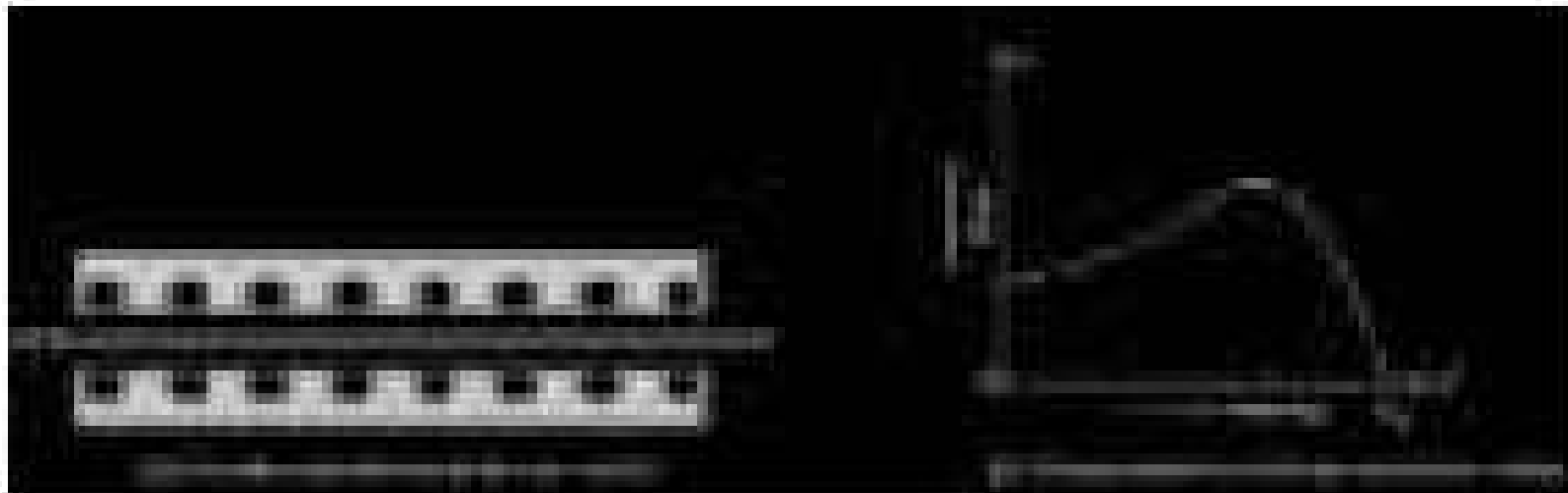
- For fixed secondary, primary will move in the direction of travelling wave

Types of LIM

Single-sided linear induction motor (SLIM)

Double-sided linear induction motor (DLIM)

primary is placed on both the sides of the secondary



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Table 1. Summary of the results of the 2010 survey.

Question	Response	Percentage
1. How satisfied are you with the current situation in the country?	Very satisfied	10%
	Satisfied	20%
	Not satisfied	70%
2. What is the main reason for your dissatisfaction?	Corruption	45%
	Unemployment	35%
	Low wages	20%
	Other	10%
3. Do you think the government is doing enough to solve these problems?	Yes	15%
	No	85%
4. If you were in charge, what would you do to improve the situation?	Reduce corruption	55%
	Create jobs	30%
	Increase wages	15%
	Other	10%

Notes:

1. The survey was conducted in 2010, and the results are based on the responses of the respondents at that time. The survey was conducted in a random sample of the population.

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Two Phase AC SERVOMOTORS



- To control the machine it is operated with fixed voltage for the reference phase and variable voltage for the control phase.
- The torque-speed characteristics are essentially linear (high rotor resistance assumed) for various control phase voltages.

- In low-power control applications (below a few watts), a special rotor construction is used to reduce the inertia of the rotor. A thin cup of nonmagnetic conducting material is used as the rotor (*drag-cup rotor*).



- A stationary iron core at the middle of the conducting cup completes the magnetic circuit

ANALYSIS: TRANSFER FUNCTION AND BLOCK DIAGRAM



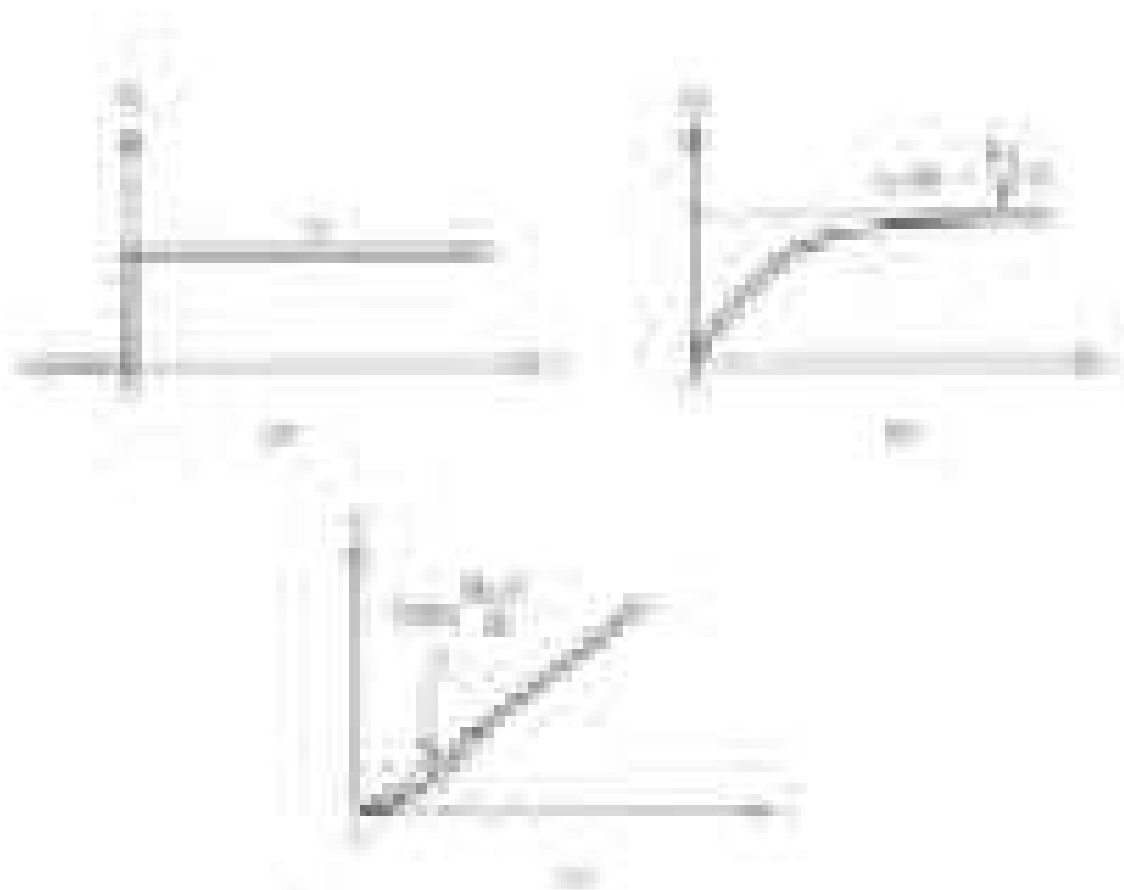


Transfer functions.

Time Response for a Step Change in Control Phase Voltage Open Loop Operation

Consider a step change in the control phase voltage V_a





Step response in a two-phase servo system.

- (a) Step change in V_a .
- (b) Response in speed.
- (c) Response in position.

1. $\frac{1}{2}mv^2$
 2. $\frac{1}{2}mv^2$

1. $\frac{1}{2}mv^2$ measurement
 2. $\frac{1}{2}mv^2$ measurement
 3. $\frac{1}{2}mv^2$ measurement



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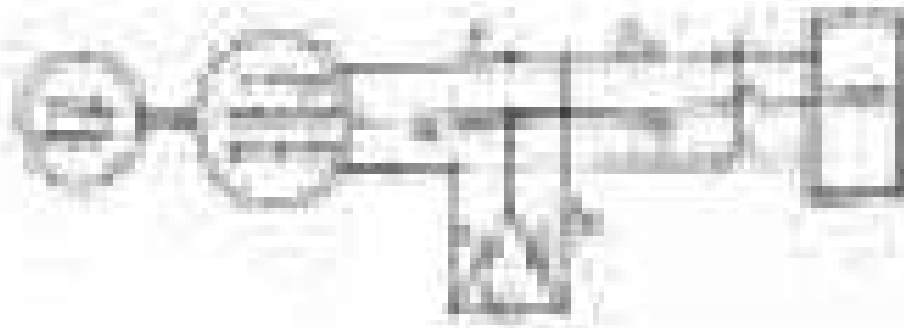
Induction machine as generator



- When an induction machine is connected to the supply, it will supply power to the supply if the supply voltage is high enough to excite the machine's magnetizing branch. The voltage across the machine will be high enough to excite the machine's magnetizing branch.
- When connected to the supply, the machine will supply power to the supply if the supply voltage is high enough to excite the machine's magnetizing branch. The voltage across the machine will be high enough to excite the machine's magnetizing branch.
- The induction machine's magnetizing branch is a series combination of the machine's magnetizing inductance and the supply's magnetizing inductance. The voltage across the machine will be high enough to excite the machine's magnetizing branch.

[illegible]

Self excited induction generator



- Capacitive reactive power, $Q = Q_1$, reactive power needed by 3-phase induction generator + Q_2 , reactive power needed by the load
- The reactive current of a capacitor depends upon the voltage across its terminals, i.e., capacitor voltage

$$I_c = \frac{Q}{V}$$



(Conversion of oil before, at and after end of reaction tank)

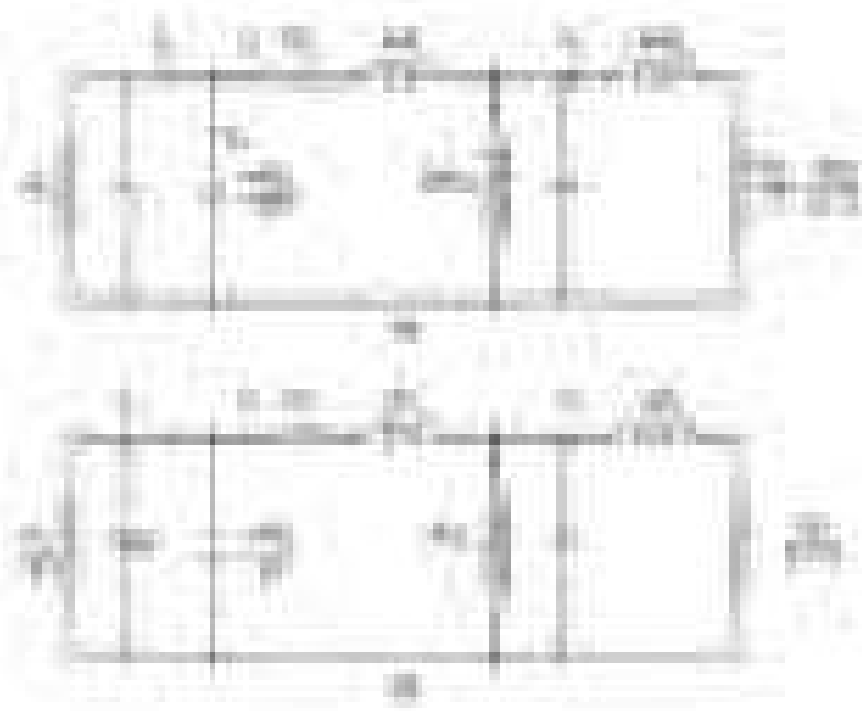
Voltage Build-up in self-excited induction generator



Self excited induction generator

- The delta- connected capacitors across the generator terminals provide the magnetizing current necessary to excite the isolated generator
- Operating frequency depends primarily upon rotor speed but is affected by the load, while the voltage is mainly decided by capacitor reactance (X_C) at the operating frequency.





Voltage Buildup in SEIG



When the switch is closed, the current I starts to flow through the inductor, and the induced voltage V_L begins to build up.

The induced voltage V_L is given by:

$$V_L = \frac{d\Phi}{dt}$$

where Φ is the magnetic flux.

As the current I increases, the magnetic flux Φ also increases, and the induced voltage V_L continues to build up until it reaches a steady-state value.

Unit 2

Stepper motor

- *Def.* A motor in which the rotor turns in discrete movements is called a stepper motor.



- The angle through which the motor shaft rotates for each command pulse is called the *step angle* β .
- It is observed, the smaller the step angle, the greater the number of steps per revolution and higher the resolution or accuracy of positioning obtained.

- The resolution is given by the number of steps needed to complete one revolution of the rotor shaft. The higher the resolution, the greater the accuracy of positioning of objects by the motor.

$$\text{Resolution} = \text{No. of steps/revolution} = 360^\circ/\beta$$

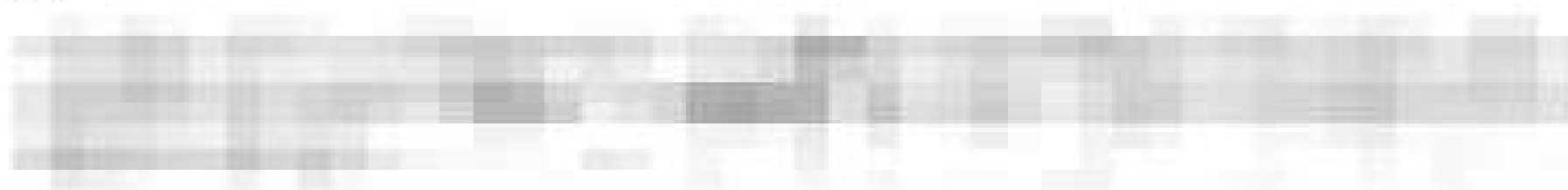
- When the pulse rate is high the shaft rotation seems continuous and operation at a high rate is called **slewing**.

-

Q1



Q2







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2. The second part of the document outlines the various methods and techniques used to collect and analyze data. It includes a detailed description of the experimental setup and the procedures followed during the study.

3. The third part of the document presents the results of the study, showing the data collected and the analysis performed. It includes a series of tables and graphs that illustrate the findings of the research.

4. The fourth part of the document discusses the implications of the study and the conclusions drawn from the results. It highlights the significance of the findings and the potential applications of the research.

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6. The sixth part of the document includes a list of references and a bibliography, citing the various sources used in the study. It also includes a list of figures and tables, providing a clear and concise overview of the data presented.

7. The seventh part of the document includes a list of appendices, providing additional information and data that support the findings of the study. It includes a list of figures and tables, providing a clear and concise overview of the data presented.

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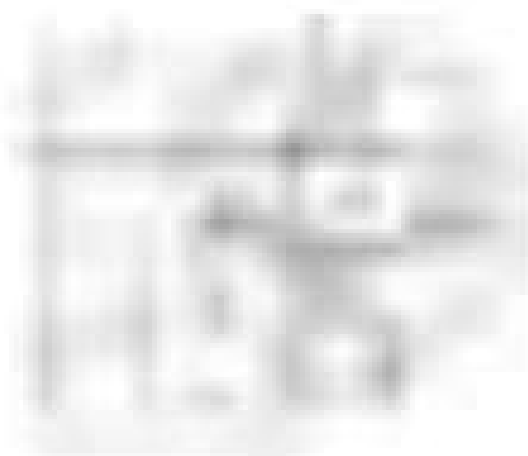
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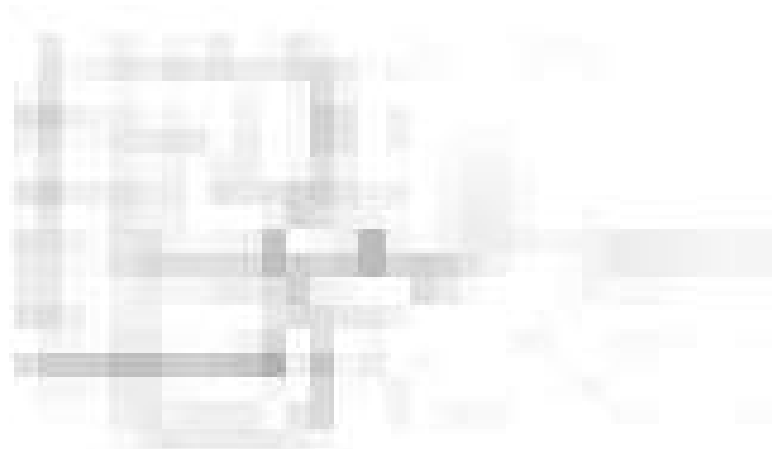
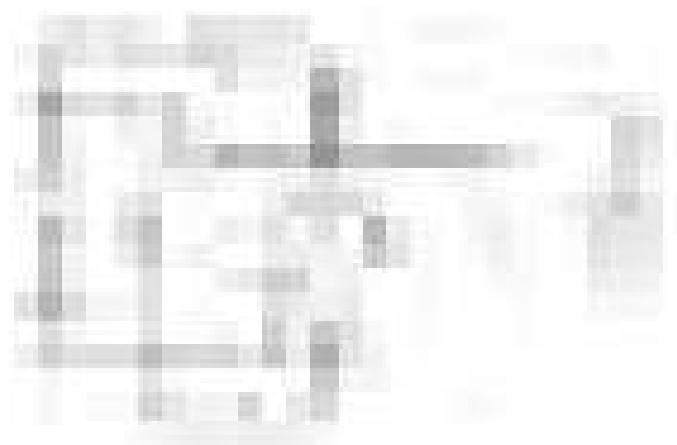
VARIABLE-RELUCTANCE STEPPER MOTOR

A. Single-Stack Stepper Motor



Basic circuit for a four-phase, 4/2 pole stepper motor.

- Reluctance torque is generated because of the tendency of the ferromagnetic rotor to align itself along the direction of the resultant magnetic field.
- Sequence: A, B, C, D etc. for 90 degree rotation in clockwise direction.



Operating modes of stepper motor for 90 step.



Sequence: A, A + B, B, B + C, and so forth

Operating modes of stepper motor for 45 step.

- **Microstepping:** The method of gradually shifting of excitation from one phase to another (e.g. From A to B with an intermediate step $A+B$) is known as microstepping.
- Lower values of step angle can be obtained by using a stepping motor with more number of poles on stator and teeth on rotor.

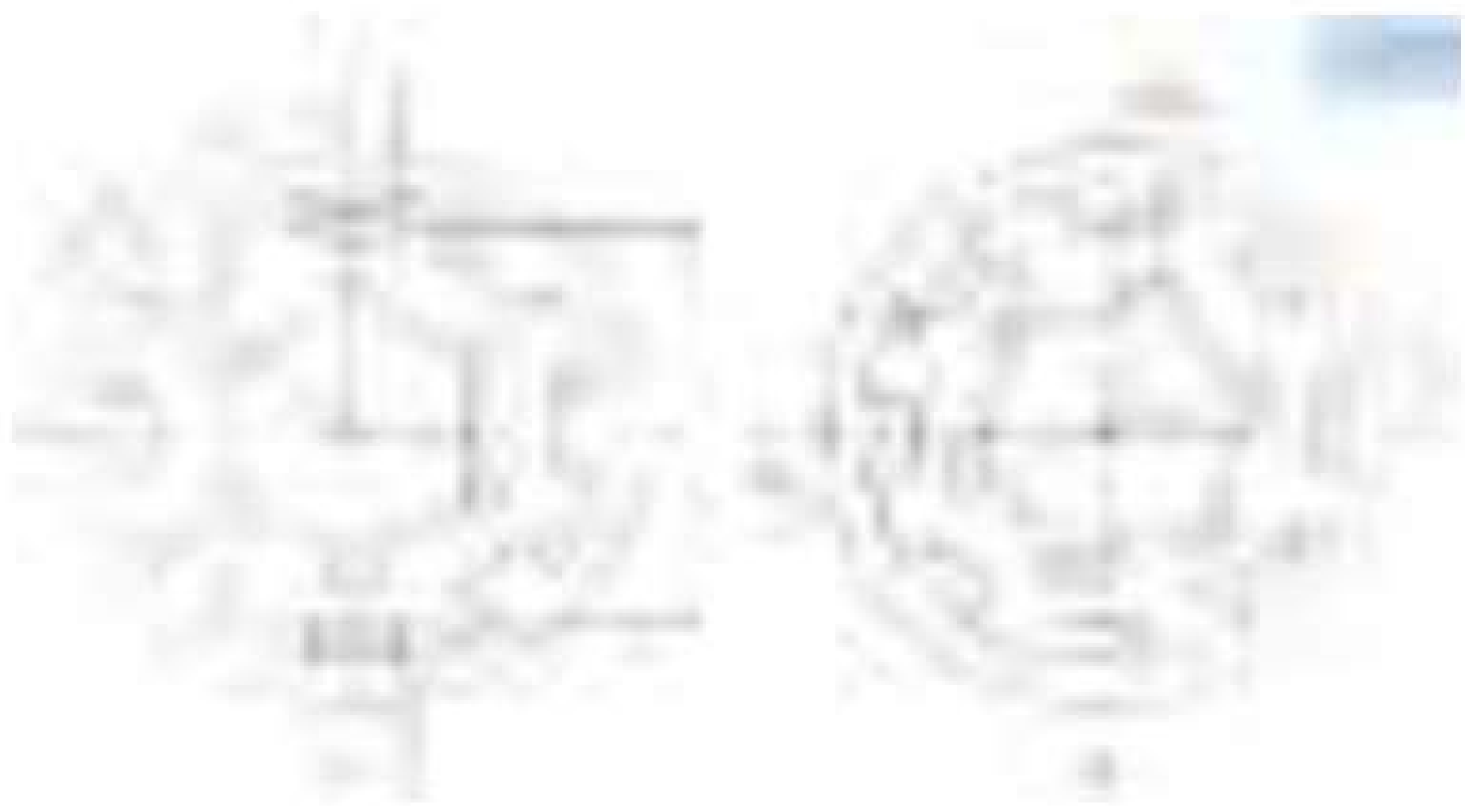


Figure 1. Two circular diagrams, likely representing celestial spheres or astronomical models, with various lines and labels.

Multistack Stepper Motor

- A Multi Stack or m stack variable reluctance stepper motor is made up of m identical single stack variable reluctance motor. The rotor is mounted on the single shaft. The stator and rotor of the Multi Stack Variable motor have the same number of poles and hence, the same pole pitch.
- All the stator poles are aligned in a Multi-Stack motor. But the rotor poles are displaced by $1/m$ of the pole pitch angle from each other. The stator windings of each stack forms one phase as the stator pole windings are excited simultaneously. Thus, the number of phases and the number of stacks are same.



Cross section of a three-stack, variable-reluctance stepper motor parallel to the shaft.

- There are 12 stator and rotor poles in each stack. The pole pitch for the 12 pole rotor is 30° , and the step angle or the rotor pole teeth are displaced by 10° degrees from each other.



Let N_r be the number of rotor teeth and m be the number of stacks or phases.

Hence, Tooth pitch is represented by the equation shown below.



As there are 12 poles in the stator and rotor, thus the value of $N_r = 12$. Now, putting the value of N_r in the equation (1) we get



The value of $m = 3$. Therefore, the step angle will be calculated by putting the value of m in the equation (2).



- When the phase winding A is excited the rotor teeth of stack A are aligned with the stator teeth as shown in the figure below.

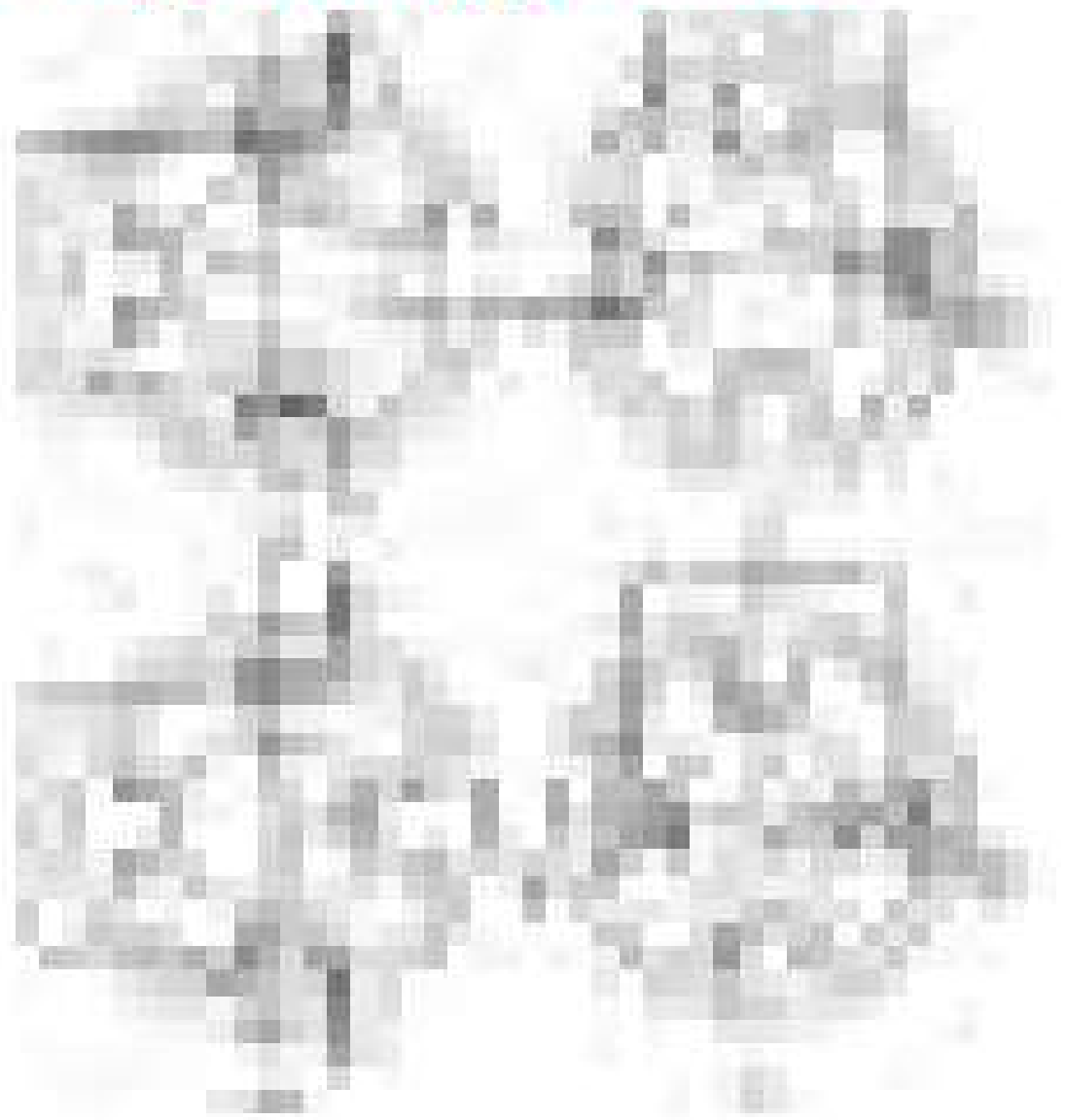


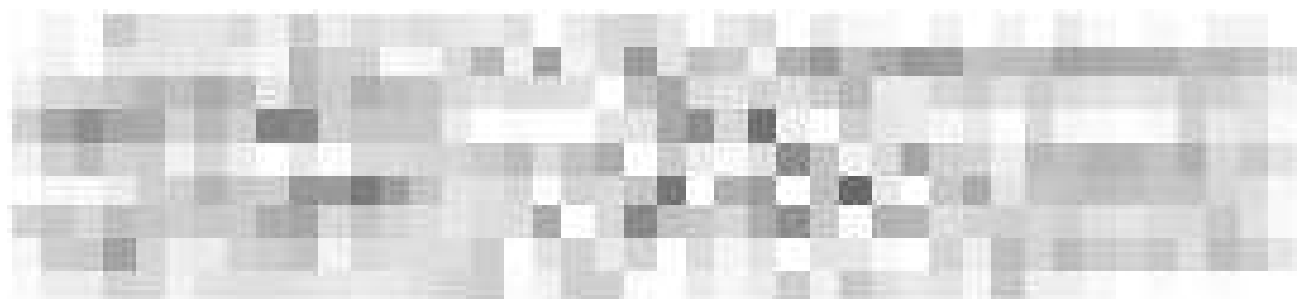
- When phase A is de-energized, and phase B is excited, rotor teeth of the stack B are aligned with the stator teeth. The rotor movement is about 10 degrees in the anticlockwise direction.



- Similarly, now phase B is de-energized, and phase C is excited. The rotor moves another step of $1/3$ of the pole pitch in the anticlockwise direction.
- However, during this whole process (A – B – C – A) the rotor has moved one rotor tooth pitch.

Permanent magnet stepper motor





Half Step mode excitation

The diagram shows a cross-section of a 2-phase motor with 4 poles and 4 stator windings. The top two windings are shaded gray, indicating they are excited. The bottom two are white, indicating they are not excited. The rotor is shown in the center with 4 poles.



Rotor rotation through 45° with both windings excited together In PMSM

Hybrid Stepper Motor



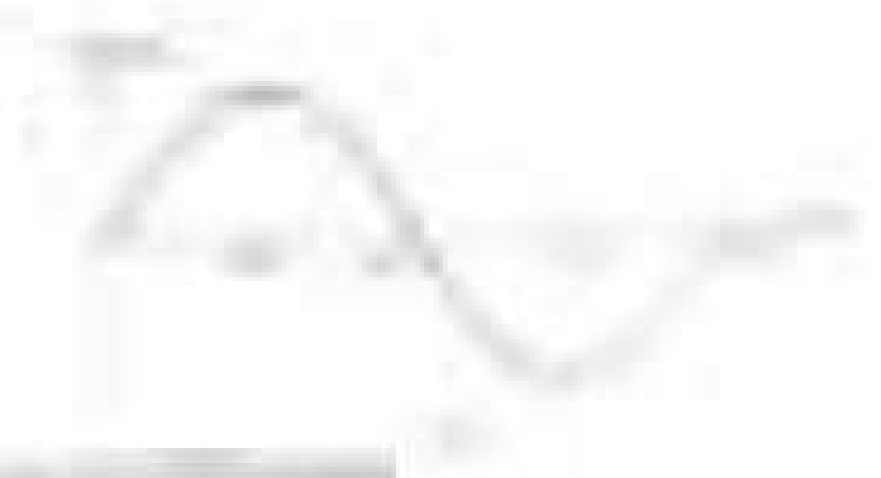
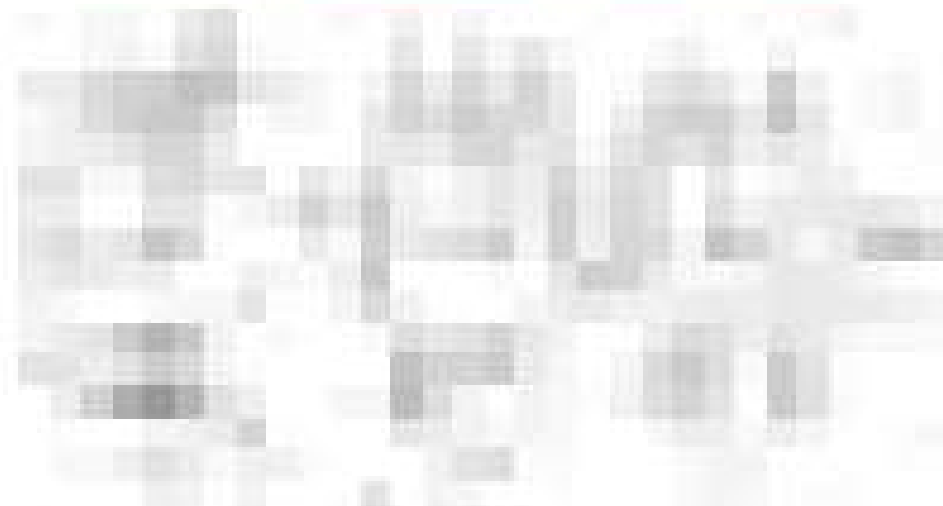




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Characteristics of Stepper Motor

A) Torque-Displacement Characteristic









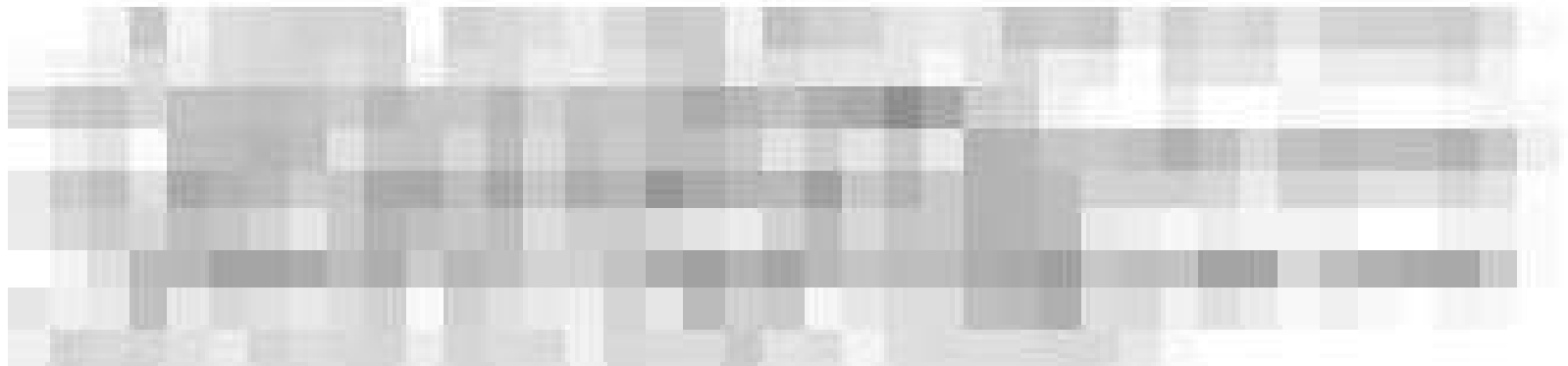
B) Torque pulse rate characteristic



- With increase in stepping rate, the rotor gets less time in driving the load from one position to the next, the driving torque is therefore decreased

- **Pull-in torque:** It shows the maximum stepping rate for the various values of the load torque at which the motor can start, synchronize, stop or reverse.
- **Pull-out torque characteristics:** It shows the maximum stepping rate of the motor where it can run for the various values of load torque. But it cannot start, stop or reverse at this rate.
- The area between curves 1 and 2 represents the various torque values, the range of stepping rate, which the motors follow without losing the synchronism when it has already been started and synchronized. This is known as **Slew Range**.

DRIVE CIRCUITS



A) Unipolar Drive Circuit



- A phase winding is excited by applying a control signal to the base of the transistor (a sufficiently high base current is passed through the base of the transistor)
- The dc supply voltage V_s is chosen so that it produces the rated current I in the winding.

Figure 10.10

- The maximum voltage across the transistor occurs at the instant of switch off, and is

Figure 10.11



B) Bipolar Drive Circuit

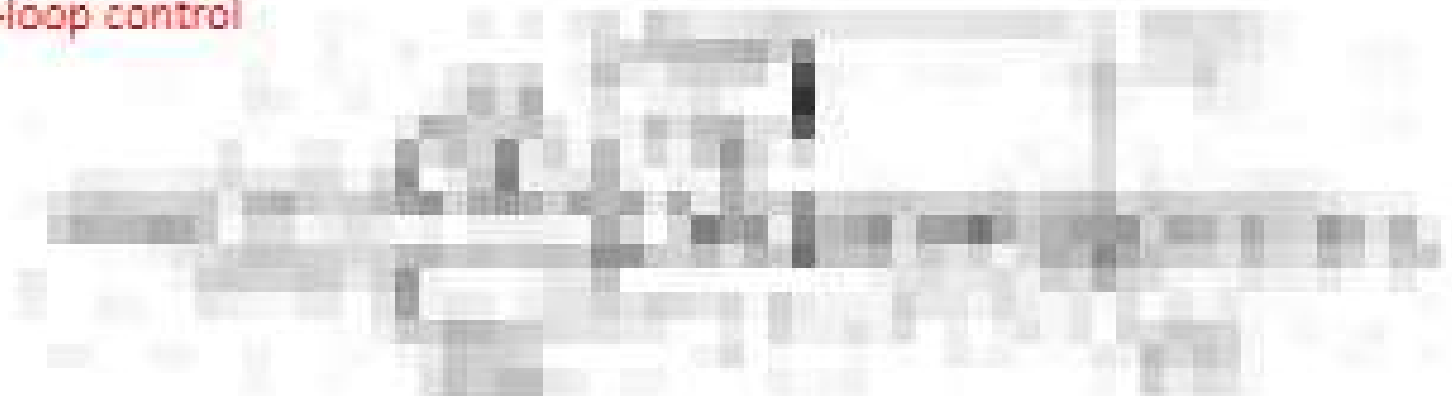


One phase of a bipolar drive circuit

- Bipolar drive circuit suitable for a permanent magnet or hybrid-type stepper motor.
- The transistors are switched in pairs according to the current polarity required for the phase winding
- The four diodes D1 to D4 connected in antiparallel with the switching transistors provide the paths for the freewheeling currents
- Note that when current flows through D3 and D4 to the dc supply, some of the energy stored in the phase winding inductance at turnoff (of the transistors) is returned to the supply. This improves the overall system efficiency, and is a significant advantage of the bipolar drive circuit over the unipolar drive circuit.
- Bipolar drive circuits require more switching devices and are therefore more expensive than unipolar drive circuits.
- Note that the freewheeling currents in the bipolar drive circuit decay more rapidly than in the unipolar drive circuit, because the dc supply opposes them. Consequently, no additional freewheeling resistance is necessary in the bipolar drive circuit.

Control of Step Motors

A) Open-loop control

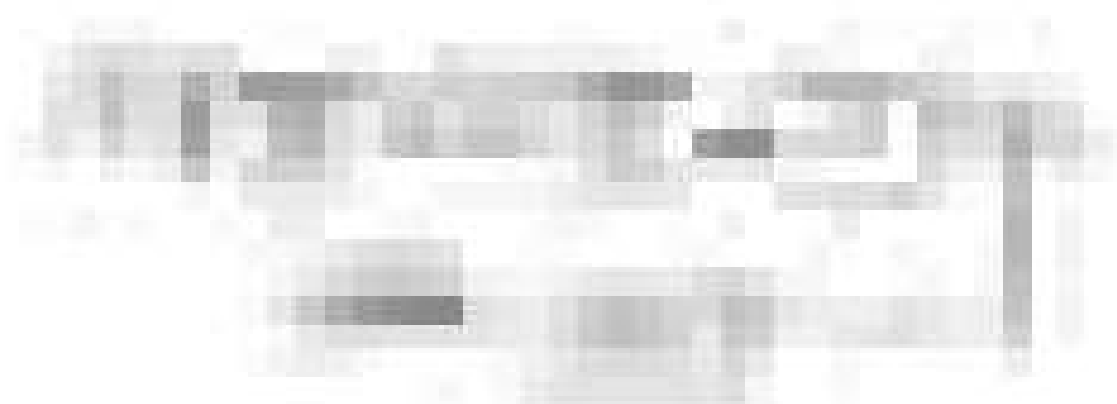


Open-loop control of a step motor

- The command to the pulse generator sets the number of steps for rotation and direction of rotation
- The Translator is a simple logical device and distributes the **position pulse train** to the different phases
- The amplifier block amplifies this signal and drives current in the corresponding winding.

- The direction of rotation can also be reversed by sending a **direction pulse train** to the translator. After receiving a directional pulse the step motor reverses the direction of rotation.
- The major disadvantage of the open loop scheme is that in case of a missed pulse, there is no way to detect it and correct the switching sequence. A missed pulse may be due to malfunctioning of the driver circuit or the pulse generator. This may give rise to erratic behaviour of the rotor.

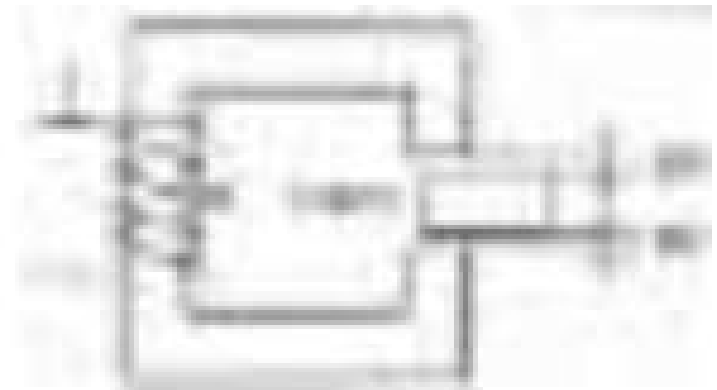
B) Closed-loop control



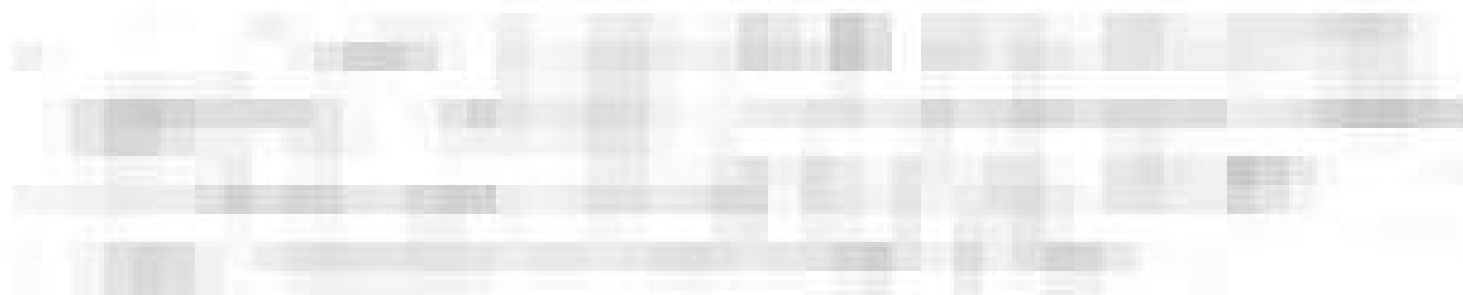
Feedback control of a step motor

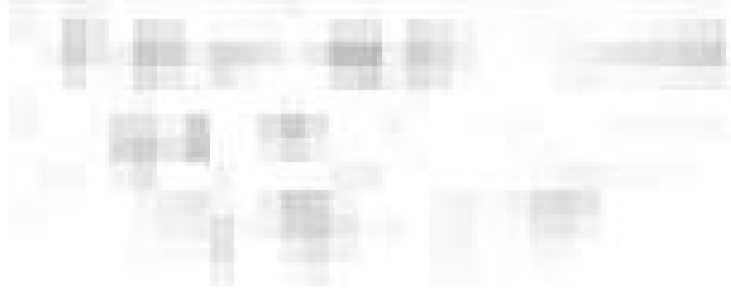
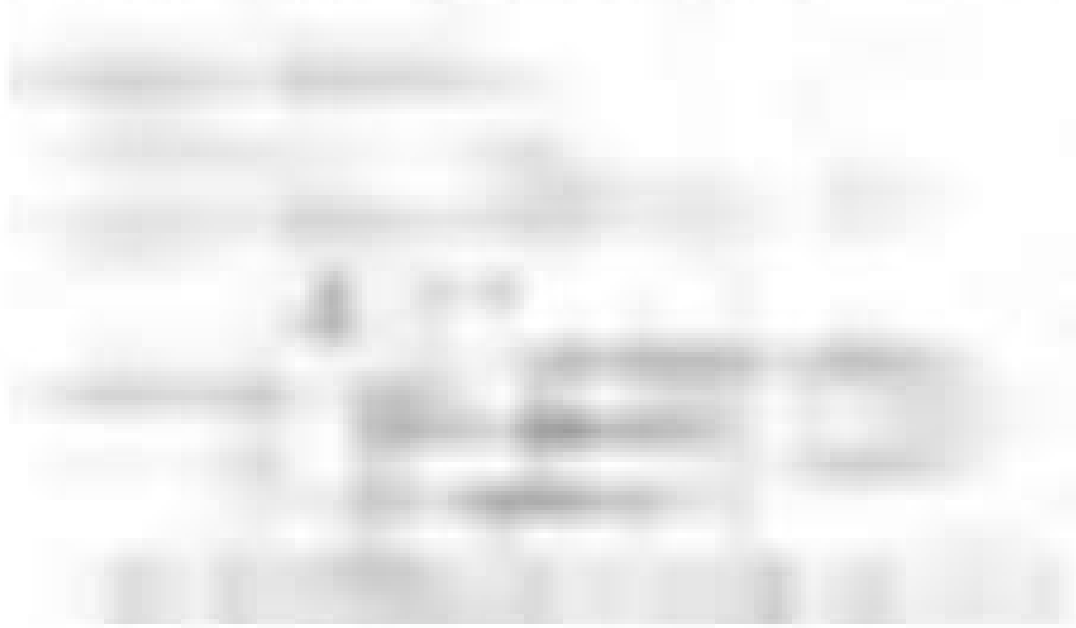
The closed loop arrangement has the advantage over open loop control, since it does not allow any pulse to be missed and a pulse is sent to the driving circuit after making sure that the motor has rotated in the proper direction by the earlier pulse sent. In order to implement this, we need a feedback mechanism that will detect the rotation in every step and send the information back to the controller. The incremental encoder here is a digital transducer used for measuring the angular displacement.

Torque/Force equation of Stepper Motor



Case 1: Core permeability is infinite





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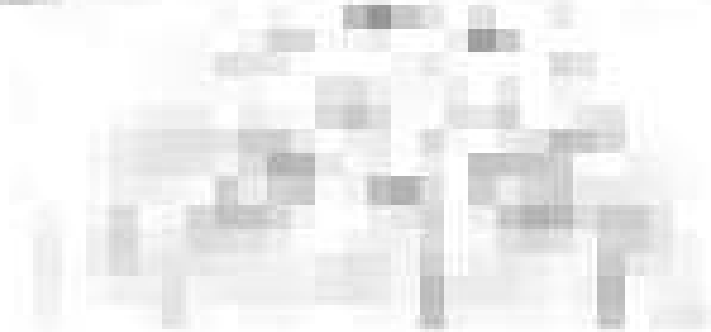


The diagram illustrates a complex network or system architecture. It features several rectangular blocks of varying sizes, some of which are labeled with text. These blocks are interconnected by a series of lines, suggesting a flow or relationship between different components. A large, irregular shape on the right side of the diagram, possibly representing a cloud or a large container, is also connected to the network. The overall structure suggests a hierarchical or interconnected system, with various components and their relationships being visualized.

Introduction

The purpose of this study is to investigate the effects of a new educational program on student performance. The program is designed to improve students' understanding of the subject matter and their ability to apply the knowledge in practical situations. The study will focus on the following aspects:

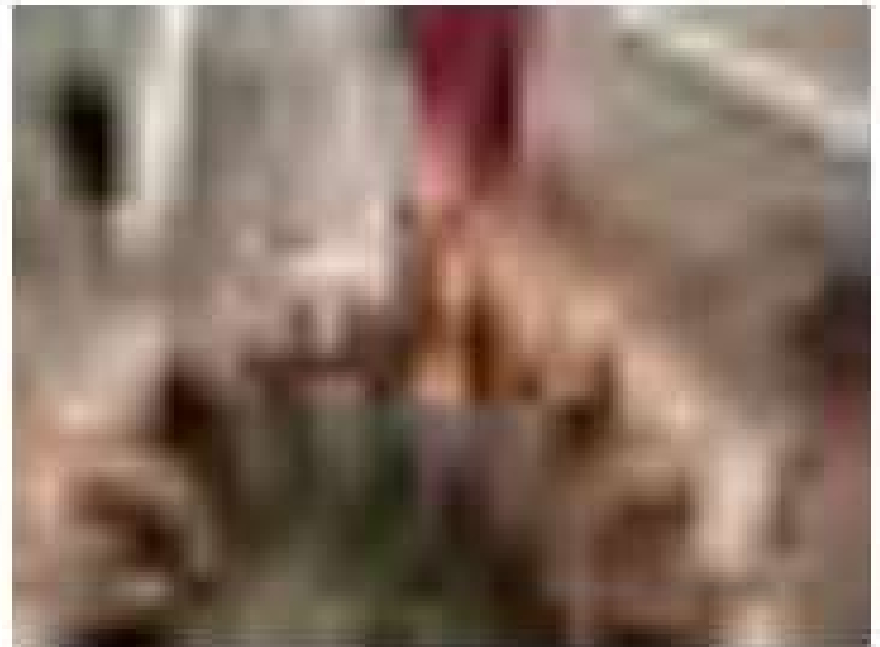
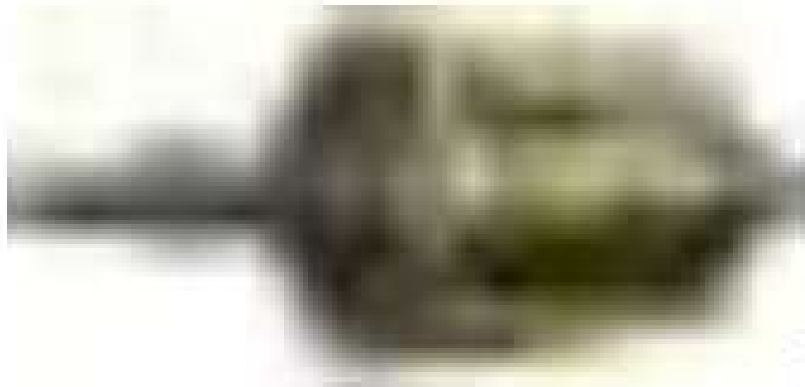
- 1. The impact of the program on students' academic performance.
- 2. The impact of the program on students' self-confidence and motivation.
- 3. The impact of the program on students' ability to work in teams.
- 4. The impact of the program on students' ability to solve problems.



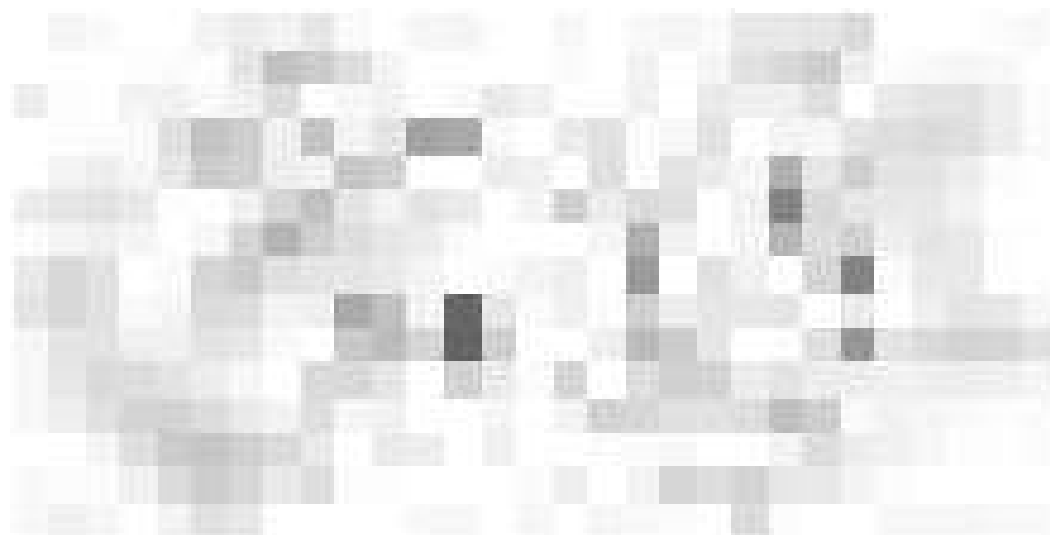


Unit 3

Switched Reluctance Motors







1. **Introduction**

2. **Background**

3. **Methodology**

4. **Results**

5. **Conclusion**

6. **References**

7. **Appendix**

8. **Index**

9. **Glossary**

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16. **Index**

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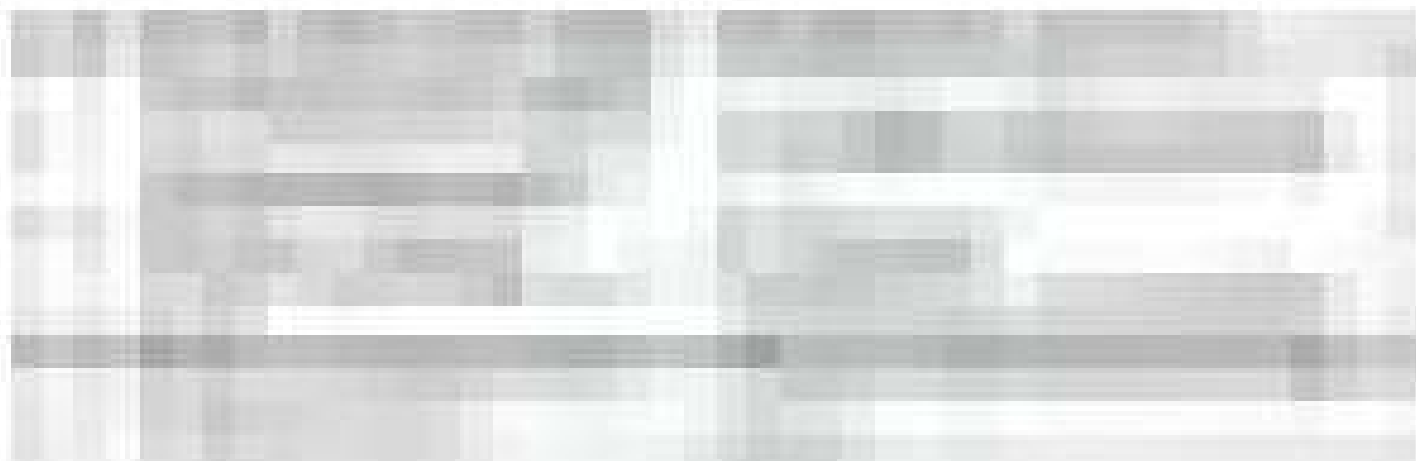
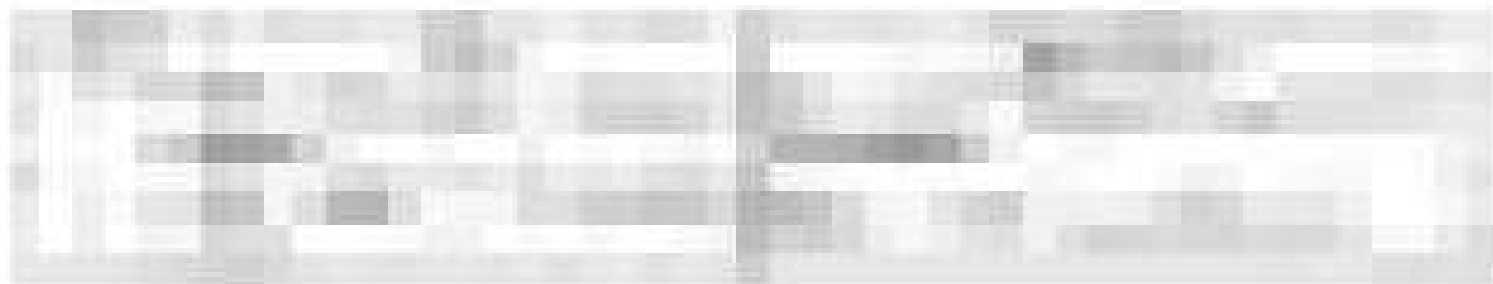
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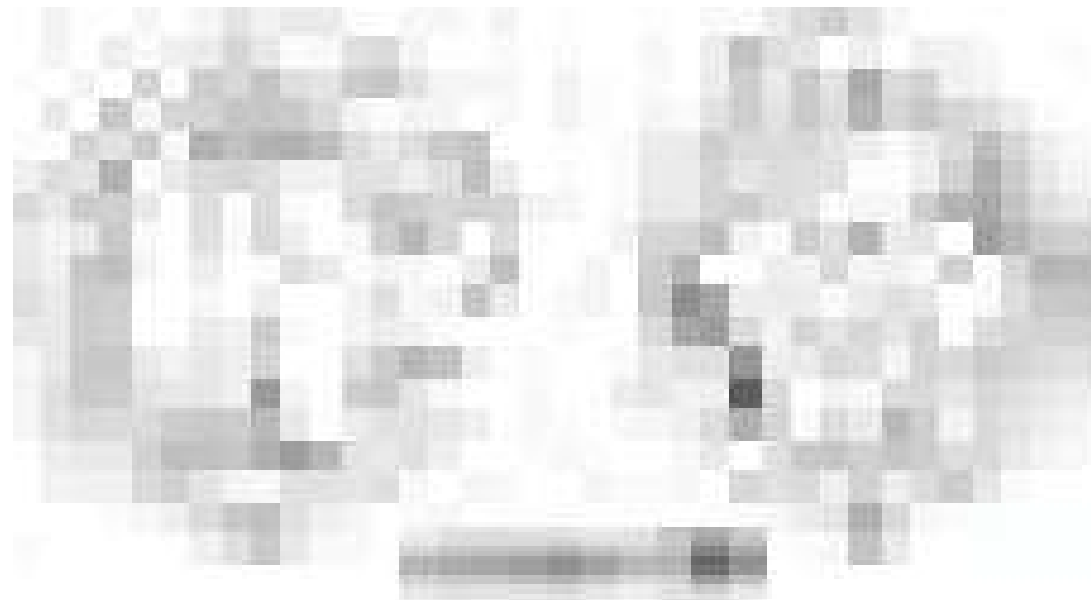
9. **Glossary**

10. **Index**

11. **Glossary**



Principle of operation



For CCW rotation sequence of excitation is ABC.

Torque Developed Expression

Torque is produced due to magnetic interaction between the main magnetic field due to excitation and rotating.

$$T = P / \omega_m \quad \text{--- (1)}$$

According to Faraday's law of electromagnetic induction, induced EMF due to change in flux linkage,

$$E = P \Phi \frac{d\theta}{dt} \quad \text{--- (2)}$$

According to Faraday's law, eqn (2) is,

$$E = P \Phi \frac{d\theta}{dt} = \omega_m \frac{d\Phi}{d\theta} \quad \text{--- (3)}$$

multiplying both sides of eqn (3) by $d\theta$ on the second term,

$$E d\theta = \omega_m \frac{d\Phi}{d\theta} d\theta = \omega_m d\Phi \quad \text{--- (4)}$$



Every student in the system has
 the same $\frac{1}{10}$ chance of being selected

Random Process Design: The system is designed to
 ensure that the results are
 unbiased







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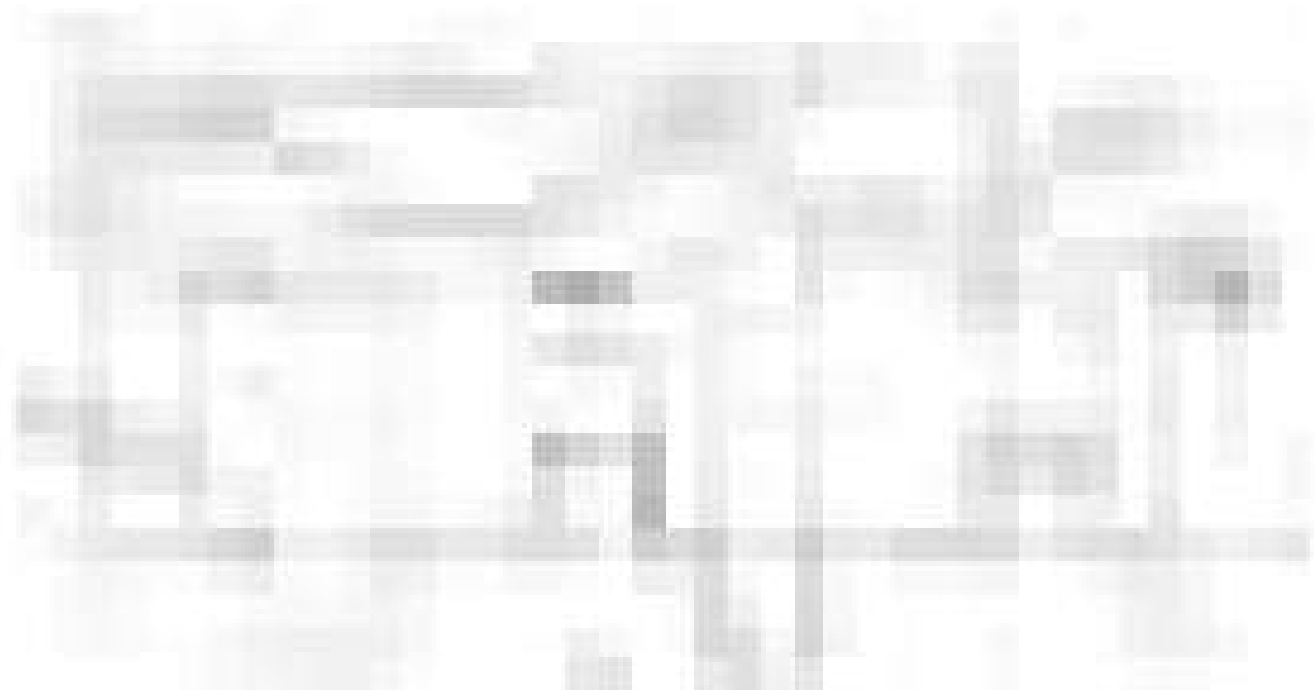
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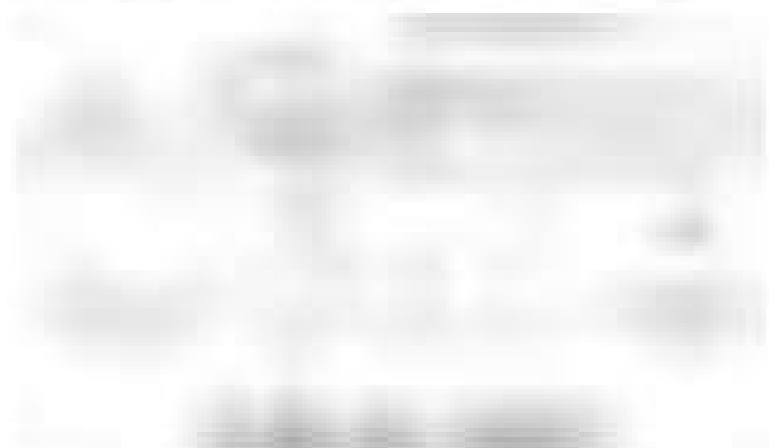
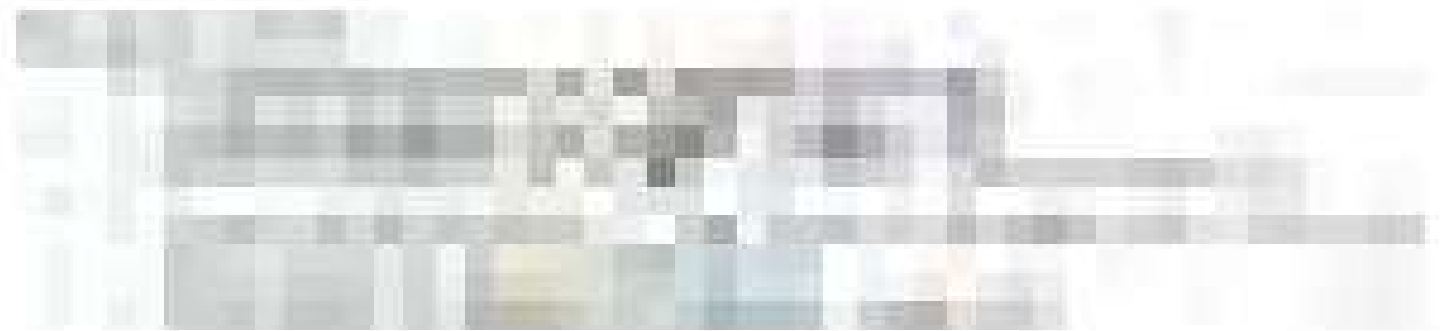
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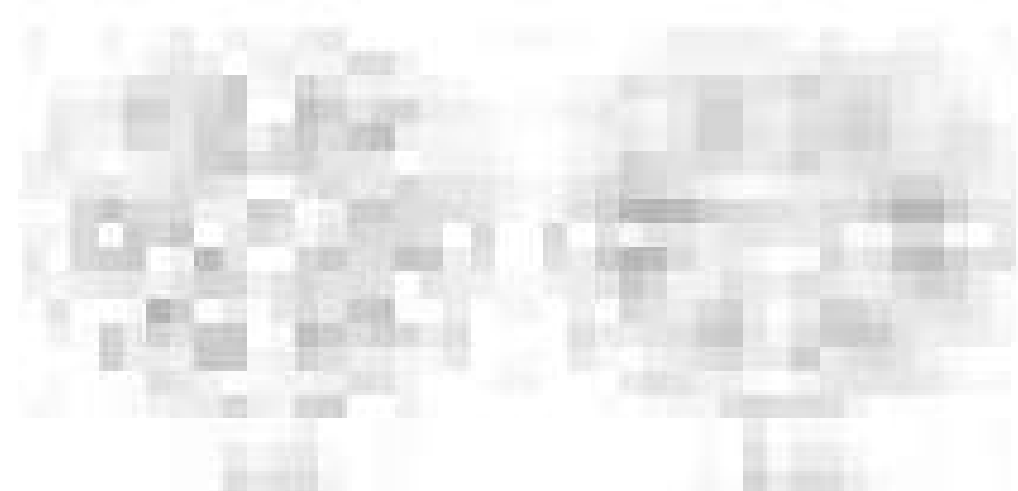
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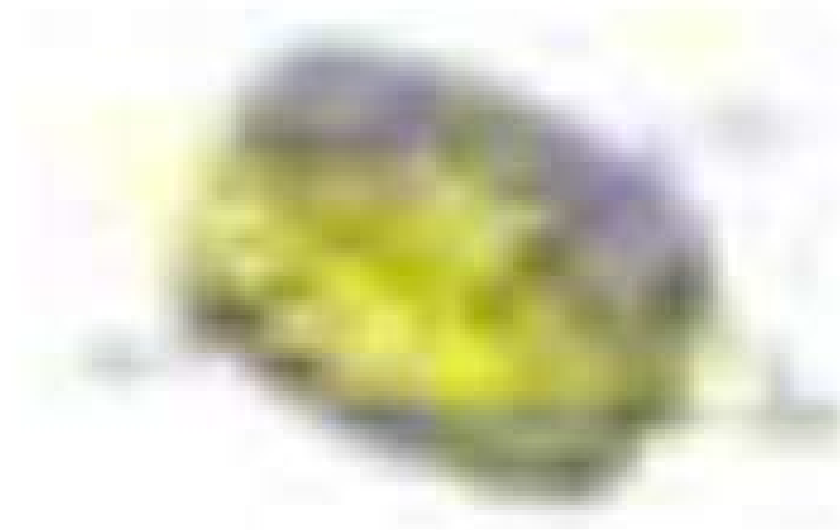






Axial-flux switched reluctance motors

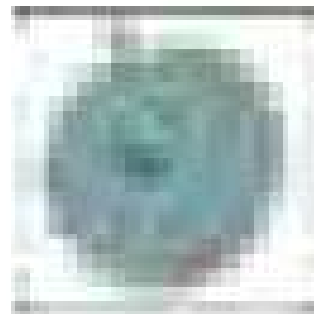
In these motors, the flux path is aligned with the motor axis, and they are used for cases where the motor length is of high importance and the motors with a small length and high torque are preferred for applications such as air conditioning fans and electric vehicles



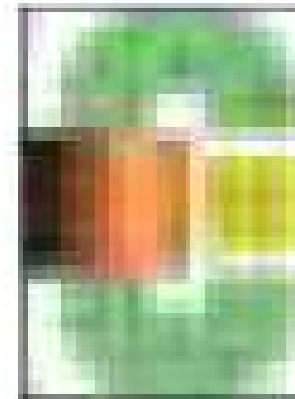
Axial field SRM: The magnetic field path is along the axial direction.



Whole motor



Rotor



The short magnetic flux path

Linear-switched reluctance motors

- Linear-switched reluctance motors (LSRMs) are similar to conventional SRMs in their structure except that their rotor and stator are cut open taking a linear form
- One of the applications of these motors is in electric trains and subways



One side LSRM



Two sided LSRM with winding on the translator

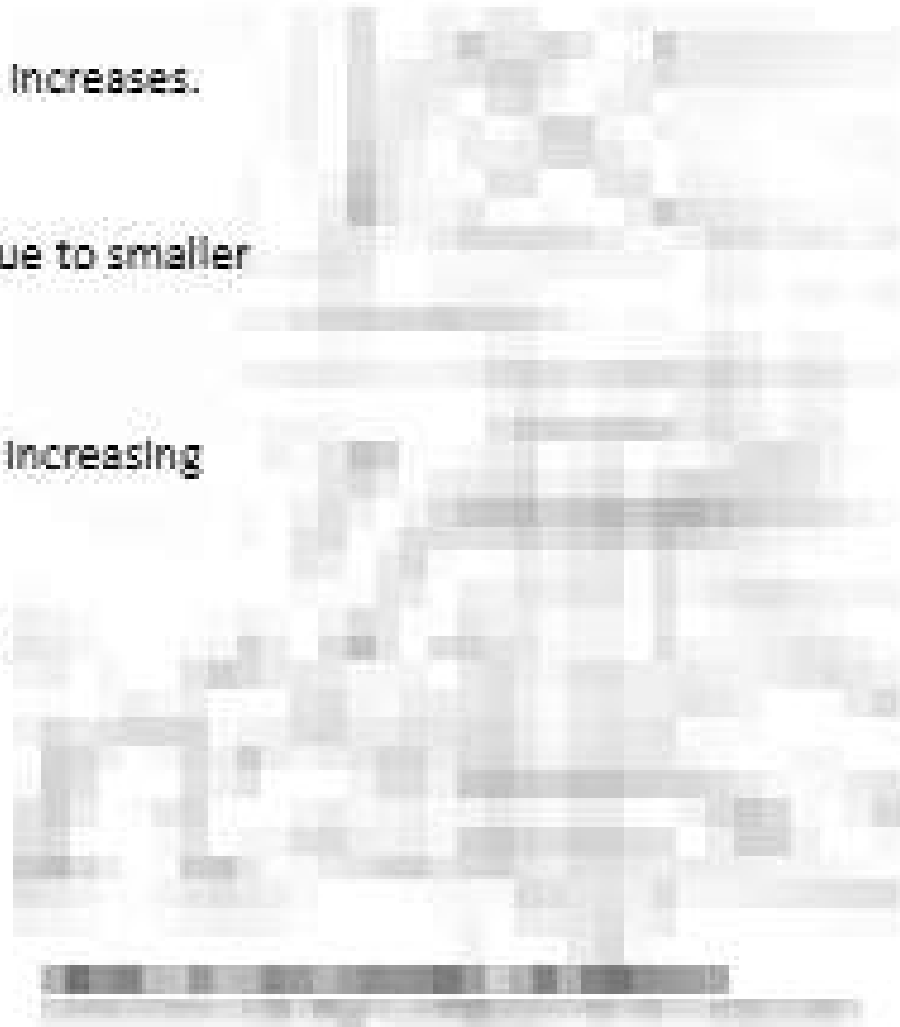
Operating modes



A) Single pulse mode $\xrightarrow{\text{also known as}}$ High speed mode

Current rise is within limits during the small time interval of each phase excitation.
It depends winding inductance and motional counter emf generated in stator winding

1. Input voltage V_s is applied before L increases.
2. Current is buildup to larger value due to smaller inductance L , up to θ_1 .
3. After θ_1 , current decreases due to increasing L and back emf.
4. At θ_2 , negative voltage is applied and current falls to 0 at θ_3 .



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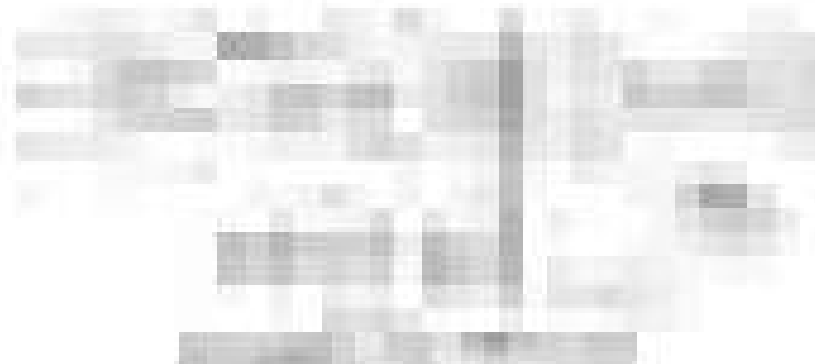
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B) PWM (or chopping) pulse mode $\xrightarrow{\text{also known as}}$ **Low speed mode**

1. Initially, current in each phase is buildup during long period to higher value.
2. Current rise is kept within acceptable rating of motor and inverter components. Hence, current limiting device is used.



TORQUE-SPEED CHARACTERISTICS



Torque developed (i.e.) average torque developed but SRM depends upon the current waveform of SRM phase winding. Current waveform depends upon the conduction period and chopping details. It also depends upon the speed.

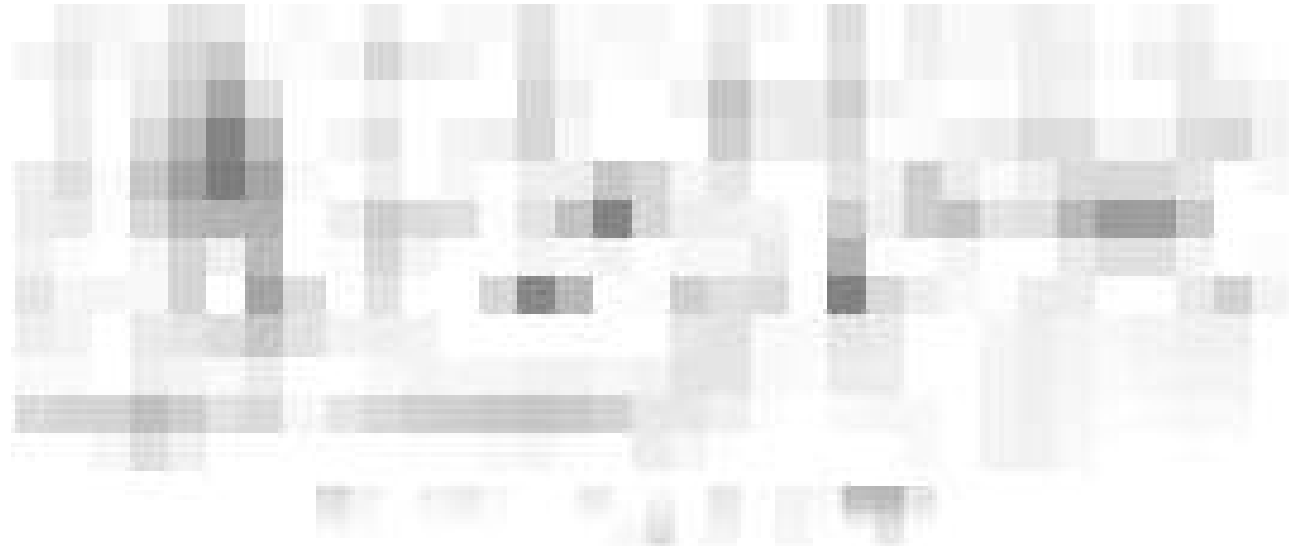
- The first region is known as the constant torque region, where the supply of voltage and commutation angles is fixed and is located below the rated speed, ω_b
- The second region identified as the constant power region, starts from the rated speed ω_b . In this region applied voltage remains at its rated value and as the rated speed is increased, the maximum torque is sustained by advancing the turn on angle with a fixed commutation angle. In this region, the torque falls inversely to the motor speed, $1/\omega$.
- Finally, there is a practical limitation to advancing the turn on angle, which, lets say, begins at some speed called ω_p . At this point, the third region starts and the torque decreases as $1/\omega^2$. This mode is known as the natural mode and is usually neglected for most motor technology.



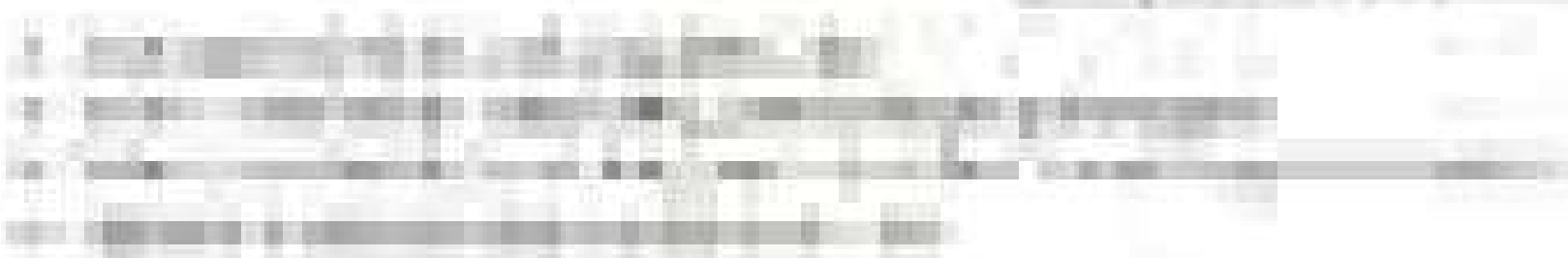
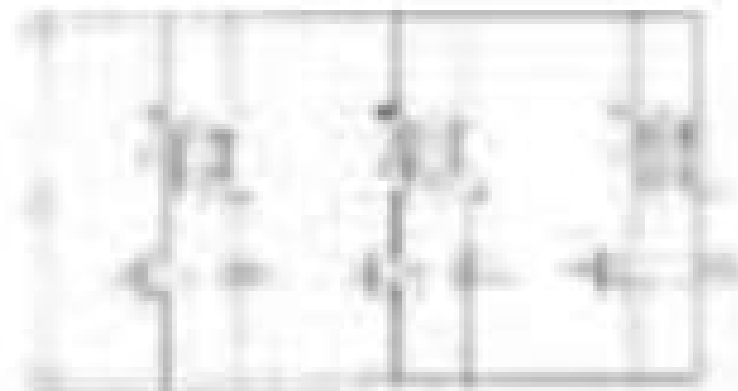
Torque Speed Capability Curve



Inverter drive circuits



Phase winding using bifilar wires



1. The stator is divided into three main sections, each representing a phase of the winding.

2. Each section contains a series of coils connected in a specific sequence to create a balanced three-phase system.

3. The bifilar wires are used to connect the coils, ensuring proper phase sequence and current flow.

4. The diagram shows the physical layout of the stator segments and the placement of the windings.

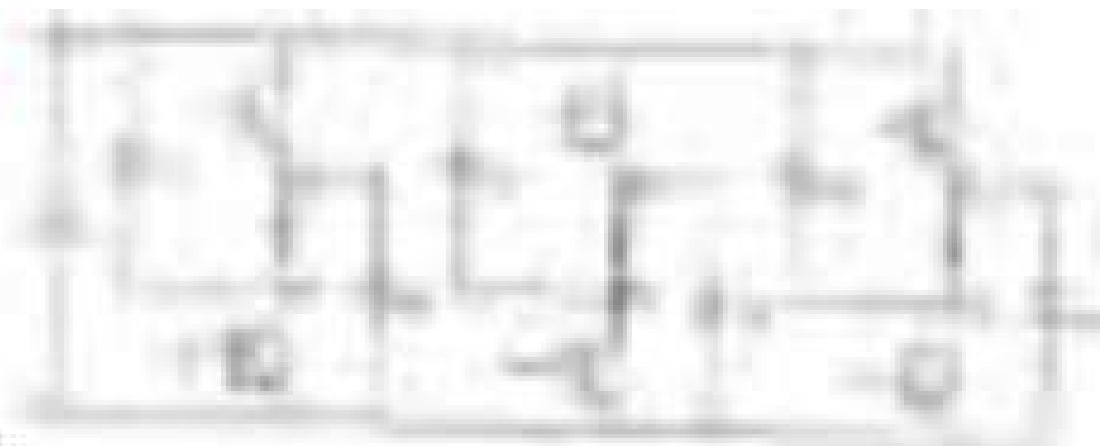
5. The winding pattern is designed to produce a rotating magnetic field when the motor is energized.

6. The bifilar connection allows for precise control of the current in each phase, optimizing the motor's performance.

7. The diagram illustrates the complex interconnection of the stator segments and the resulting three-phase winding.

8. The final result is a motor stator with a balanced three-phase winding, ready for operation.

Two Power Semiconductor Switching Devices and two diodes per phase



1. The circuit is a three-phase bridge rectifier.
2. The circuit consists of six power semiconductor switching devices (thyristors or IGBTs) and two diodes per phase.
3. The circuit is used for converting AC to DC.
4. The circuit is used for controlling the output voltage.
5. The circuit is used for controlling the output current.
6. The circuit is used for controlling the output power.
7. The circuit is used for controlling the output frequency.
8. The circuit is used for controlling the output phase angle.
9. The circuit is used for controlling the output ripple.
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Split – link circuit used with even phase number



- Each switch is connected to all four phases
- The switches are connected in a series
- The switches are connected in a parallel
- The switches are connected in a series-parallel
- The switches are connected in a parallel-series
- The switches are connected in a series-parallel-series
- The switches are connected in a parallel-series-parallel
- The switches are connected in a series-parallel-series-parallel
- The switches are connected in a parallel-series-parallel-series

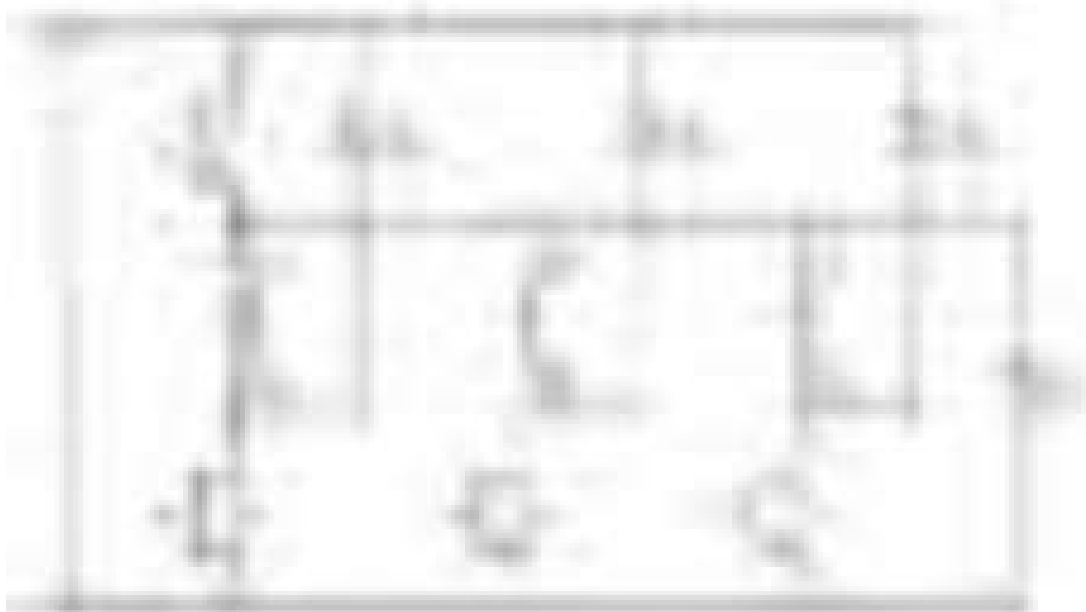
Advantages:

- Each switch is connected to all four phases
- The switches are connected in a series

Disadvantages:

- Each switch is connected to all four phases
- The switches are connected in a series

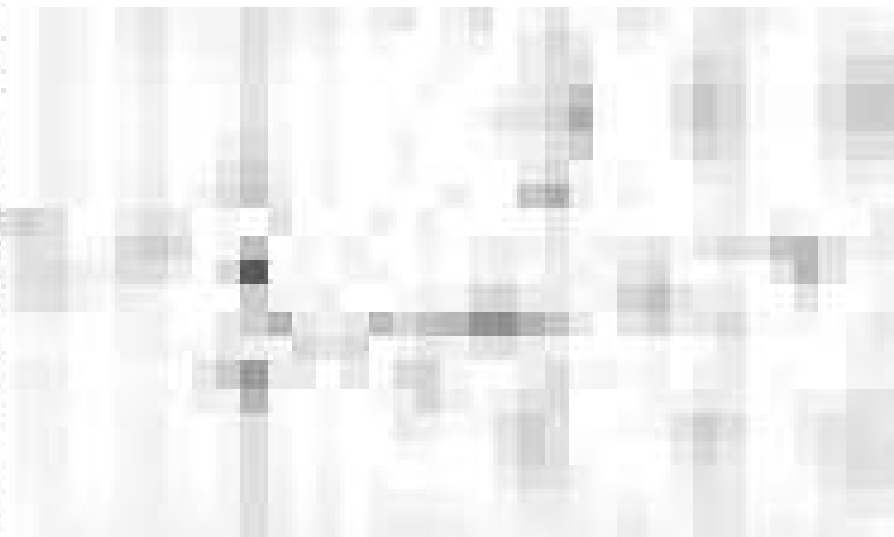
(n+1) power switching devices and (n+1) diodes



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C-Damp Circuit

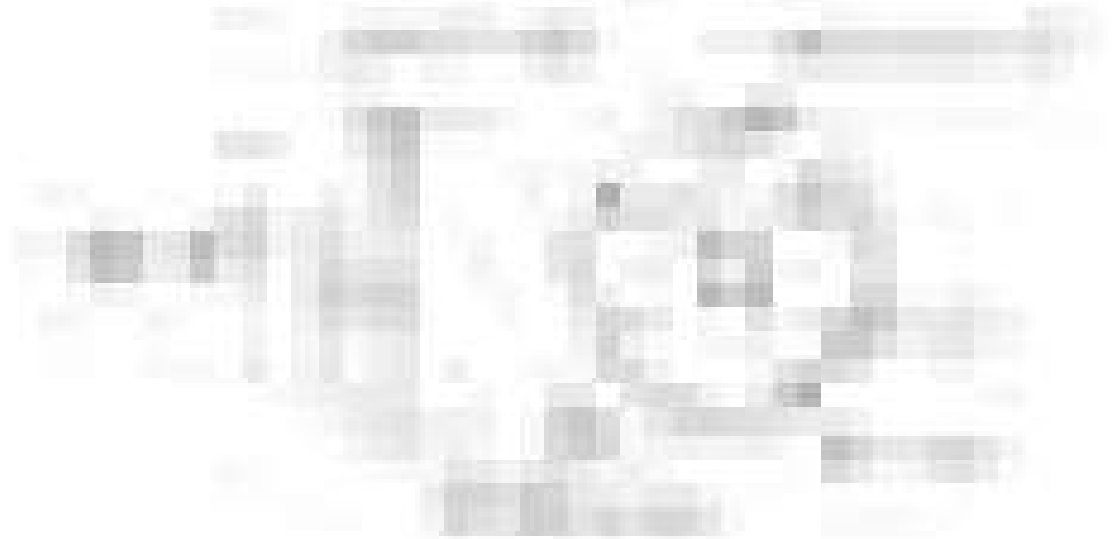
In that converter, assume that T_1 is turned on to energize the phase a . When the phase current i_a exceeds the reference value, T_1 is turned off, this enables the diode D_1 to be forward biased, and the current path is closed through the dump capacitor C_d which increases the voltage across it in order to achieve fast demagnetization as asymmetric converter. Then the excess energy from the dump capacitor is transferred into the dc source via L_r by turning on the dump switch T_r . The voltage of the capacitor is regulated to be maintained at twice the supply voltage ($2U_i$) in order to apply $(-U_i)$ across the outgoing phase for yielding faster demagnetization. The dump switch T_r is operated at a higher frequency than the phase switches.





Rotor Position Sensors

Phototransistor Sensors



- Consist of revolving shutter with 120 degree gap.
- When the gap is aligned with the phototransistor PT1, the phototransistor will generate a current due to the light, while phototransistor PT2 and PT3 have only a very small leakage currents because the light is blocked by the revolving shutter.

ROTARY ENCODER

Absolute encoder, which can provide the absolute value of the rotation angle (complicated and expensive).

Incremental encoder, provides only the incremental value of the rotation (most widely used).

- There are two sensor types used in encoders to generate digital signals: such as magnetic and optical. The latter is more commonly used.
- The resolution of an incremental encoder is frequently described in terms of pulse per revolution (PPR), which is the total number of output pulses per complete revolution of the encoder shaft.

Two configurations

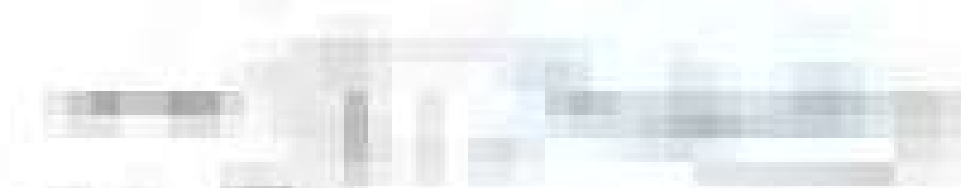
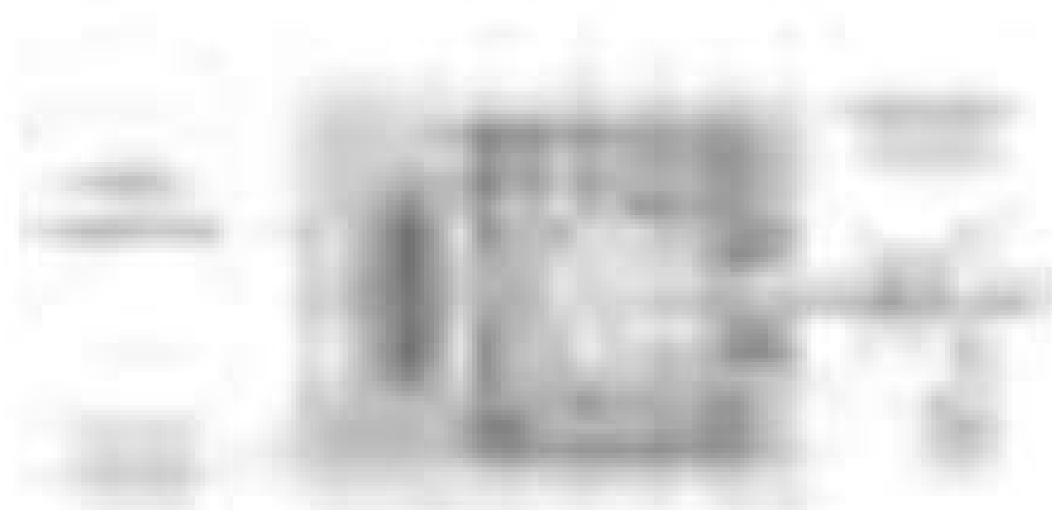
Shaft type that connects the shaft of a rotor with a coupling.

Hollow type, in which the shaft of a rotor is inserted into.



- It consists of a moving disc mounted to the rotating shaft, light sources (LEDs), and light receivers (phototransistors). The moving disc has the same number of slits as PPR. The light of LEDs passing through the slits on the disc is transmitted to phototransistors, and in turn, is converted to square wave shaped electric signals
- Commonly, the encoder has three outputs called A, B, and Z. The total number of A and B pulses per revolution is equal to PPR, with which the angular position and speed can be calculated. The A and B pulses are 90 out of phase, which allows the identification of the direction of rotation. For example, when rotating in the forward direction, pulse A is ahead of pulse B. There is another pulse Z known as the index or reference pulse besides pulses A and B. Pulse Z is generated once per revolution and can be used to set the reference position.





- The primary winding of a resolver, called reference winding, is located in the rotor and is excited through a rotary transformer. The two secondary windings, called SIN and COS Windings, are located in the stator and mechanically displaced by 90 degree from each other. In the resolver operation, a shaft angle θ can be measured from signals induced in the secondary windings after injecting AC voltage signal into the primary winding.
- When the primary winding is excited by an AC voltage V_r through a rotary transformer, voltages in the secondary windings are induced differently depending on the angle θ of the rotor shaft. The induced voltages vary as sine or cosine of the rotor angle, respectively. From an arctangent function of these signals, we can know the absolute angle θ of the rotor connected to the shaft as

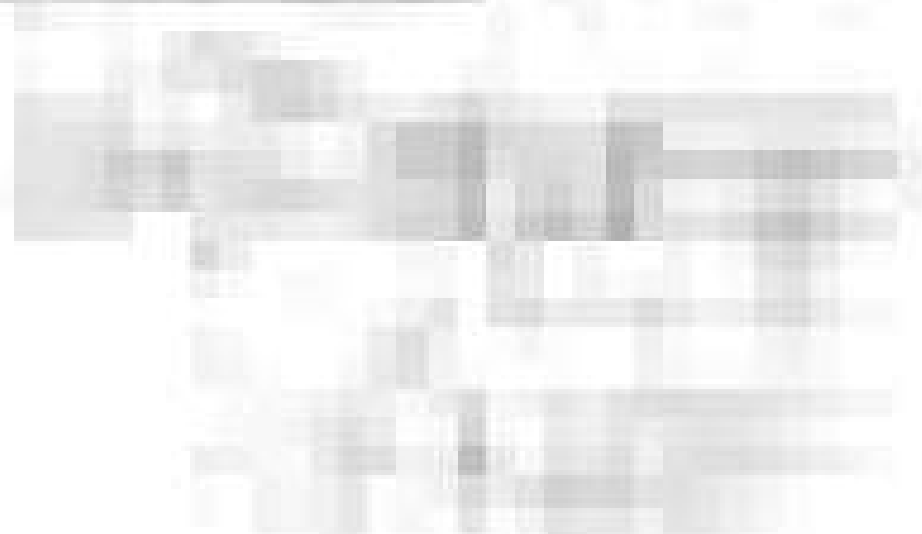
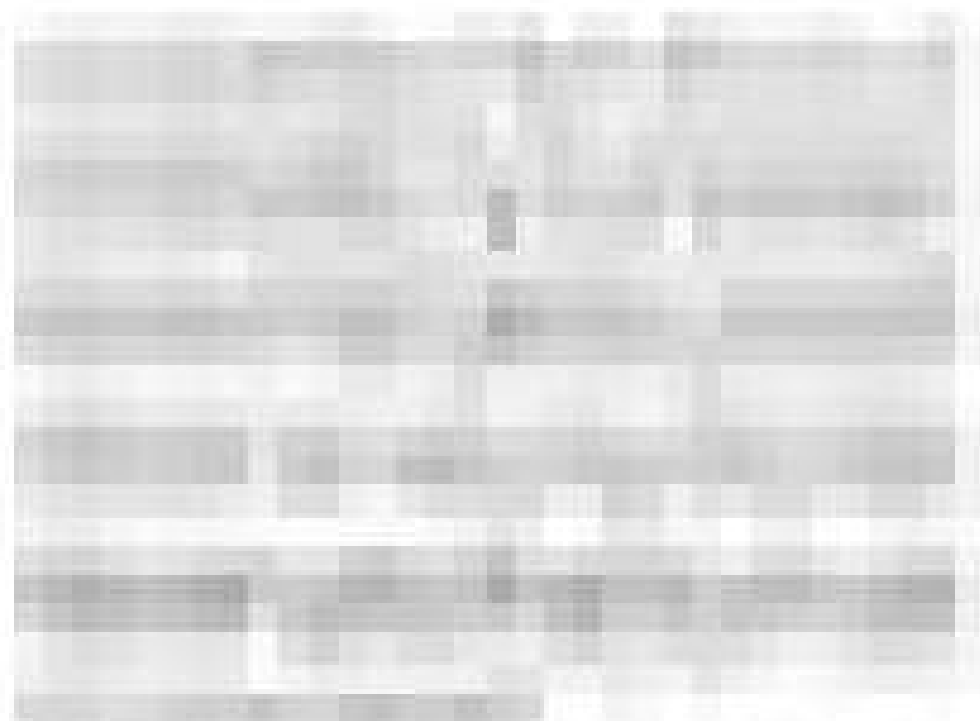


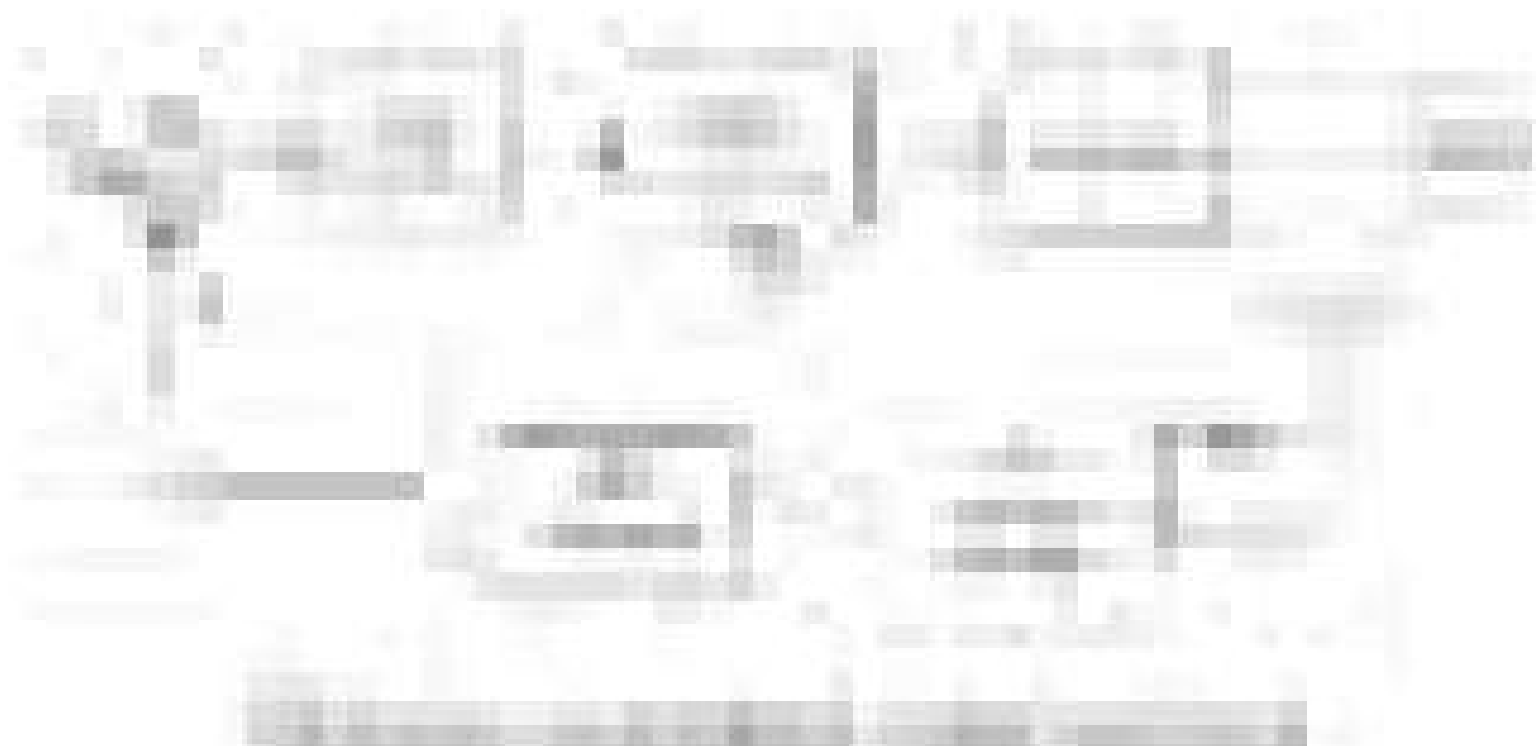
Sensorless operation

Problem with sensor

- Position sensors are discrete in nature.
- Adds complexity to the system.
- More costly.
- Installation of sensor is time taking and tedious job.
- Tends to reduce the reliability of the drive system.







CLOSED-LOOP, SPEED-CONTROLLED SRM DRIVE



ROTOR POSITION MEASUREMENT AND ESTIMATION METHODS



Unit 4

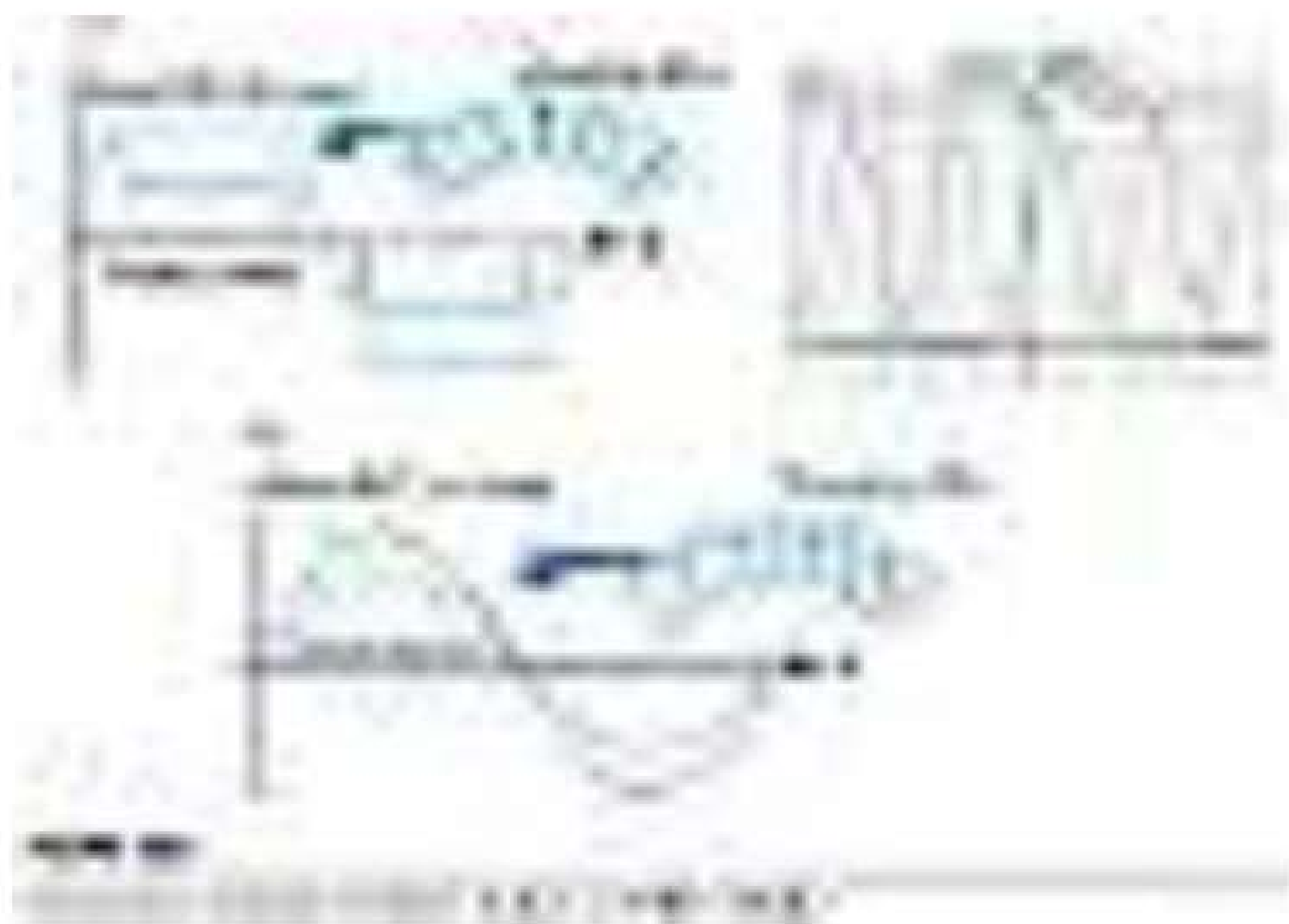
Brushless DC Motor







The first part of the paper discusses the importance of the
 financial system in the
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 highlights the role of the
 central bank in
 monetary policy and the
 regulation of banks. The
 second part of the paper
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 It highlights the role of the
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Construction of PMLDC motor



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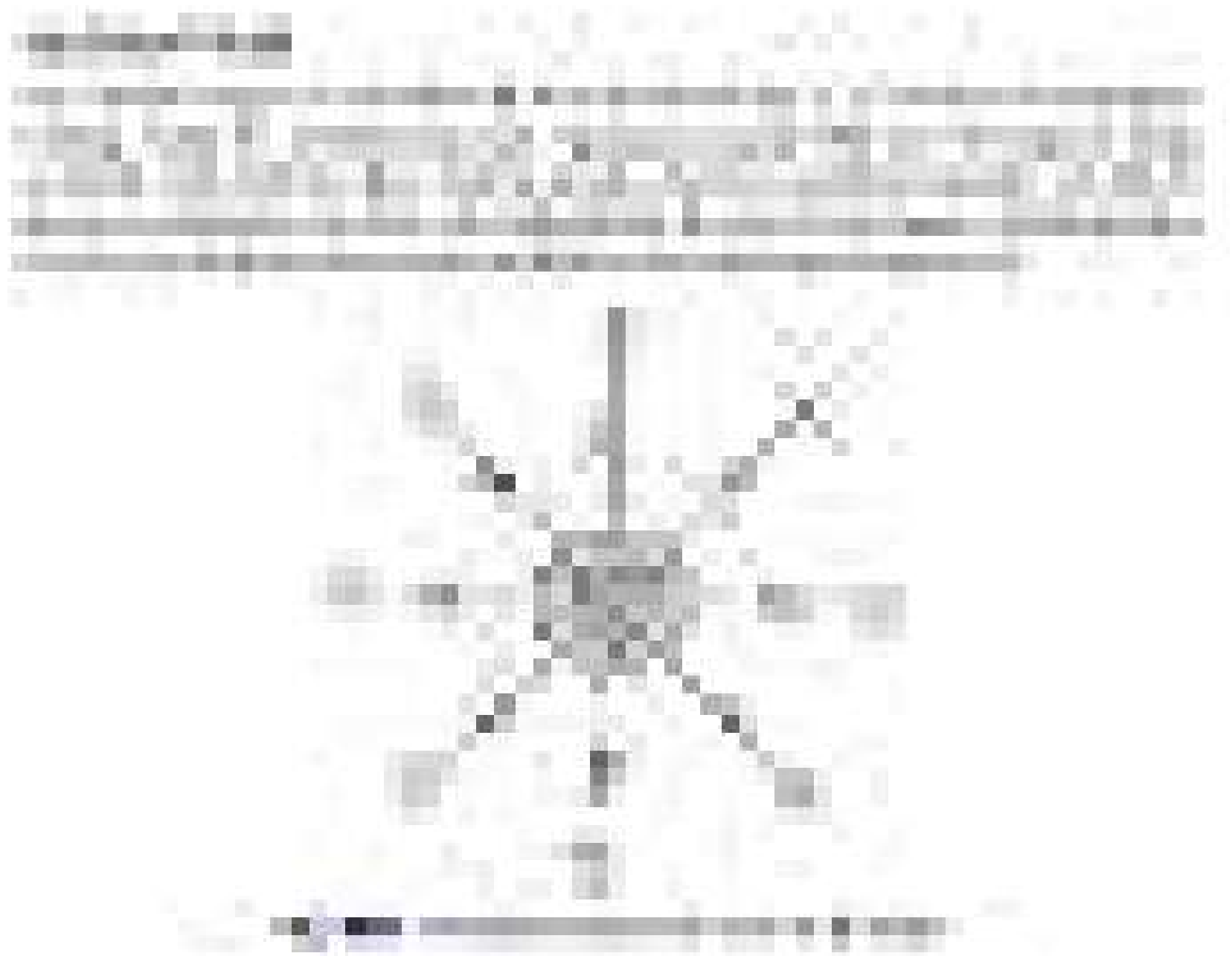
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Advantages



Applications





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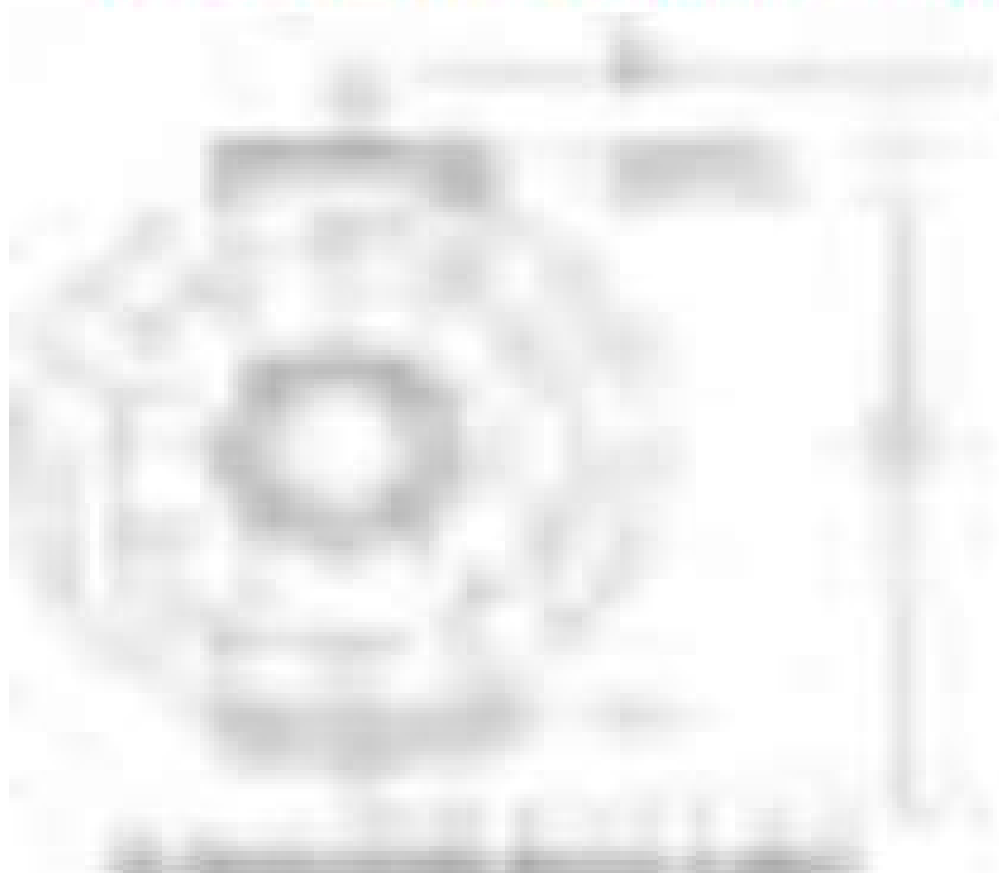
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Commutator

1. **Introduction**
 2. **Background**
 3. **Methodology**
 4. **Results**
 5. **Conclusion**
 6. **References**

Mechanical commutator



Part	Material	Quantity	Notes
Commutator Ring	Steel	1	
Brush Holder	Aluminum	2	
Brush	Carbon	2	
Shaft	Steel	1	
Key	Steel	1	
Washer	Steel	2	
Nut	Steel	2	

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and the role of the accounting system in providing reliable financial information. It emphasizes the need for transparency and accountability in financial reporting.

2. The second part of the document outlines the various methods used to collect and analyze financial data, including the use of statistical techniques and the application of mathematical models. It highlights the importance of using appropriate methods to ensure the accuracy and reliability of the results.

3. The third part of the document discusses the challenges faced by organizations in managing their financial resources and the role of the accounting system in addressing these challenges. It emphasizes the need for effective financial management and the importance of using the accounting system to monitor and control financial performance.

4. The fourth part of the document discusses the role of the accounting system in providing financial information to management and the importance of using this information to make informed decisions. It emphasizes the need for accurate and timely financial information and the role of the accounting system in providing this information.

5. The fifth part of the document discusses the role of the accounting system in providing financial information to external stakeholders and the importance of using this information to build trust and confidence. It emphasizes the need for transparency and accountability in financial reporting and the role of the accounting system in providing this information.

6. The sixth part of the document discusses the role of the accounting system in providing financial information to the public and the importance of using this information to make informed decisions. It emphasizes the need for accurate and timely financial information and the role of the accounting system in providing this information.

7. The seventh part of the document discusses the role of the accounting system in providing financial information to the government and the importance of using this information to make informed decisions. It emphasizes the need for accurate and timely financial information and the role of the accounting system in providing this information.

8. The eighth part of the document discusses the role of the accounting system in providing financial information to the media and the importance of using this information to make informed decisions. It emphasizes the need for accurate and timely financial information and the role of the accounting system in providing this information.

9. The ninth part of the document discusses the role of the accounting system in providing financial information to the academic community and the importance of using this information to make informed decisions. It emphasizes the need for accurate and timely financial information and the role of the accounting system in providing this information.

10. The tenth part of the document discusses the role of the accounting system in providing financial information to the general public and the importance of using this information to make informed decisions. It emphasizes the need for accurate and timely financial information and the role of the accounting system in providing this information.

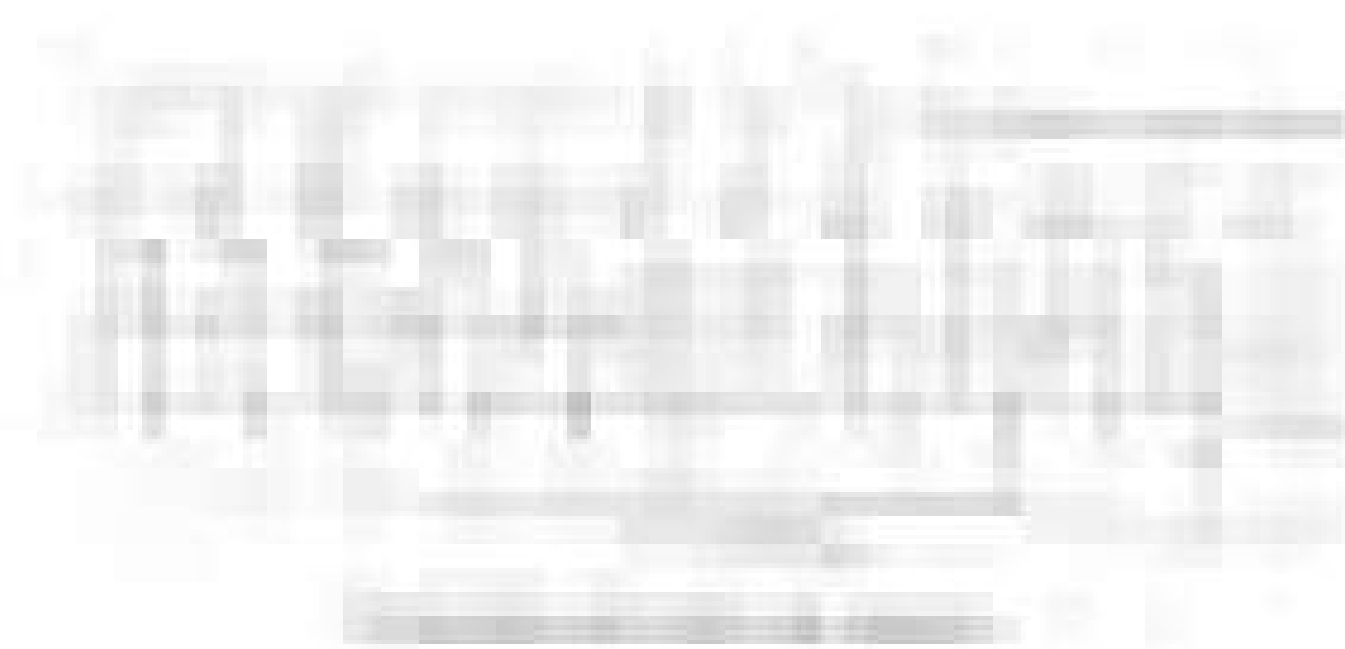
Electronics commutator



1. Introduction

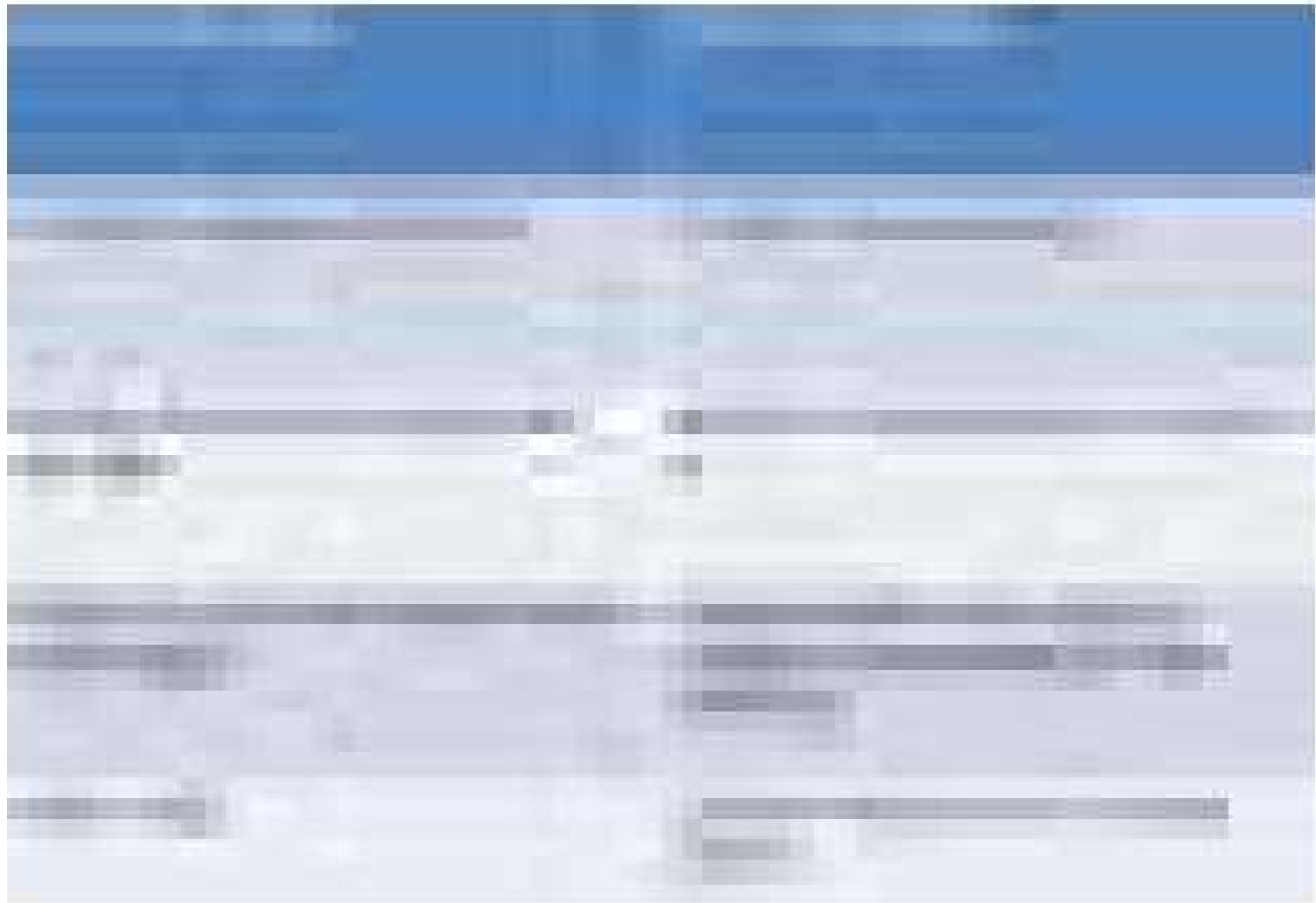
2. The commutator is a device that converts the alternating current (AC) generated by the armature into direct current (DC) for the external circuit. It consists of a cylindrical structure with multiple segments, each connected to a brush. As the armature rotates, the brushes make contact with the segments, allowing the current to flow in one direction.

3. The commutator is a key component in many electrical machines, including motors and generators. It is used to convert the AC generated by the armature into DC for the external circuit.

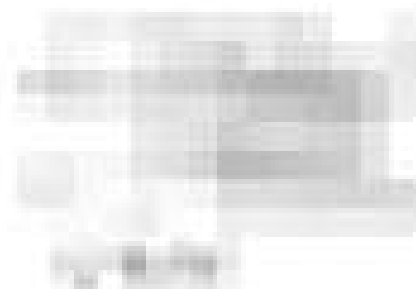
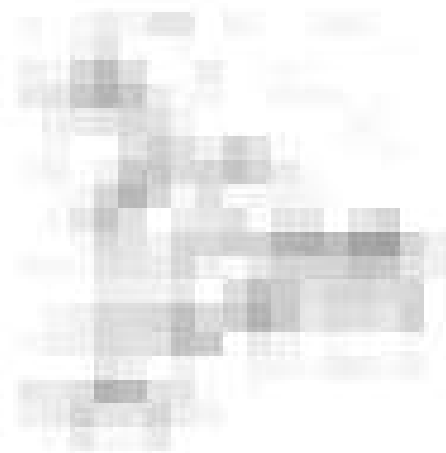
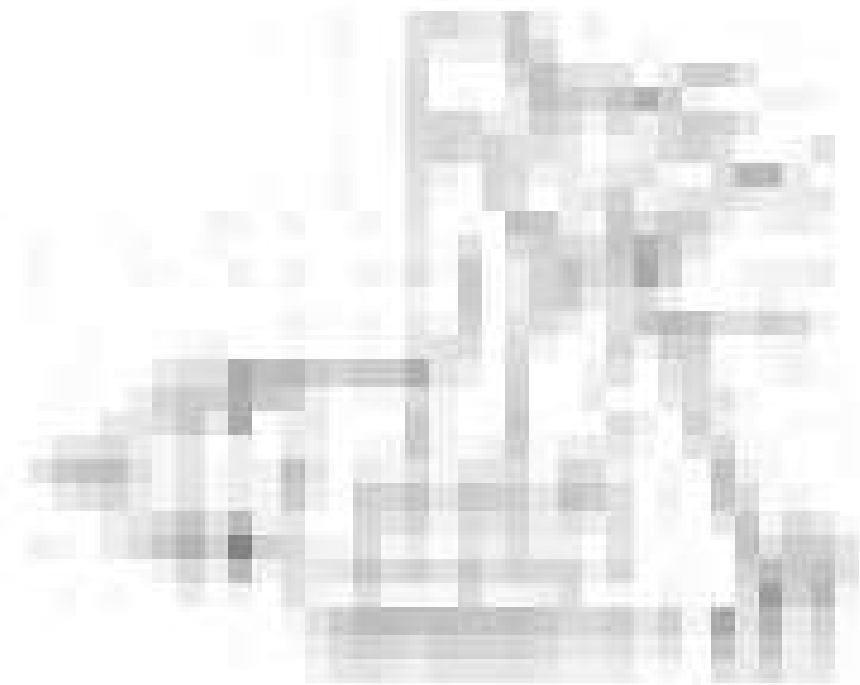


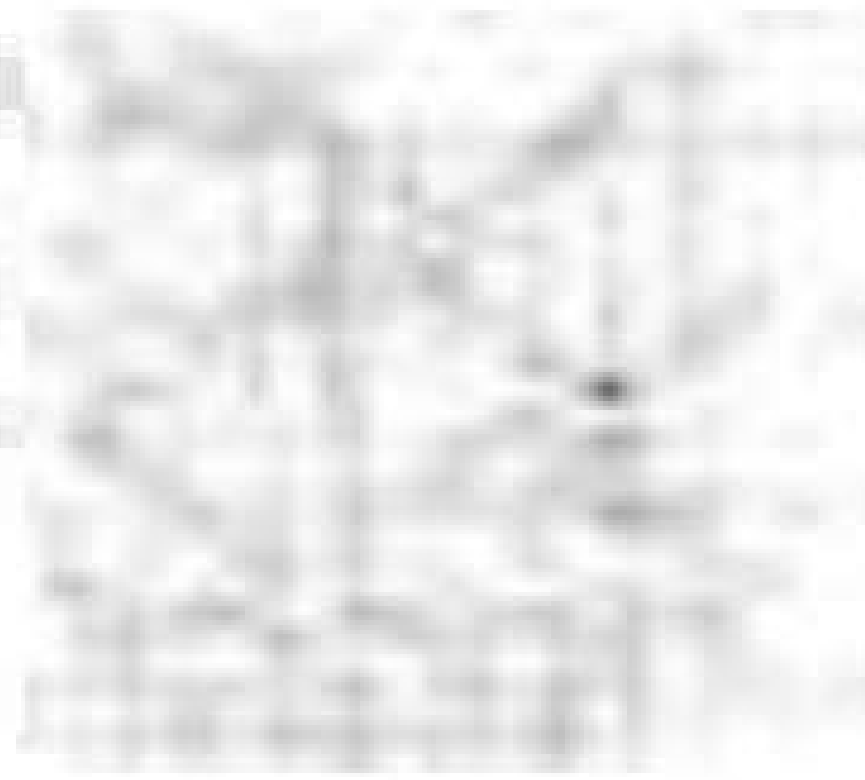
Comparison between mechanical and electronic commutator

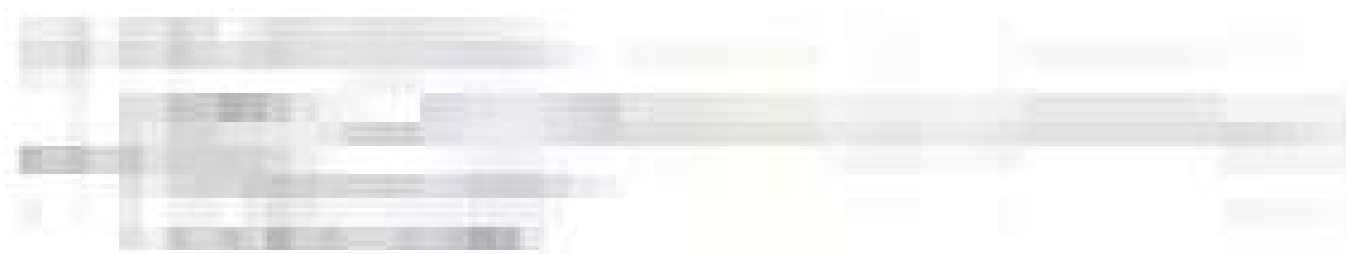


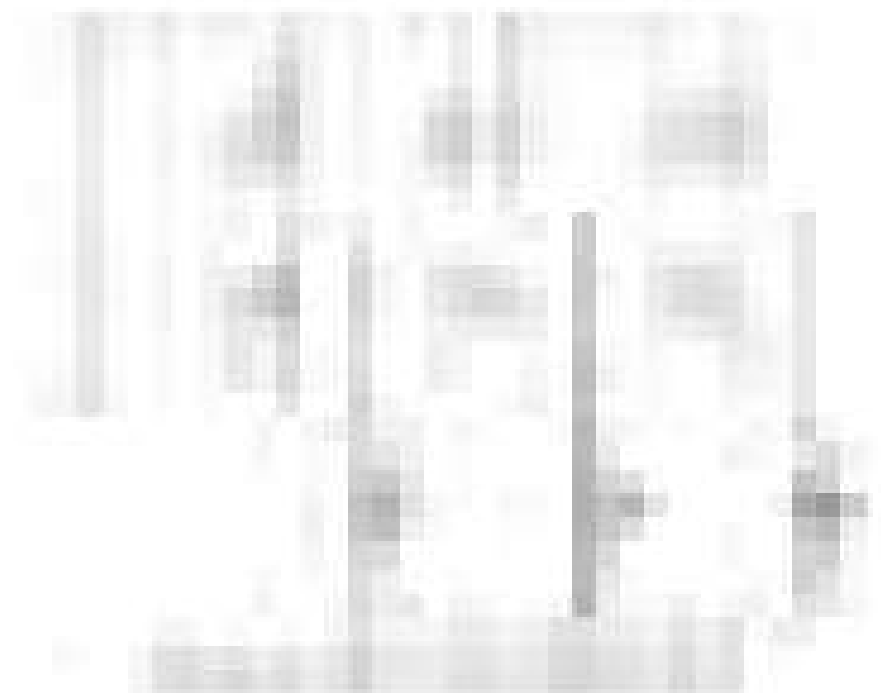


Operating principle of BLDC motor



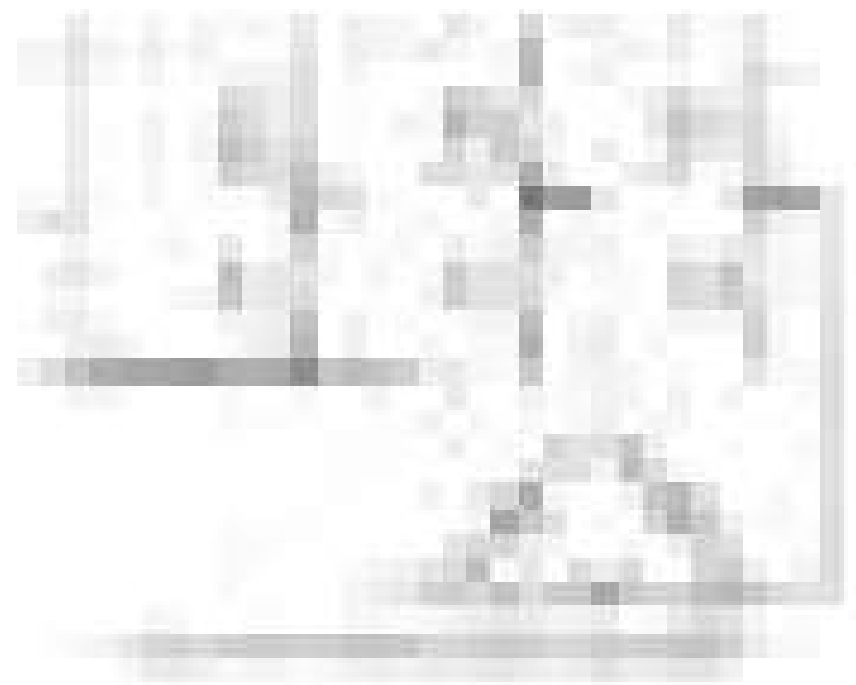
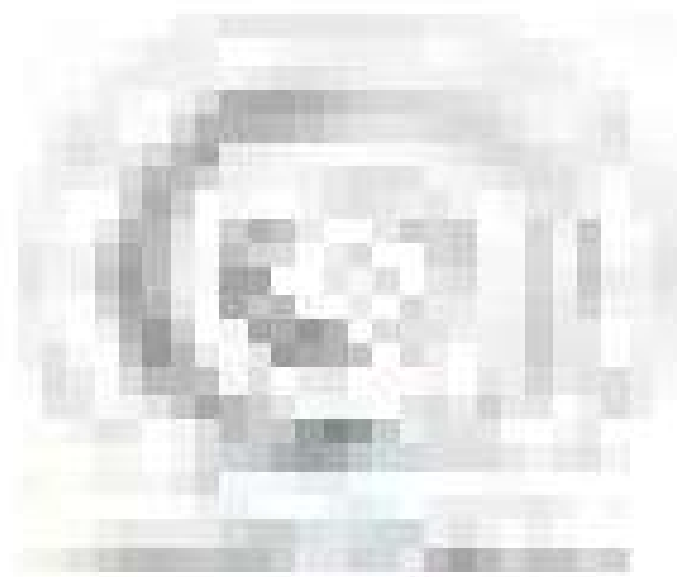
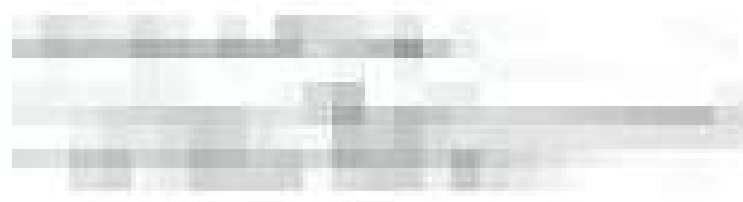




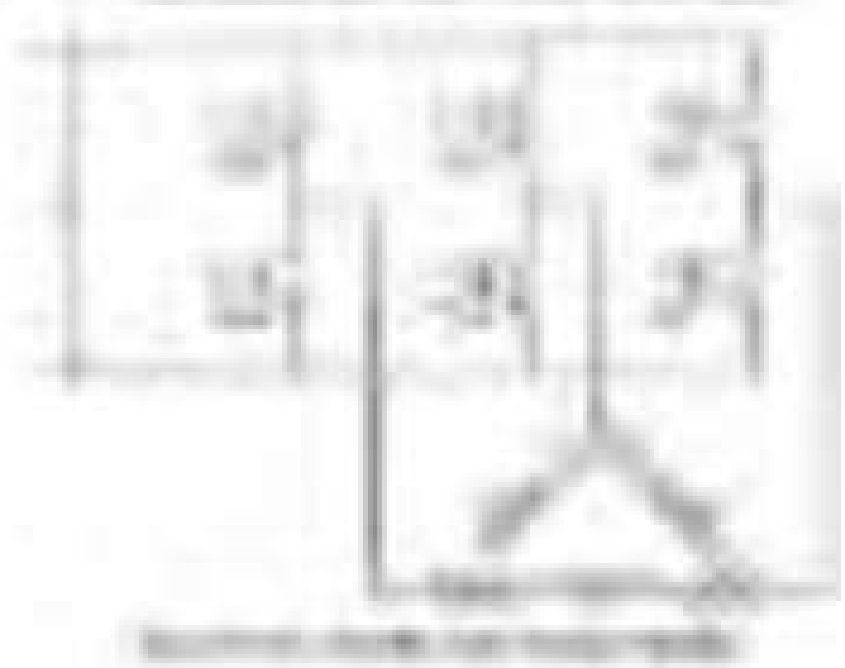
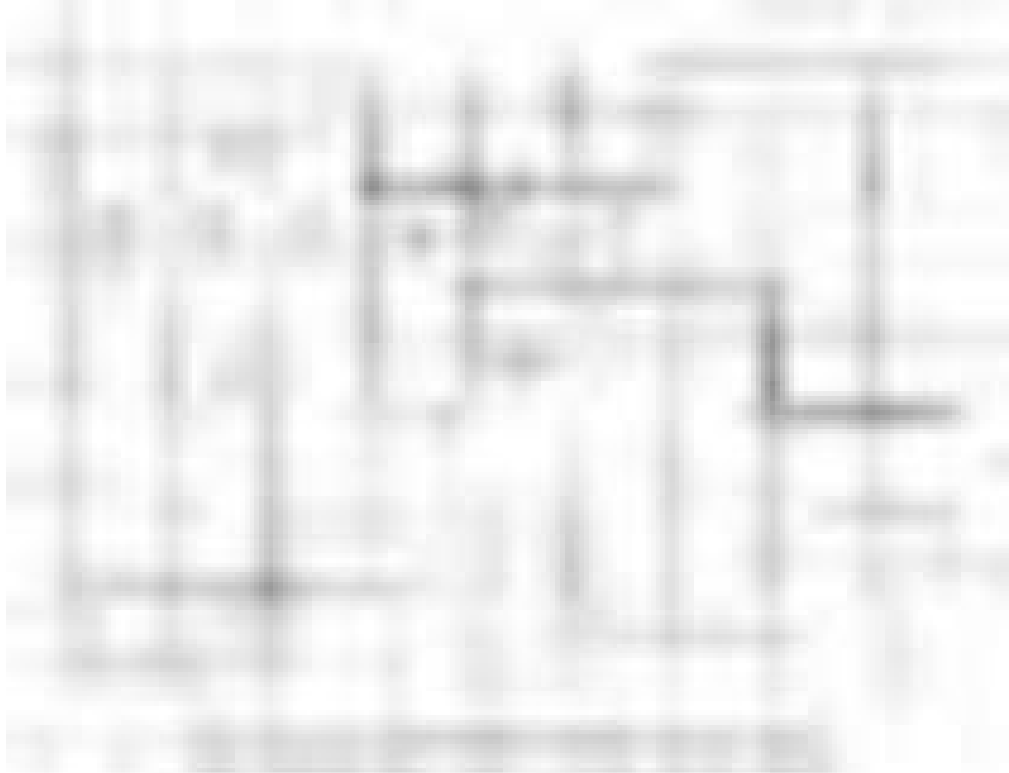


In the BLDC motor drive, only two of the three-phase windings are excited, while the other winding is left unexcited.

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	Feb 1	Interest		1.00	
	Mar 1	Interest		1.00	
	Apr 1	Interest		1.00	
	May 1	Interest		1.00	
	Jun 1	Interest		1.00	
	Jul 1	Interest		1.00	
	Aug 1	Interest		1.00	
	Sep 1	Interest		1.00	
	Oct 1	Interest		1.00	
	Nov 1	Interest		1.00	
	Dec 1	Interest		1.00	
1901	Jan 1	Balance		100.00	
	Feb 1	Interest		1.00	
	Mar 1	Interest		1.00	
	Apr 1	Interest		1.00	
	May 1	Interest		1.00	
	Jun 1	Interest		1.00	
	Jul 1	Interest		1.00	
	Aug 1	Interest		1.00	
	Sep 1	Interest		1.00	
	Oct 1	Interest		1.00	
	Nov 1	Interest		1.00	
	Dec 1	Interest		1.00	
1902	Jan 1	Balance		100.00	
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	Mar 1	Interest		1.00	
	Apr 1	Interest		1.00	
	May 1	Interest		1.00	
	Jun 1	Interest		1.00	
	Jul 1	Interest		1.00	
	Aug 1	Interest		1.00	
	Sep 1	Interest		1.00	
	Oct 1	Interest		1.00	
	Nov 1	Interest		1.00	
	Dec 1	Interest		1.00	



Date		Time		Location		Activity		Remarks	
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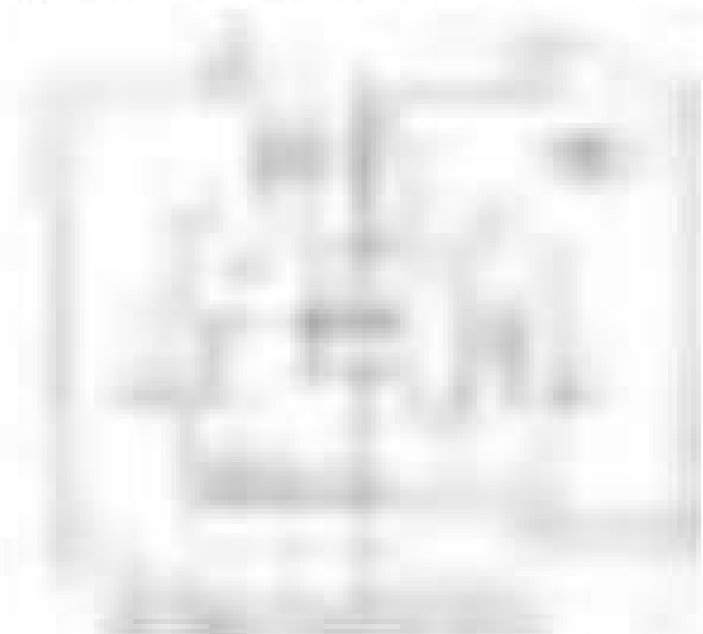
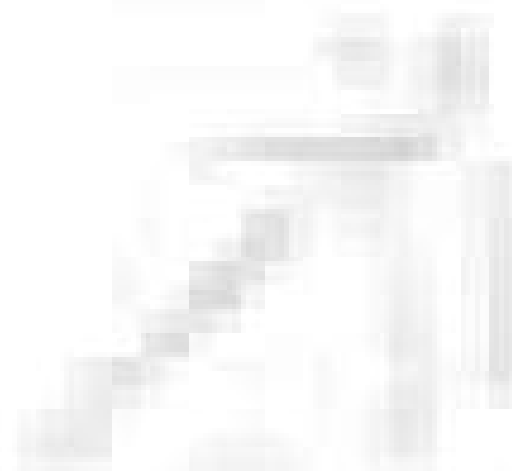
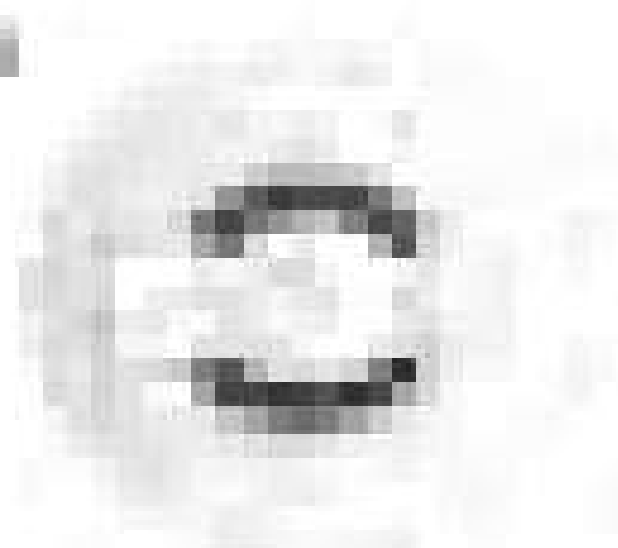
$B = \mu_0 H + B_0$

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part of the document outlines the specific procedures and protocols that must be followed when conducting financial transactions. It details the steps for approval, documentation, and reporting, ensuring that all actions are in compliance with relevant laws and regulations.

3. The third part of the document provides a comprehensive overview of the organization's financial goals and objectives for the upcoming year. It includes a detailed budget breakdown, identifying key areas for investment and potential risks, and outlining strategies to achieve the desired financial outcomes.

The first part of the paper discusses the importance of the research and the objectives of the study. It then presents a literature review of the existing research on the topic. The methodology section describes the research design and the data collection process. The results section presents the findings of the study, and the conclusion section summarizes the main findings and provides recommendations for future research.



K_c : carter's coefficient,

A_g - air gap area through which the flux passes
as it crosses the gap

$$\frac{B_m}{B_g} = \frac{\mu_r \mu_0 H_m}{\mu_0 H_g}$$

$$\frac{B_m}{B_g} = \mu_r \frac{H_m}{H_g}$$

If we write the ratio of magnet pole area to air gap area as

$$\frac{A_m}{A_g} = \frac{A_p}{A_g}$$

$$\frac{B_m}{B_g} = \mu_r \frac{H_m}{H_g} \frac{A_g}{A_m}$$

$$\frac{B_m}{B_g} = \mu_r \frac{H_m}{H_g} \frac{A_g}{A_p}$$

$$\frac{B_m}{B_g} = \mu_r \frac{H_m}{H_g} \frac{A_g}{A_p}$$

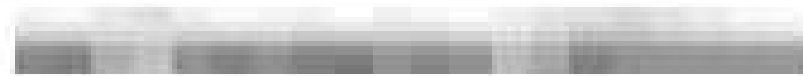
$$\frac{B_m}{B_g} = \mu_r \frac{H_m}{H_g} \frac{A_g}{A_p}$$

$$\frac{B_m}{B_g} = \mu_r \frac{H_m}{H_g} \frac{A_g}{A_p}$$









If the phase windings are star-connected, then at any time there are just two phases and two transistors conducting.



$$V = E + RI$$

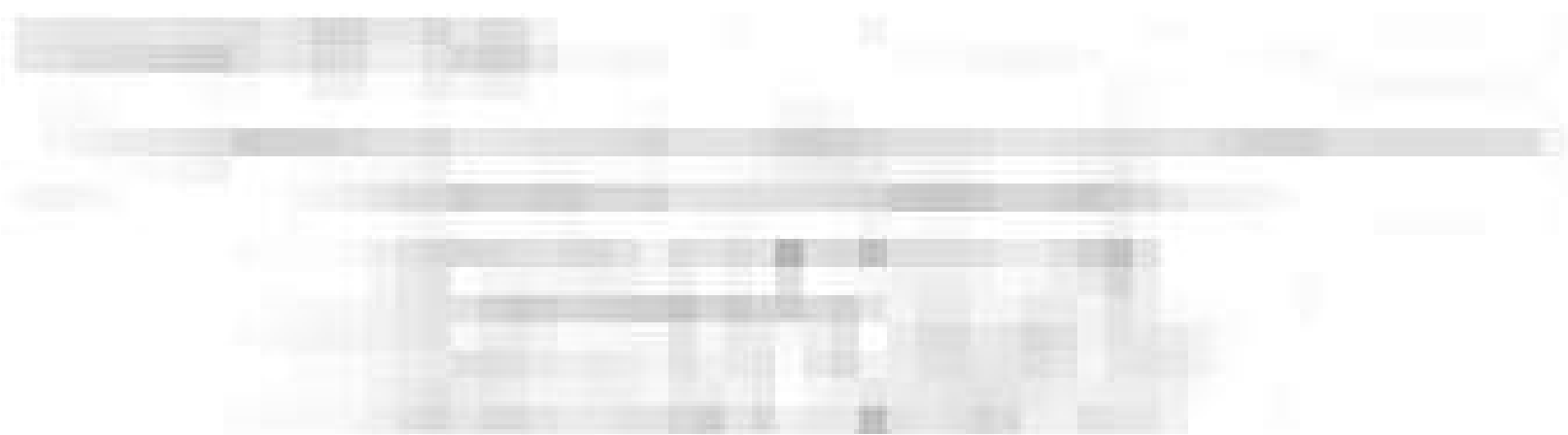


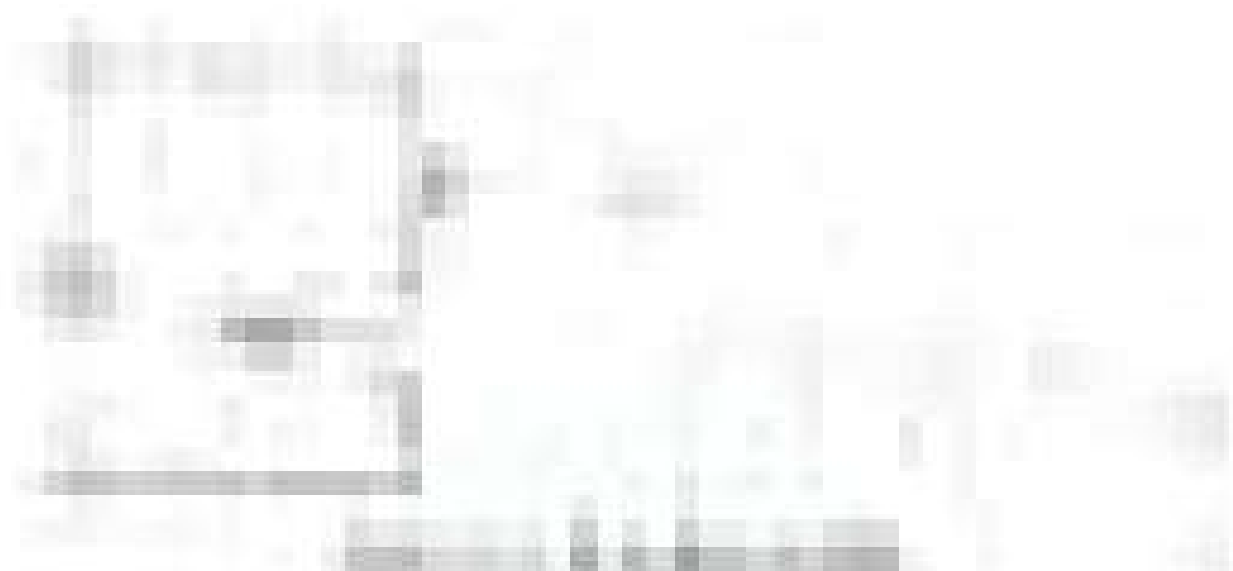
Mathematical Analysis of the Problem



Mathematical Analysis of the Problem







1. The first part of the document is a header section containing the title and the author's name. The title is "The Role of the Teacher in the 21st Century" and the author is "John Doe".

2. The second part of the document is an abstract. It provides a brief overview of the main points of the paper, including the importance of the teacher's role in the 21st century and the challenges they face.

3. The third part of the document is the introduction. It discusses the changing landscape of education and the need for teachers to adapt to new technologies and pedagogical approaches.

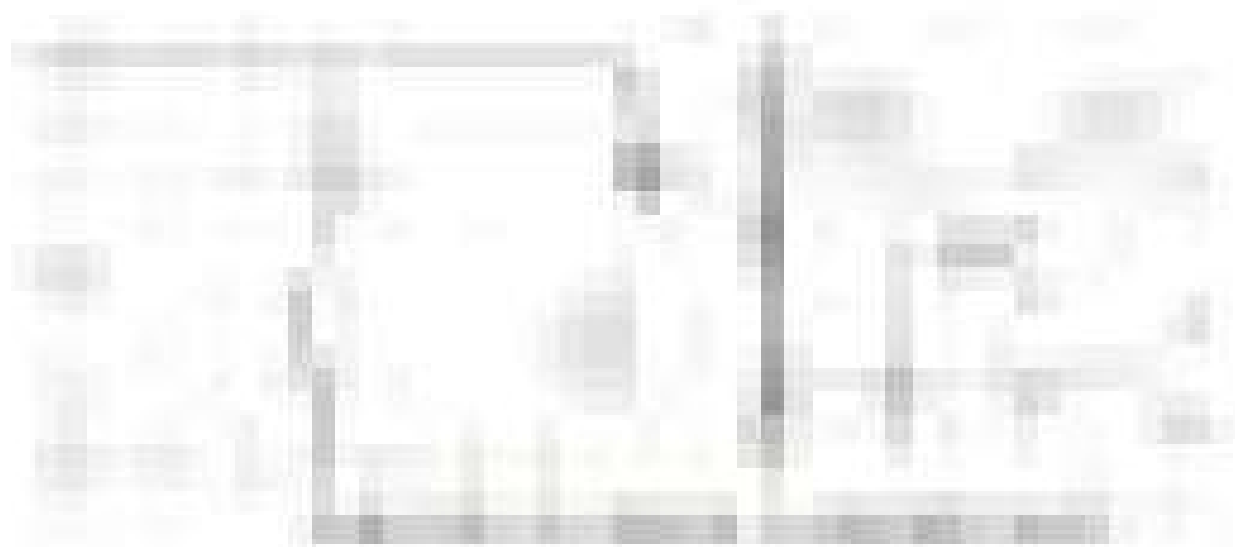
4. The fourth part of the document is the main body of the paper. It is divided into several sections, each focusing on a different aspect of the teacher's role. These sections include: "The Teacher as a Facilitator", "The Teacher as a Collaborator", "The Teacher as a Leader", and "The Teacher as a Lifelong Learner".

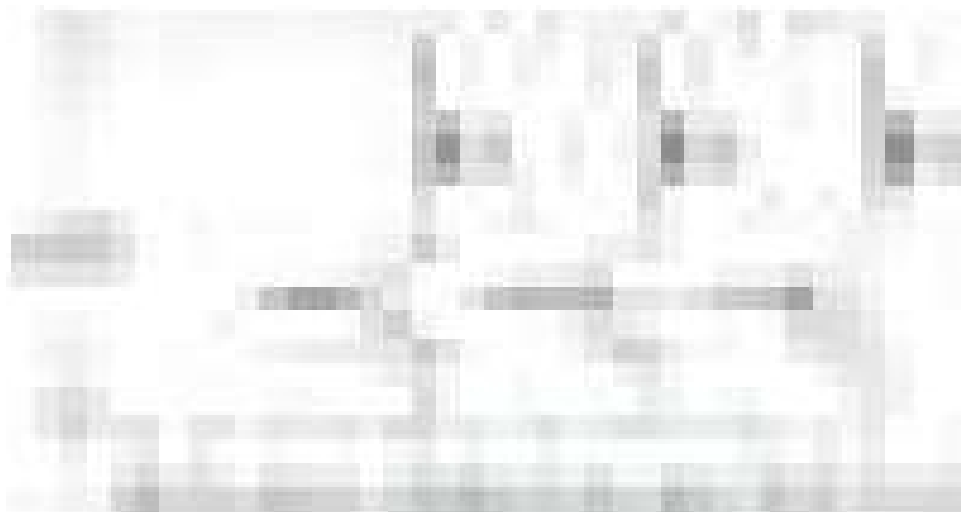
5. The fifth part of the document is the conclusion. It summarizes the key findings of the paper and offers some final thoughts on the future of education.

6. The sixth part of the document is the references. It lists the sources used in the paper, including books, articles, and websites.

7. The seventh part of the document is the appendix. It contains additional information that is not included in the main body of the paper, such as a list of figures and tables.







1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes the need for transparency and accountability in financial reporting.

2. The second part of the document outlines the various methods and techniques used to collect and analyze data. It includes a detailed description of the experimental procedures and the statistical analysis performed.

3. The third part of the document presents the results of the study, showing the trends and patterns observed in the data. It includes several tables and graphs to illustrate the findings.

4. The fourth part of the document discusses the implications of the results and the potential applications of the findings. It highlights the need for further research and the importance of sharing the results with the relevant community.

5. The fifth part of the document provides a conclusion and a summary of the key findings. It reiterates the main points of the study and offers some final thoughts on the future of the research.



1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities within the organization. It emphasizes the need for transparency and accountability in financial reporting.

2. The second part of the document outlines the various methods and tools used to collect and analyze data. It highlights the role of technology in streamlining data collection and analysis processes.

3. The third part of the document focuses on the interpretation of the collected data. It discusses the various statistical techniques and models used to derive meaningful insights from the data.



Printed Circuit Board (PCB) Motor





1. The first step in the process of creating a new product is to identify a market need. This involves conducting market research to understand what consumers want and what problems they are trying to solve.

2. Once a market need is identified, the next step is to develop a concept. This involves brainstorming ideas and creating a rough sketch of the product. It's important to consider the feasibility of the idea and how it will be manufactured.

3. The third step is to create a prototype. This is a physical model of the product that allows you to test its functionality and make any necessary adjustments. Prototyping can be done using various methods, such as 3D printing or CNC machining.

4. After the prototype is created, the next step is to conduct a feasibility study. This involves evaluating the product's potential for success in the market, considering factors such as cost, competition, and distribution channels.

5. The final step in the process is to launch the product. This involves creating a marketing plan, setting up a distribution network, and promoting the product to the target market. It's important to monitor sales and customer feedback to ensure the product is meeting its intended purpose.

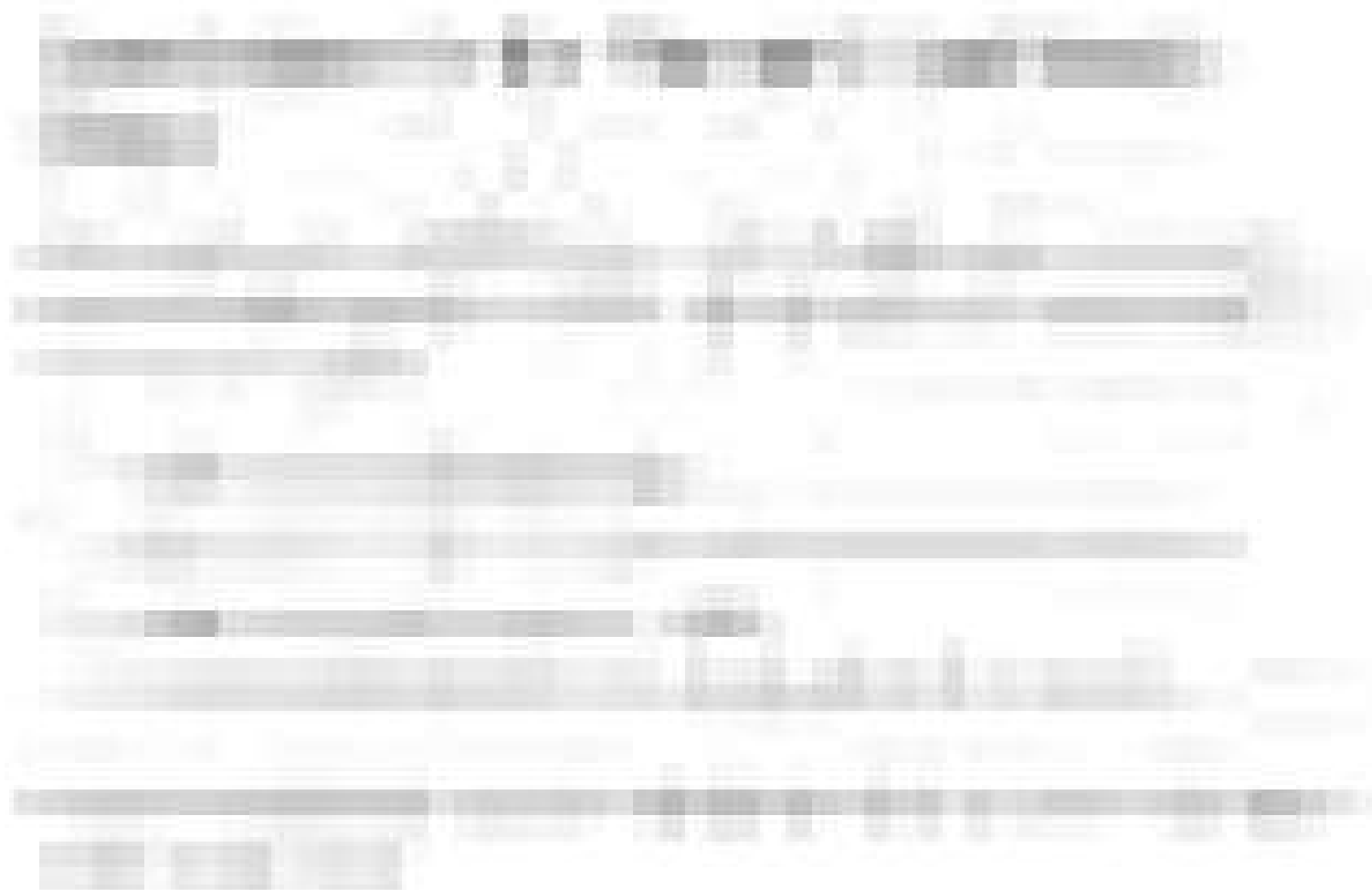
6. Once the product is launched, the process of creating a new product continues. This involves gathering customer feedback, identifying areas for improvement, and developing new products based on market needs.

7. The process of creating a new product is an ongoing one. It requires a commitment to innovation and a willingness to take risks. By following these steps, you can increase your chances of creating a successful new product.

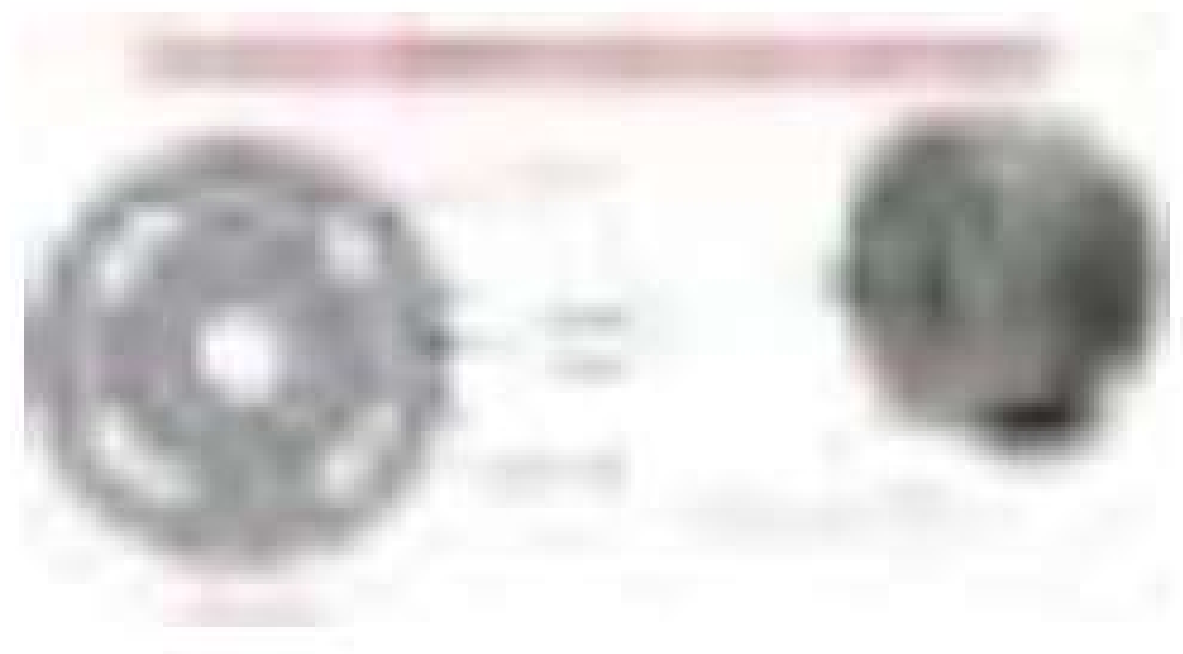
8. The process of creating a new product is a complex one, but it is also a rewarding one. It allows you to bring your ideas to life and create something that can make a difference in the world.

9. The process of creating a new product is a journey, not a destination. It requires patience, persistence, and a willingness to learn from failure. By following these steps, you can create a new product that meets the needs of the market and makes a positive impact.

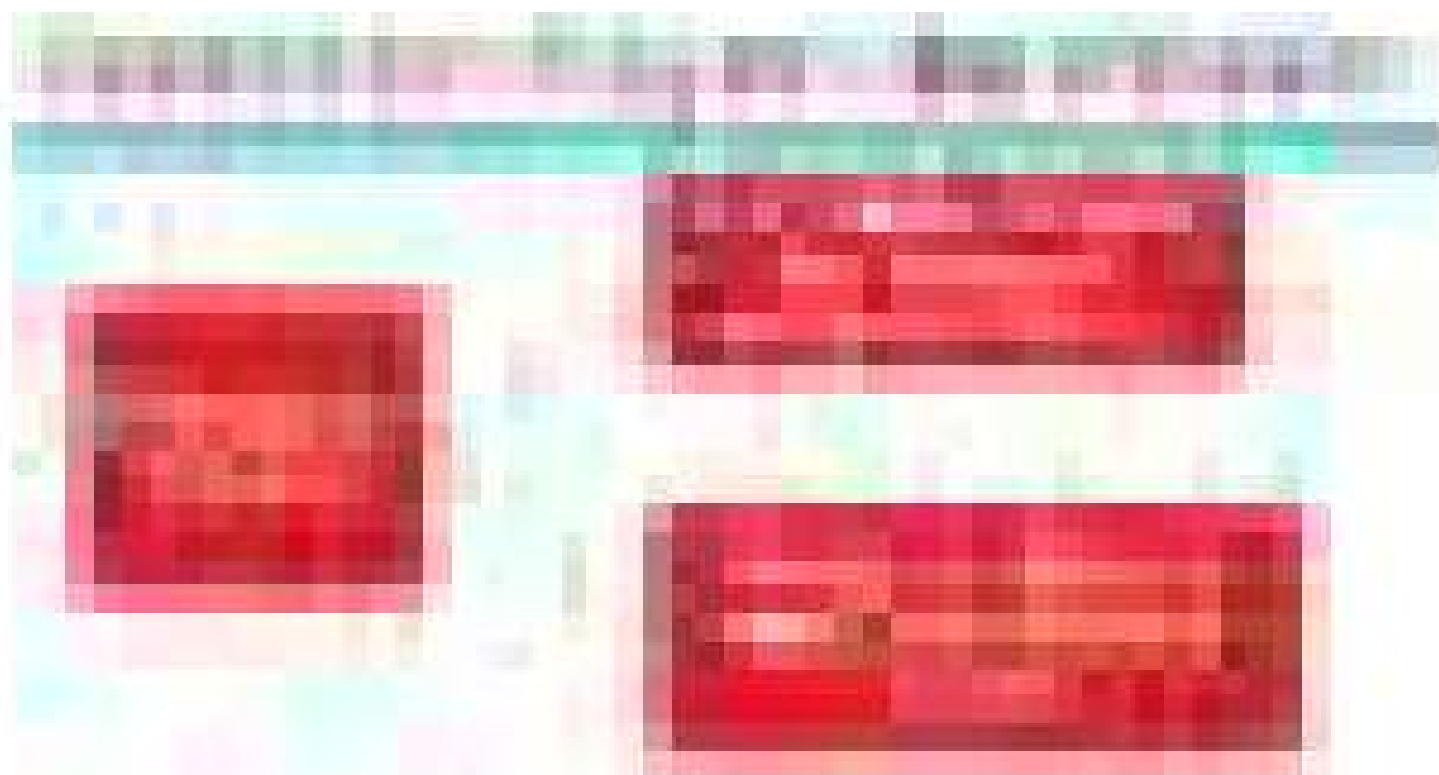
10. The process of creating a new product is a continuous one. It requires a commitment to innovation and a willingness to take risks. By following these steps, you can create a new product that meets the needs of the market and makes a positive impact.



Permanent Magnet Synchronous Generator





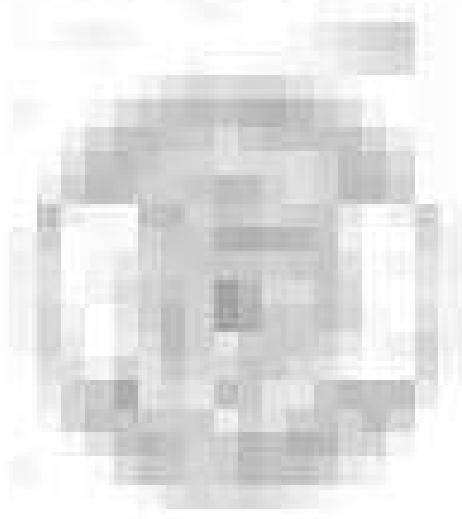
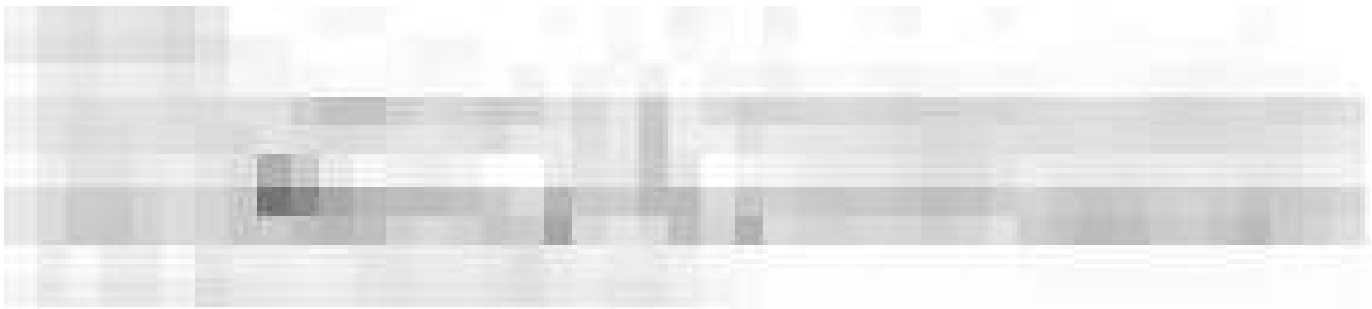


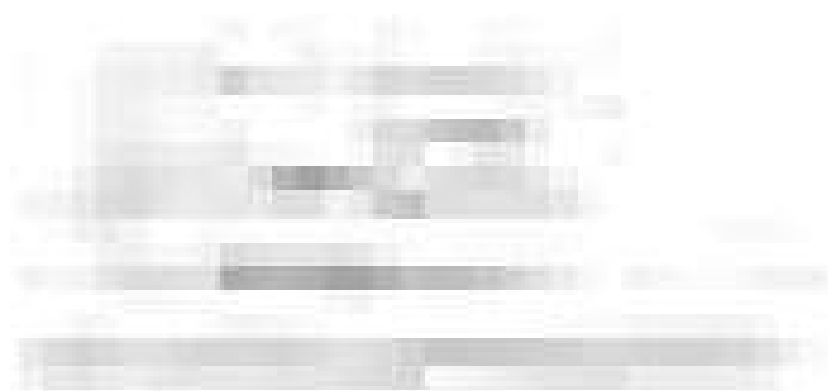


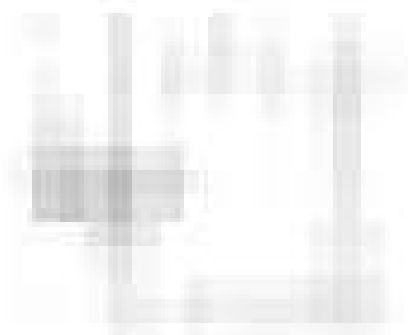




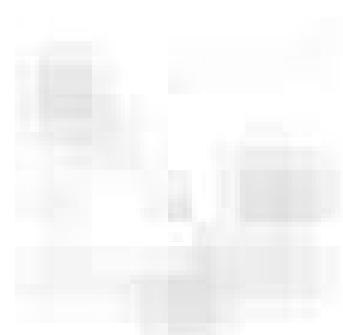
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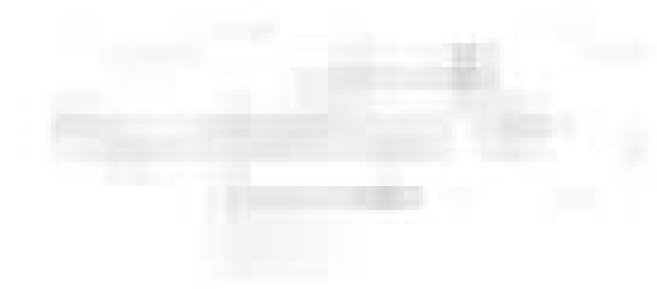




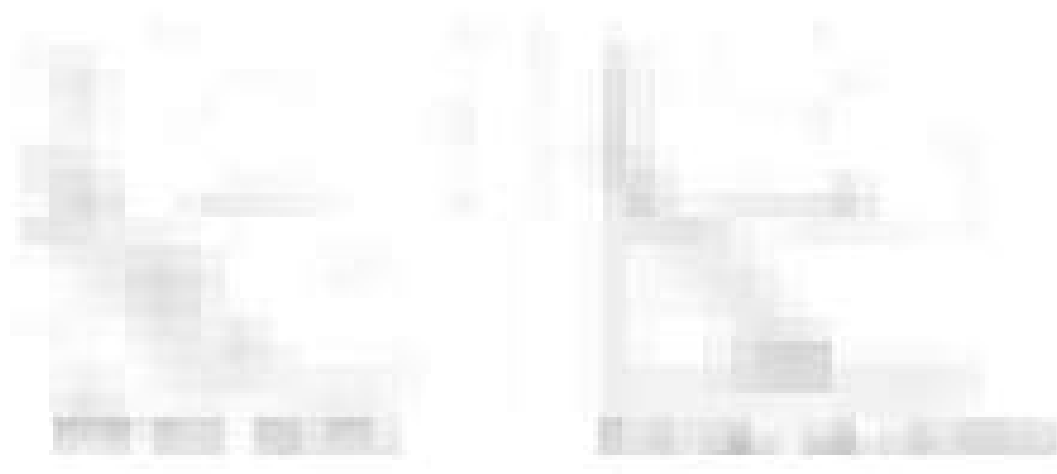
Schematic diagram



Speed-torque characteristics



Parameter	Value
Motor	1000
Load	1000
Feedback	1000



By changing the supply voltage, the no-load speed N_0 of the motor is changed without affecting the slope of the characteristic

By change the effective resistance of the armature circuit (inserting some resistance in series with the armature), the slope of the speed-torque characteristic changes without affecting the no-load speed N_0 of the motor

The following table shows the results of the regression analysis for the dependent variable "Performance" (Y-axis) and the independent variable "Experience" (X-axis). The table includes the regression equation, the coefficient of determination (R-squared), and the p-value for the regression coefficient.

Variable	Regression Coefficient	Standard Error	t-statistic	p-value
Intercept	1.2	0.3	4.0	0.0001
Experience	0.5	0.1	5.0	0.0001

The regression equation is: $Y = 1.2 + 0.5X$. The coefficient of determination (R-squared) is 0.90, indicating that 90% of the variance in Performance is explained by Experience. The p-value for the regression coefficient is 0.0001, which is less than the significance level of 0.05, indicating that the regression is statistically significant.

1. The first part of the document is a letter from the President of the United States to the Congress, dated January 3, 1801.

2. The second part is a report from the Secretary of the Treasury, dated January 3, 1801.

3. The third part is a report from the Secretary of the Navy, dated January 3, 1801.

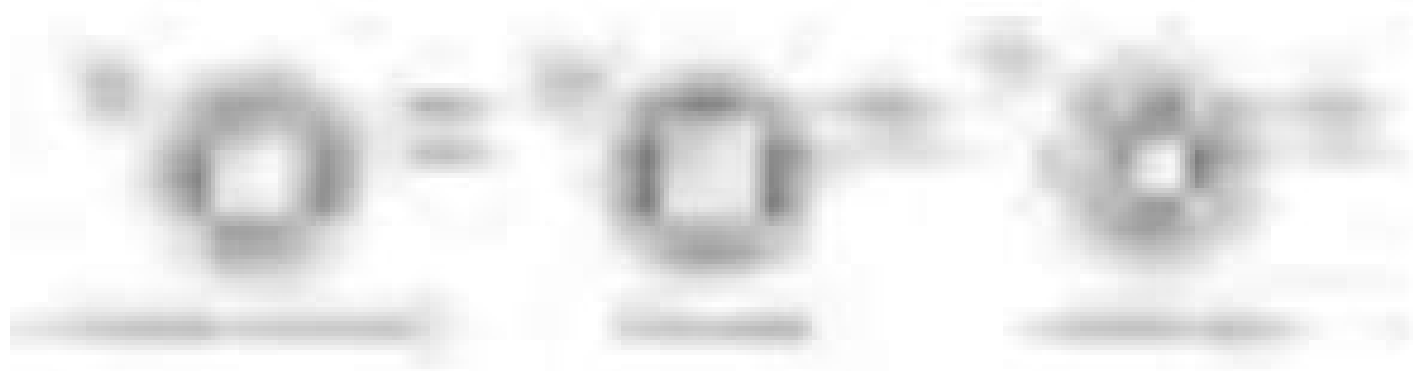
4. The fourth part is a report from the Secretary of the War, dated January 3, 1801.

5. The fifth part is a report from the Secretary of the Interior, dated January 3, 1801.

Permanent Magnet AC Motor



Permanent Magnet Synchronous Motors Types





- Since the voltages induced in the stator phases of a sinusoidal PMAC motor are sinusoidal, ideally, the three stator phases must be supplied with variable frequency sinusoidal voltages or currents with a phase difference of 120° between them. Let us now examine its behavior from a variable frequency current source.
- Norton's equivalent of the synchronous motor equivalent circuit



The mechanical power developed is

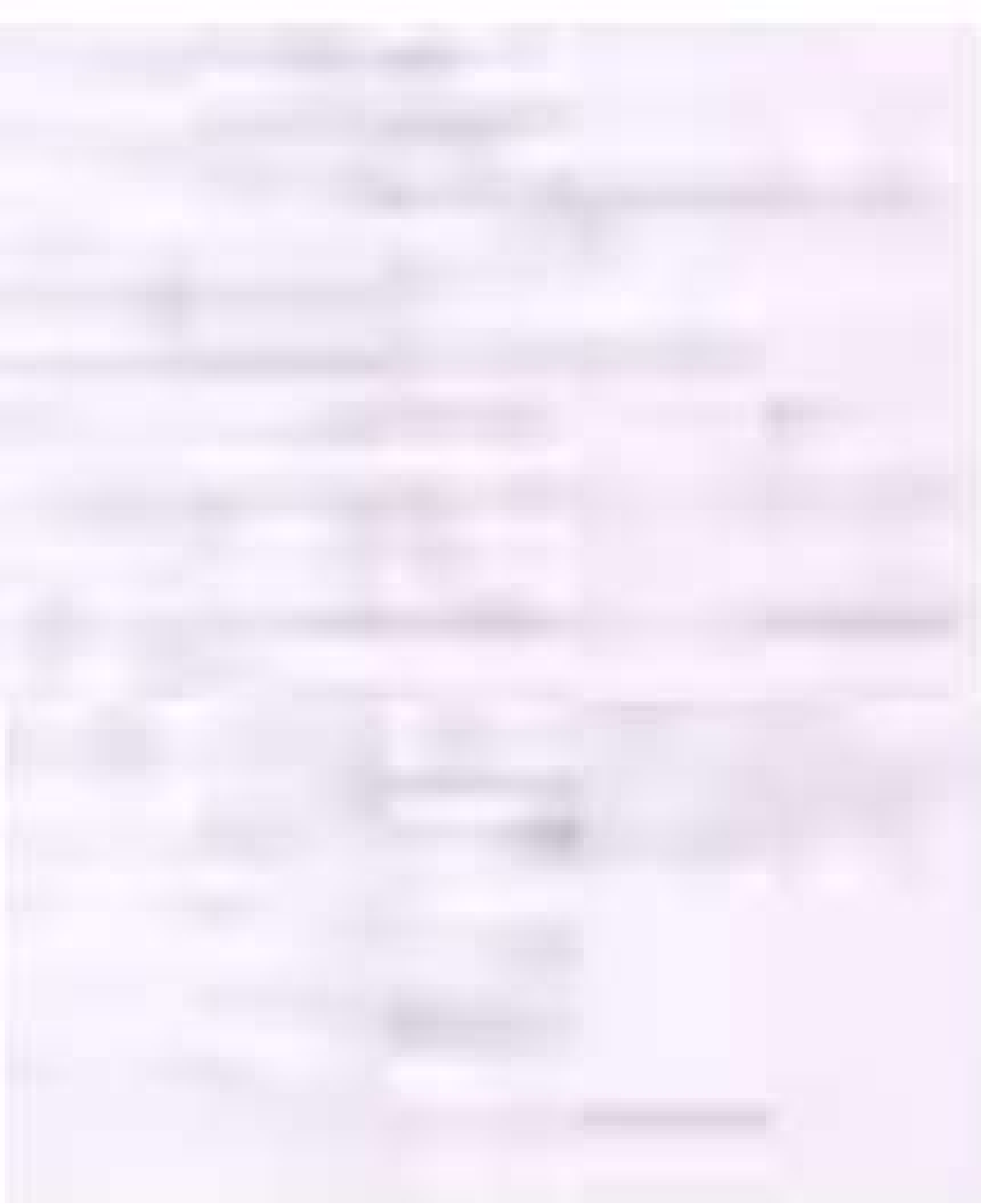


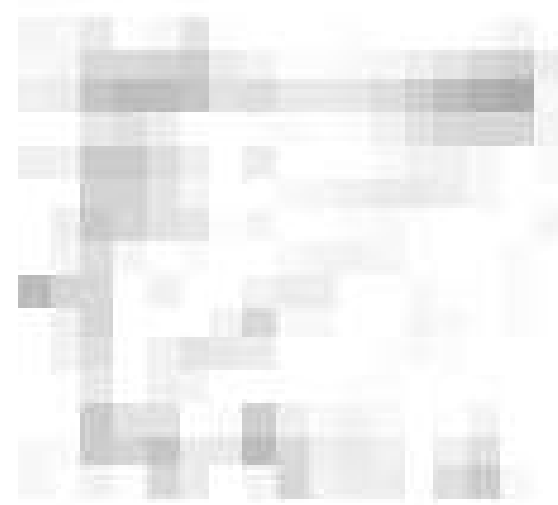


Unit 5

Single phase series motor (Universal Motor)



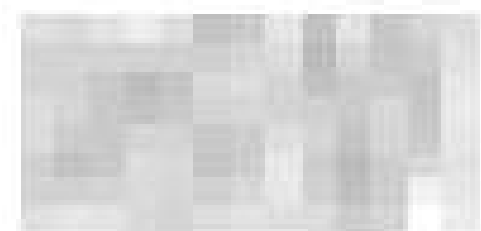
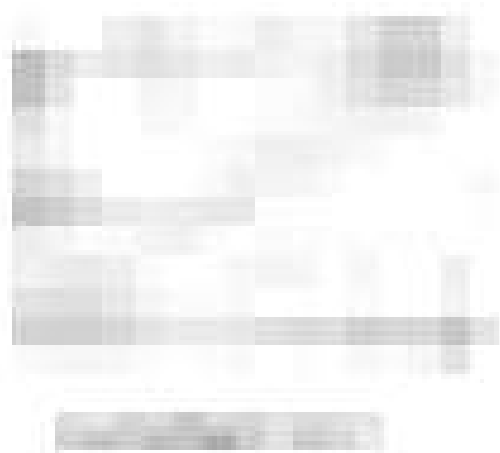
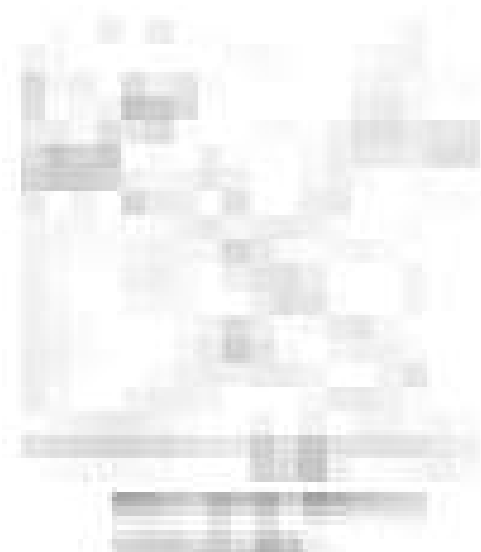
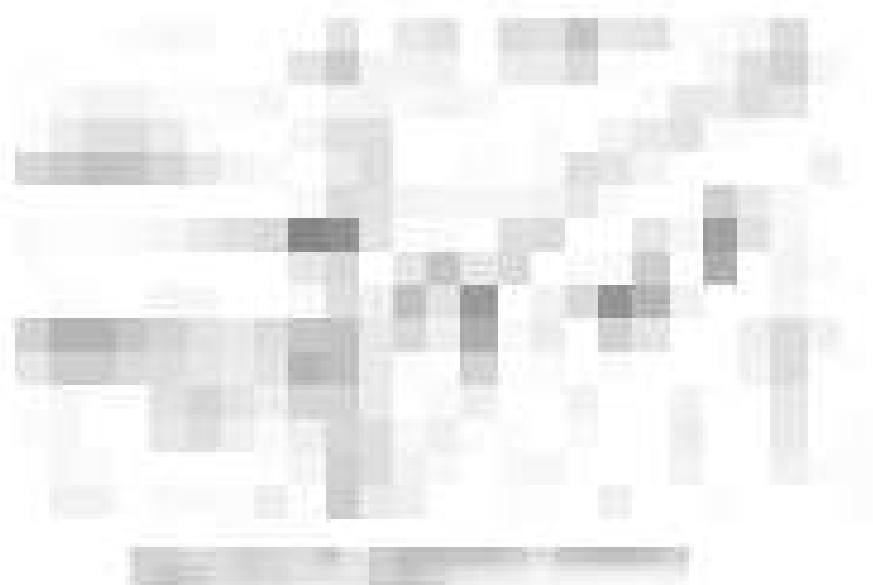


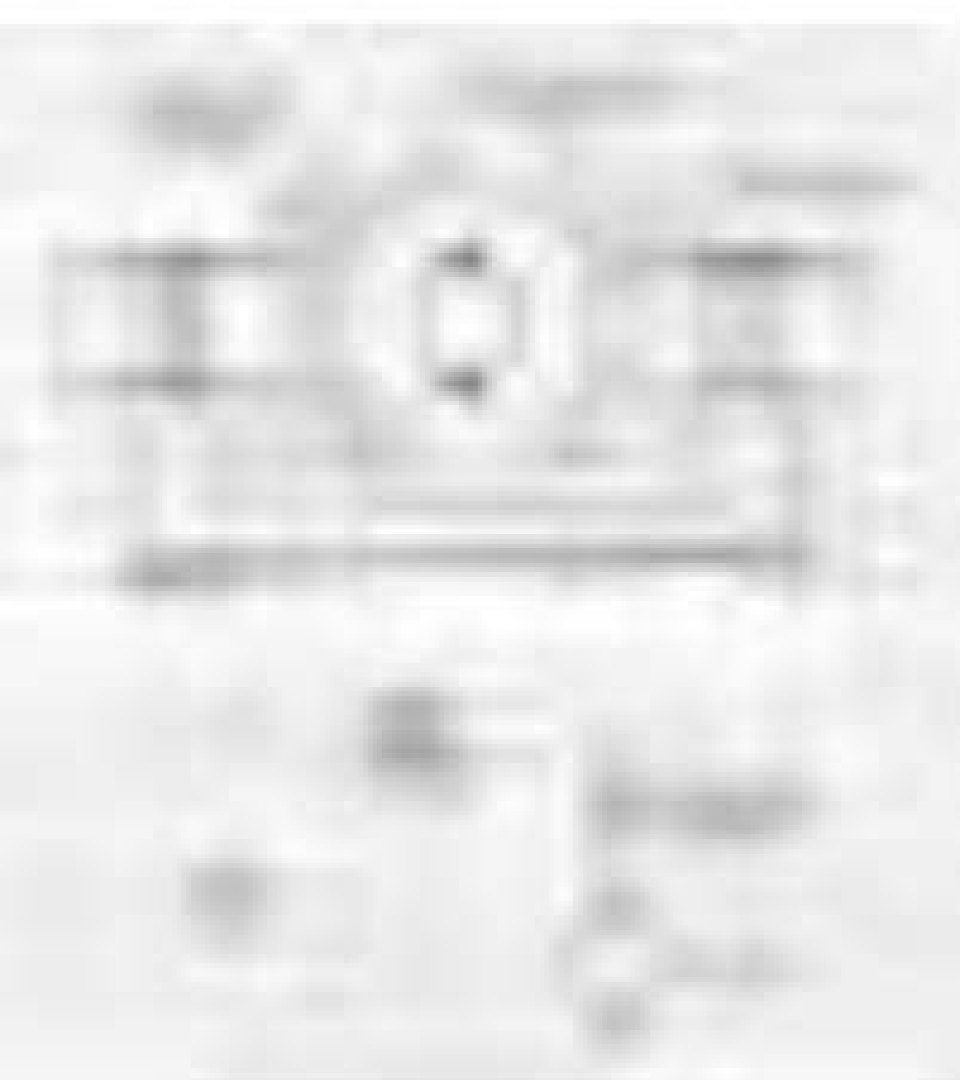


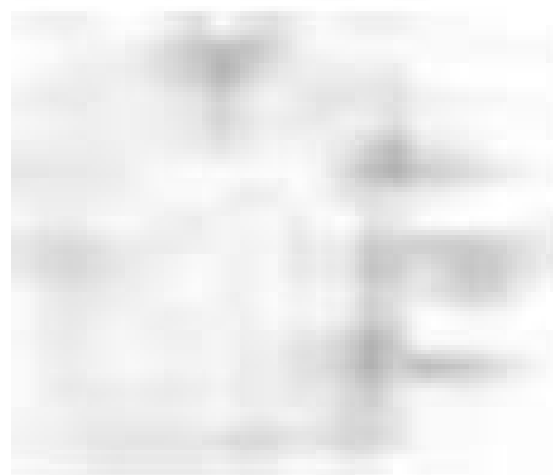
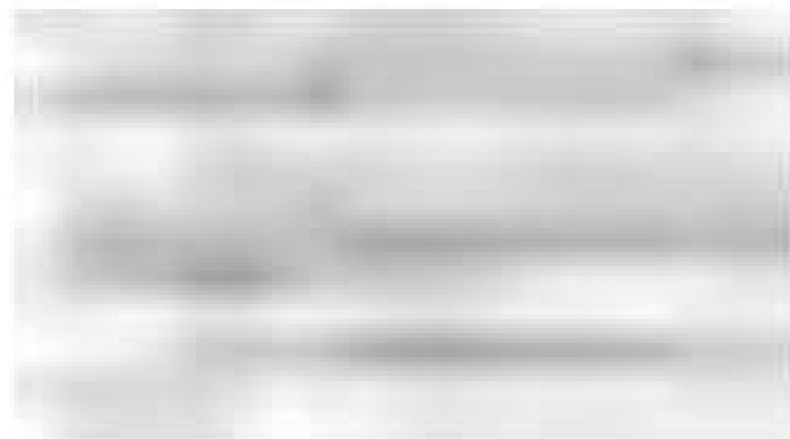
- Conductively compensated motor
- Inductively compensated universal-motor

If compensated winding connected in series with armature and field winding in such a case motor is called a **conductively compensated motor**.

If compensating winding short-circuited on itself in such a case motor is called **inductively compensated** and received excitation voltage by transformer action since it is inductively coupled.







1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part outlines the specific procedures and protocols that must be followed when recording transactions. This includes details on how data should be collected, stored, and reviewed to ensure its integrity and accuracy.

3. The third part addresses the role of the management team in overseeing the record-keeping process. It stresses the need for regular communication and collaboration between the management and the staff responsible for maintaining the records.

4. The fourth part discusses the importance of training and education for the staff involved in the record-keeping process. It highlights that ongoing training is necessary to ensure that the staff are up-to-date with the latest practices and technologies.

5. The fifth part concludes by reiterating the overall goal of the document: to ensure that the organization's records are accurate, complete, and accessible at all times. It encourages the management and staff to work together to achieve this goal.

Repulsion Motor



The main components of repulsion motor are stator, rotor and commutator brush assembly. The stator carries a single phase exciting winding similar to the main winding of single phase induction motor. The rotor has distributed DC winding connected to the commutator at one end just like in DC motor. The carbon brushes are short circuited on themselves.

- The basic principle behind the working of repulsion motor is that "similar poles repel each other." This means two North poles will repel each other. Similarly, two South poles will repel each other.



- When the stator winding of repulsion motor is supplied with single phase AC, it produces a magnetic flux along the direct axis as shown in figure above by arrow mark. This magnetic flux when link with the rotor winding, creates an emf. Due to this emf, a rotor current is produced. This rotor current in turn produces a magnetic flux which is directed along the brush axis due to commutator assembly. Due to the interaction of stator and rotor produced fluxes, an electromagnetic torque is produced. Let us discuss this aspect in detail.



Under this condition, there will not be any mutual induction between the stator and rotor windings. Therefore, no emf and hence no rotor current is produced. Thus no electromagnetic torque is developed.

In this condition, a maximum emf is induced across the brushes. This is because, the rotor and stator magnetic flux coincides and hence there is a perfect mutual coupling between them. Large rotor currents produce rotor mmf opposite to stator mmf.



- No electromagnetic torque is developed as $\alpha = 0^\circ$. Thus in repulsion motor, no electromagnetic torque is developed when the angle between the stator and rotor magnetic flux axis is either 0 or 90° .

- Electromagnetic torque T is given as

$T_e = k (\text{Stator Field Strength}) (\text{Rotor Field Strength}) \sin \alpha$
 where k is a constant.



- Since stator flux is toward A to B, South Pole (S1) is generated at A. Similarly South Pole (S2) is generated on rotor at C. Since similar poles repel each other, S1 will repel S2. Due to this repulsion between the like poles, motor will rotate in clockwise direction. *This is the reason; this motor is called Repulsion Motor.*

Torque Equation of Repulsion Motor

The number of turns N_r of coil T can be found as below.

$$\text{Mmf of coil T} = I_r N_r$$

Component of stator mmf along the brush axis $= I_s N_s \cos \alpha$

$$I_r N_r = I_s N_s \cos \alpha$$

$$N_r = N_s \cos \alpha$$

Similarly, the number of turns of coil F is given as

$$N_f = N_s \sin \alpha$$



Now, the electromagnetic torque

$$T_e = k (\text{Stator Field Strength}) (\text{Rotor Field Strength}) \sin \alpha$$

where k is a constant.

$$= k (I_s N_s) (I_r N_r \cos \alpha) \sin \alpha$$

$$= (k/2) (I_s N_s)^2 (2 \cos \alpha \sin \alpha)$$

$$= (k/2) (I_s N_s)^2 \sin 2\alpha \dots [\sin 2\alpha = 2 \cos \alpha \sin \alpha]$$

Therefore, the torque in repulsion motor is given as

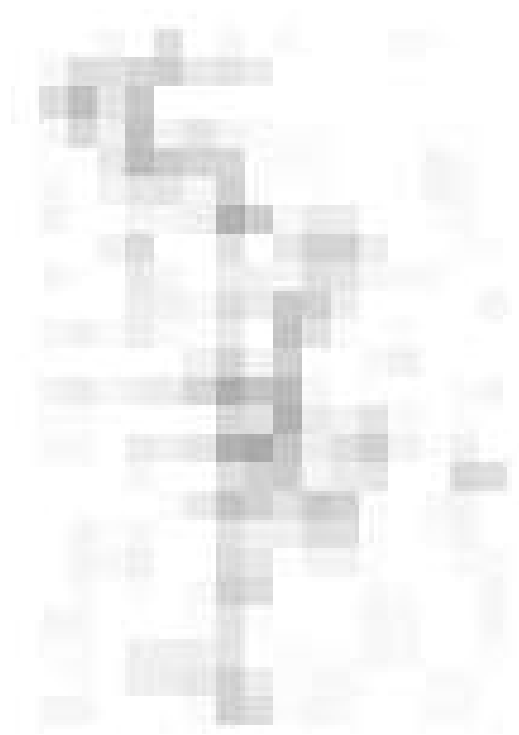
$$T_e = (k/2) (I_s N_s)^2 \sin 2\alpha$$

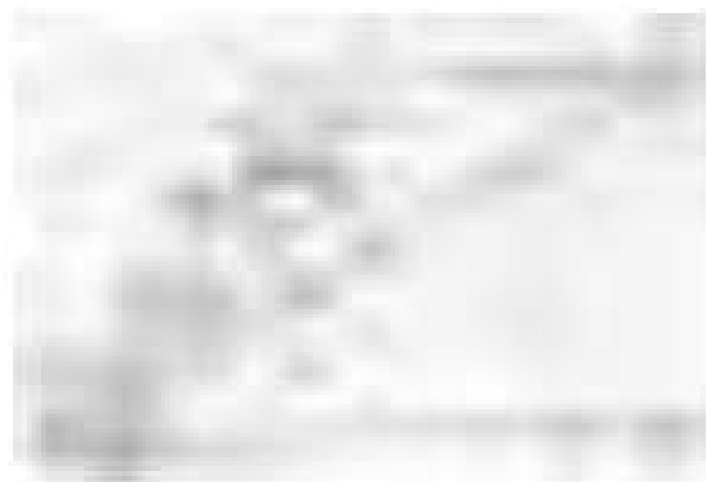
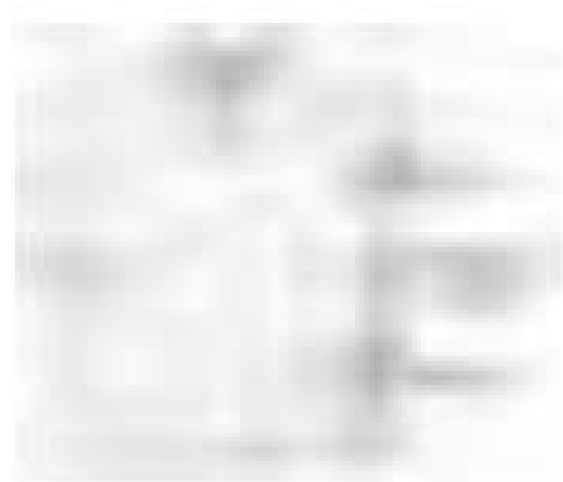
Maximum torque is achieved when stator and rotor magnetic axis are displaced from each other by 45°

The variation of current and torque with respect to different positions of brush is shown



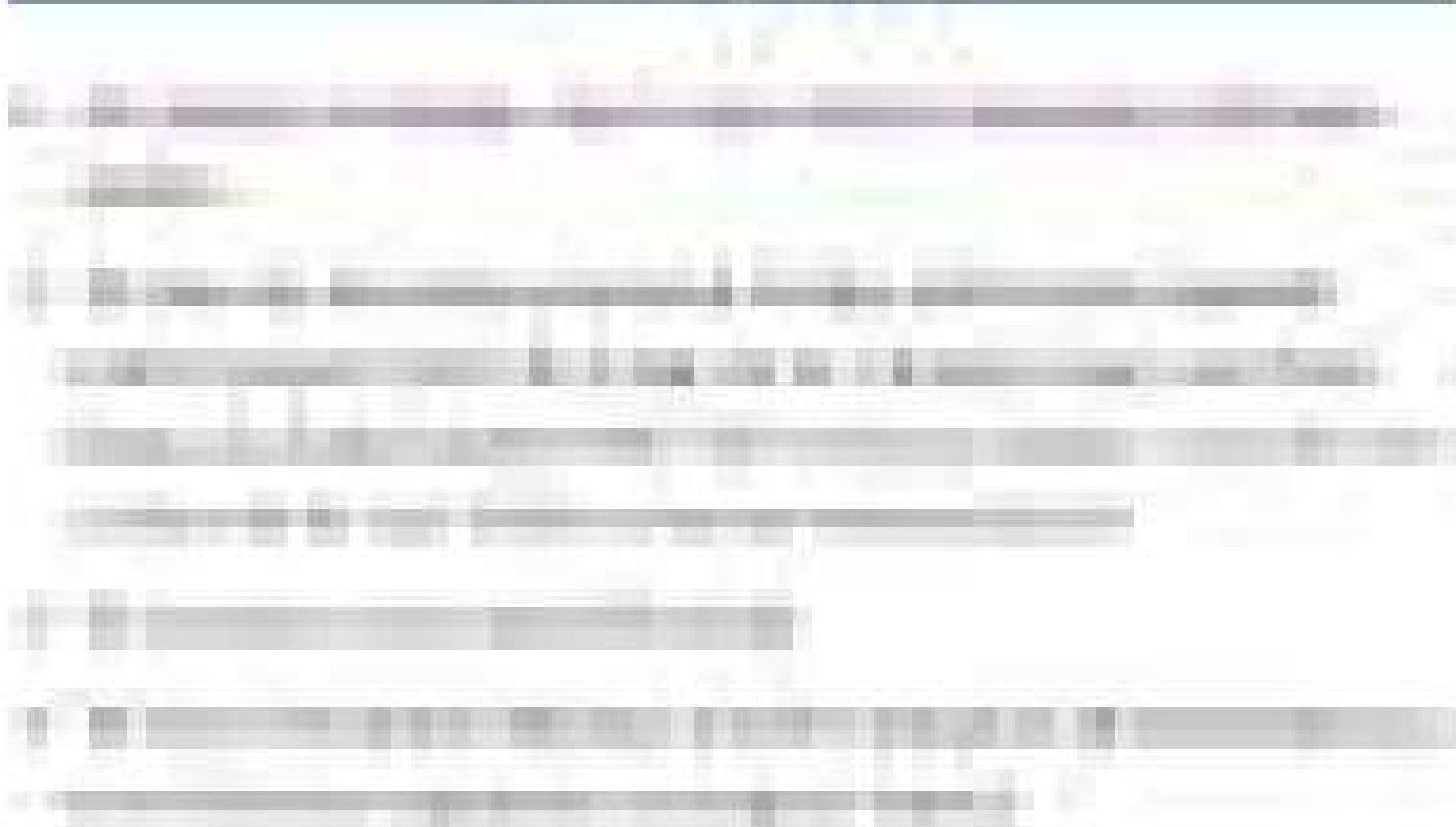
TABLE I		Variation of current and torque with respect to different positions of brush	
Brush position	Current (A)	Torque (Nm)	Speed (rpm)
1	1.5	0.5	1500
2	1.5	0.5	1500
3	1.5	0.5	1500
4	1.5	0.5	1500
5	1.5	0.5	1500
6	1.5	0.5	1500
7	1.5	0.5	1500
8	1.5	0.5	1500
9	1.5	0.5	1500
10	1.5	0.5	1500
11	1.5	0.5	1500
12	1.5	0.5	1500





Reluctance Motor







100

Supply is given applied to the stator



A rotating magnetic field is produced



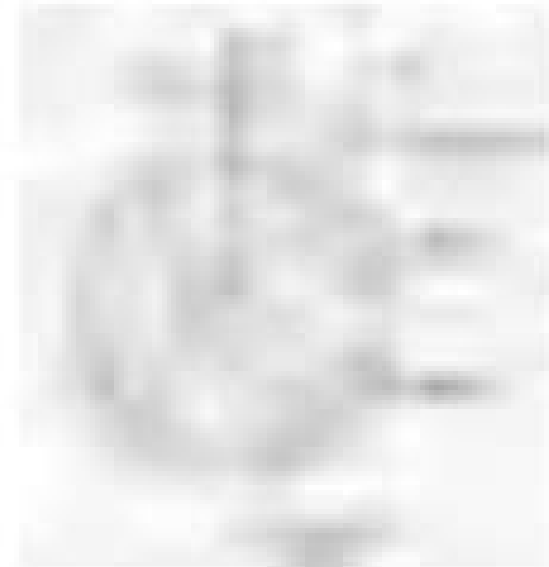
Magnetises the rotor ring and induces pole



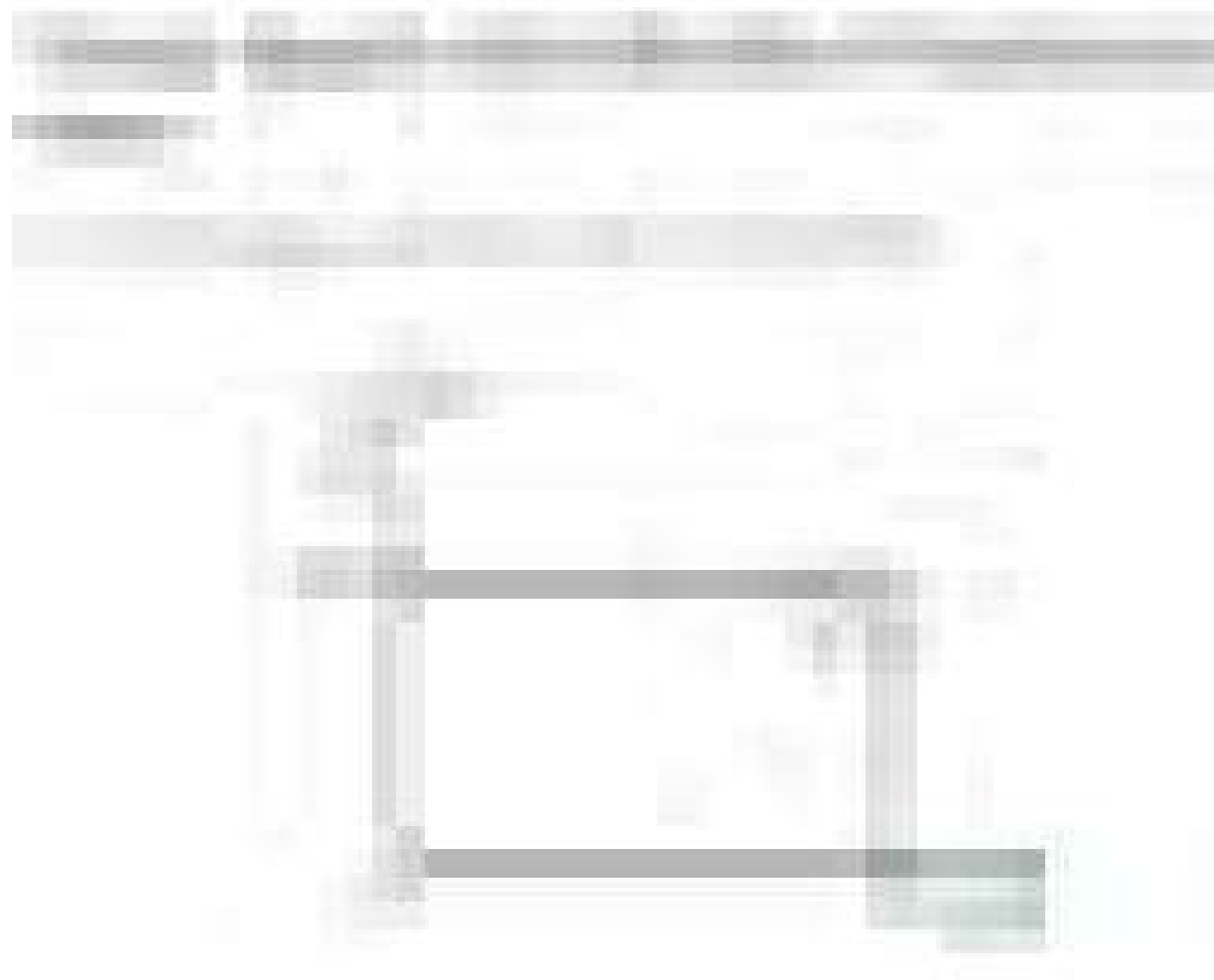
Induced rotor flux lags behind the rotating stator flux



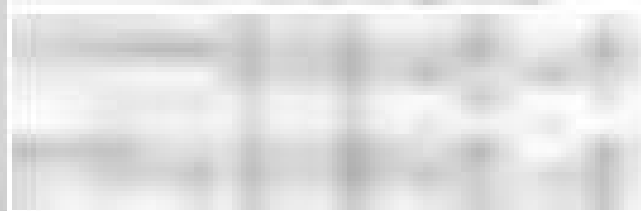
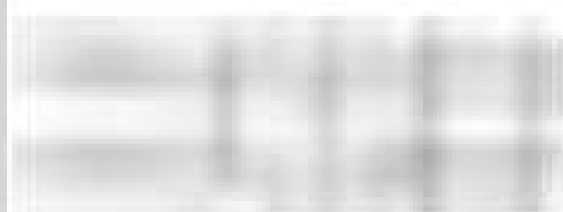
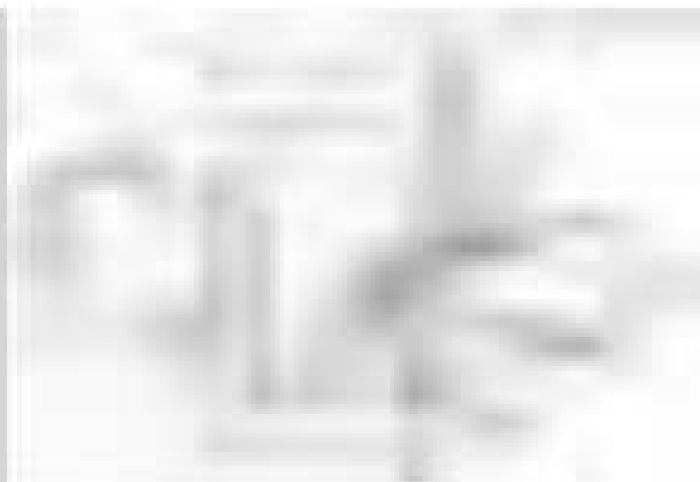
Production of the torque



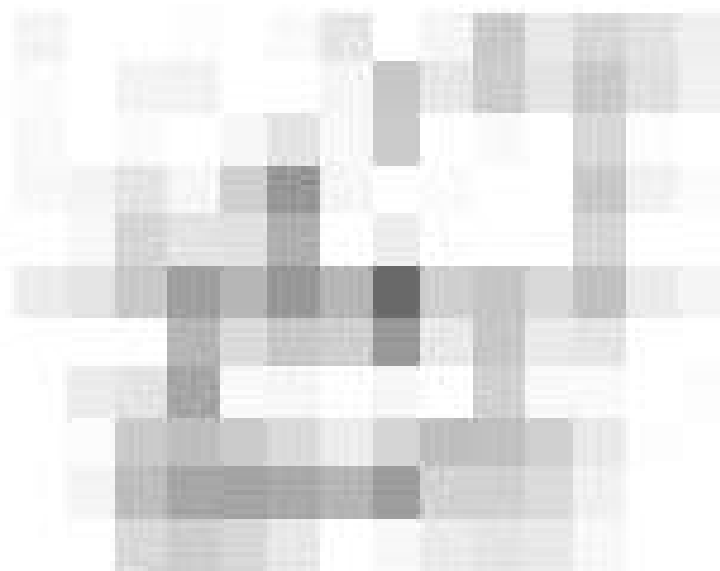


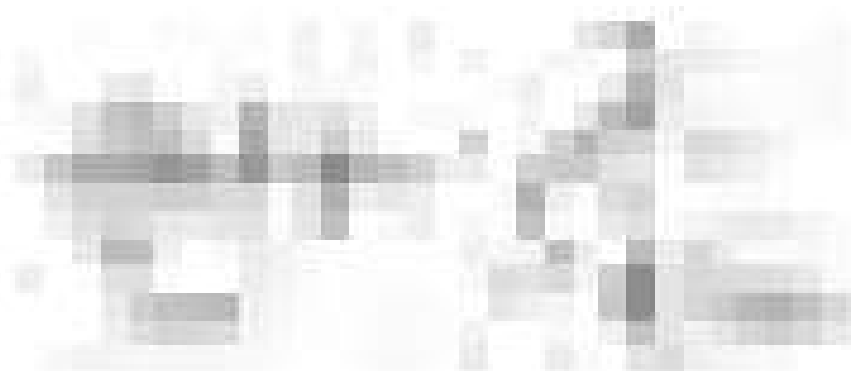






Commutation in AC motor



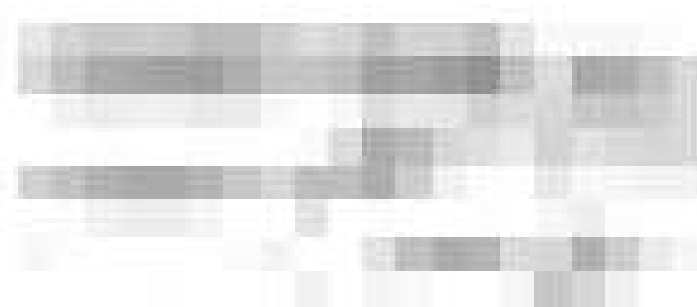
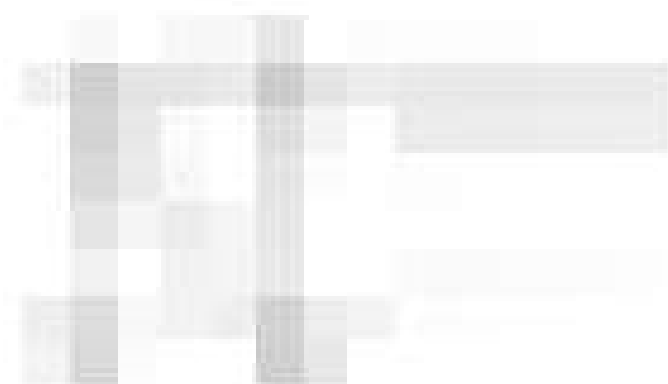


$$x_1 = \frac{\delta_i}{\ell_i}$$



Rotational emf E_g

$$E_g = \sqrt{2} \pi f_p M_c k_c$$



THE UNIVERSITY OF CHICAGO
DIVISION OF THE PHYSICAL SCIENCES
DEPARTMENT OF PHYSICS
PHYSICS 341: QUANTUM MECHANICS
PROBLEM SET 10

1. A particle of mass m is confined to a one-dimensional box of length L . The potential energy is zero inside the box and infinite outside. The wave function $\psi(x)$ is given by

$$\psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right)$$

for $0 \leq x \leq L$ and zero elsewhere. Find the probability of finding the particle in the region $0 \leq x \leq L/4$ for $n=1, 2, 3, 4$.

2. A particle of mass m is confined to a one-dimensional box of length L . The potential energy is zero inside the box and infinite outside. The wave function $\psi(x)$ is given by

$$\psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right)$$

for $0 \leq x \leq L$ and zero elsewhere. Find the probability of finding the particle in the region $L/4 \leq x \leq L/2$ for $n=1, 2, 3, 4$.

3. A particle of mass m is confined to a one-dimensional box of length L . The potential energy is zero inside the box and infinite outside. The wave function $\psi(x)$ is given by

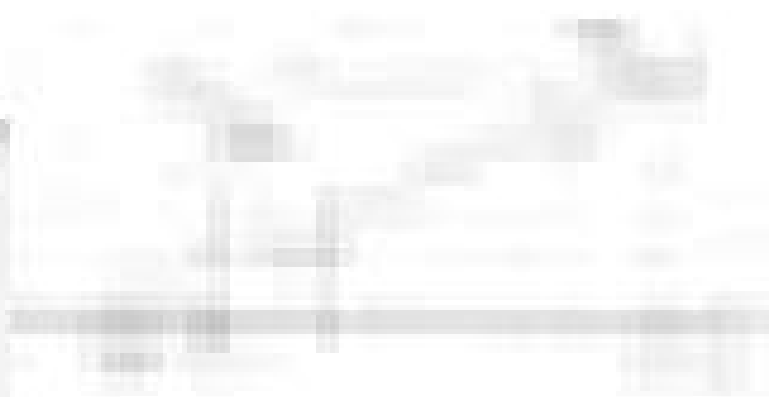
$$\psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right)$$

for $0 \leq x \leq L$ and zero elsewhere. Find the probability of finding the particle in the region $L/2 \leq x \leq 3L/4$ for $n=1, 2, 3, 4$.

4. A particle of mass m is confined to a one-dimensional box of length L . The potential energy is zero inside the box and infinite outside. The wave function $\psi(x)$ is given by

$$\psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right)$$

for $0 \leq x \leq L$ and zero elsewhere. Find the probability of finding the particle in the region $3L/4 \leq x \leq L$ for $n=1, 2, 3, 4$.



1. The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the transparency and accountability of the organization. This section also outlines the various methods used to collect and analyze data, ensuring that the information is reliable and up-to-date.

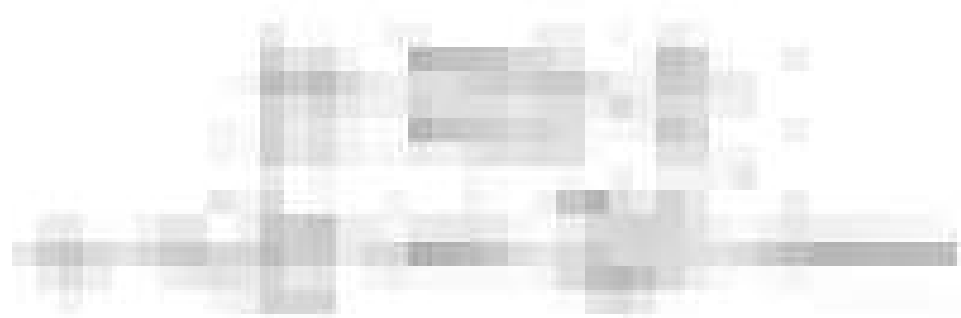
2. The second part of the document focuses on the financial aspects of the organization. It provides a detailed breakdown of the budget, including income and expenses, and discusses the strategies implemented to manage resources effectively. This section also highlights the role of the finance department in ensuring that the organization remains financially sound and sustainable.

3. The third part of the document addresses the operational challenges faced by the organization. It identifies key areas of concern, such as staffing levels, equipment maintenance, and supply chain management, and provides recommendations for addressing these issues. This section also discusses the importance of regular communication and collaboration between different departments to ensure smooth operations.

4. The fourth part of the document discusses the future plans and goals of the organization. It outlines the strategic vision and identifies the key areas for growth and development. This section also discusses the importance of innovation and research in staying ahead of the competition and achieving long-term success.

5. The final part of the document provides a summary of the key findings and conclusions. It reiterates the importance of maintaining accurate records, managing resources effectively, and addressing operational challenges. It also expresses confidence in the organization's ability to achieve its goals and maintain its position as a leader in the industry.





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SUB-SYNCHRONOUS MOTOR

Manual rotor rotation at synchronous speed



Input supply to stator



Alternating field in airgap



Stator and rotor poles interlocking



Rotor poles go ahead due to inertia



Magnetic flux goes to zero & increases in
Reverse direction



Stator poles attract rotor poles again

