SERVO MOTORS AND MOTION CONTROL SYSTEMS

(Power Amplifiers and Sensors in Servo Systems-Lecture 4)

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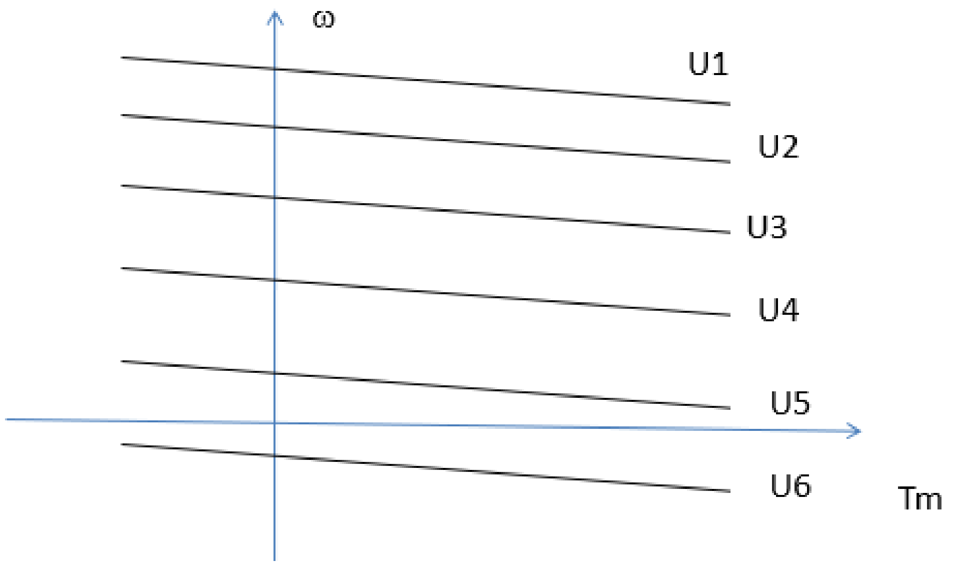
DC Servo Motors

- **Variable Speed Control**: The speed variation in DC servo motors is typically achieved by adjusting the average voltage level applied to the motor. The relationship is given by $U = V_q$, where U represents the average input voltage to the DC motor.
- **Characteristic Equation**: For many servo motors, the speed-torque characteristic can be represented as $\omega = \omega_0 - K \cdot T$, where ω is the angular velocity, ω_0 is a function of the input voltage ($f(U)$), K is a constant, and T is the torque.

AC Servo Motors

- **Voltage and Frequency Control**: In contrast to DC motors, AC servo motors require changes in both the effective value of the applied voltage and its frequency. This is typically represented as $U = f_r$, under the condition that V_{ef}/f_r remains constant.
- **Power Electronics in AC Motors**: To achieve the necessary changes in voltage and frequency, power electronic circuits are utilized. These circuits often derive their input from a fixed amplitude and frequency AC power source.

Shunt Characteristic



Power Amplifiers in Servo Systems

Power Electronics in Servo Motors

DC Motors: When powered by a fixed amplitude and frequency AC source, rectifiers are used in the power electronic circuits of DC motors. If powered by a fixed amplitude DC source, a DC-DC converter is used.

AC Motors: In the case of AC motors, the input voltage's effective value and frequency are altered using power electronic circuits, which can be fed either from a fixed amplitude and frequency AC source or a fixed amplitude DC source.

This overview highlights the fundamental differences in how DC and AC servo motors are controlled and powered. Understanding these principles is crucial for designing and implementing effective servo motor systems in various applications, ranging from robotics to precision machinery. The use of power electronics in controlling these motors is a pivotal aspect, allowing for the precise manipulation of speed and torque as per the application's demand.

Power Processing

1. DC-DC Conversion

- **Purpose**: DC-DC converters are used to change the magnitude of a DC voltage. They can step-up (boost) or step-down (buck) the voltage level.
- **Operation**: These converters use switch-mode power supply technology. They typically involve a rapidly switching transistor, an inductor, and a diode. The switching action, controlled through a technique like Pulse Width Modulation (PWM), allows for the efficient conversion of voltage levels.
- **Applications**: DC-DC converters are essential in devices where different DC voltage levels are required from a single DC power source, such as in battery-powered devices, laptops, and mobile phones.

2. AC-DC Rectification

- **Purpose**: Rectifiers convert AC power to DC power. They can provide a fixed or controllable DC output voltage.
- **Types**:
  - **Uncontrolled Rectifiers**: Use diodes and provide a fixed DC voltage.
  - **Controlled Rectifiers**: Use thyristors or other controllable switches to adjust the output DC voltage.
- **Operation**: The rectification process involves the use of diodes or thyristors to allow current flow in only one direction, effectively converting the AC input into a pulsating DC output.
- **Applications**: Rectifiers are used in power supplies for electronic devices, battery charging systems, and power conversion for motor drives.

3. DC-AC Inversion

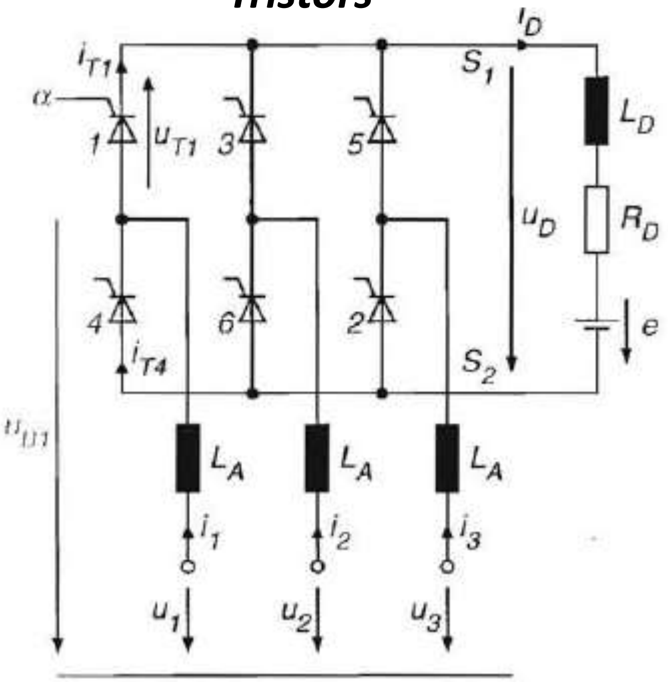
- **Purpose**: Inverters convert DC power into AC power, typically producing a sinusoidal output of controllable magnitude and frequency.
- **Operation**: Inverters use electronic switches (like IGBTs or MOSFETs) and control circuits (often employing PWM) to generate an AC waveform from a DC source.
- **Applications**: They are critical in applications such as solar power systems (converting DC from solar panels to AC), uninterruptible power supplies (UPS), and variable frequency drives for AC motors.

4. AC-AC Cycloconversion

- **Purpose**: Cycloconverters directly convert AC power at one frequency to AC power at another frequency, controlling both the voltage magnitude and frequency.
- **Operation**: They use a series of controlled switches (like thyristors) to modify the input waveform. Unlike inverters, cycloconverters do not involve an intermediate DC stage.
- **Applications**: Cycloconverters are used in high-power applications such as controlling the speed of large AC motors, such as those in rolling mills, mine hoists, or cement mills.

Rectifiers

Tristors



AC to DC Conversion in Servo Motors

When dealing with AC servo motors or situations where the power supply is an AC source, but a DC motor needs to be driven, rectifiers are used to convert the AC input to DC output. These rectifiers can be categorized based on their configuration and control methods:

Diode-Based Bridge Rectifiers (Fixed DC Output Voltage)

Single-Phase or Three-Phase: These are the simplest forms of rectifiers, using diodes to convert AC to DC.

Characteristic: They provide a fixed average DC output voltage when fed from a fixed voltage and frequency AC power source.

Application: Used in applications where a constant DC voltage is required and variations in speed or torque are not critical.

Thyristor-Based Bridge Rectifiers (Variable DC Output Voltage)

Single-Phase or Three-Phase: These rectifiers use thyristors (SCRs) instead of diodes. Thyristors are controllable semiconductor devices.

Variable Output: By controlling the firing angle of the thyristors, the average output DC voltage can be varied. This allows for more precise control of the motor speed and torque.

Application: Ideal for applications requiring variable speed and torque control, such as in heavy machinery and industrial automation.

IGBT-Based Bridge Rectifiers

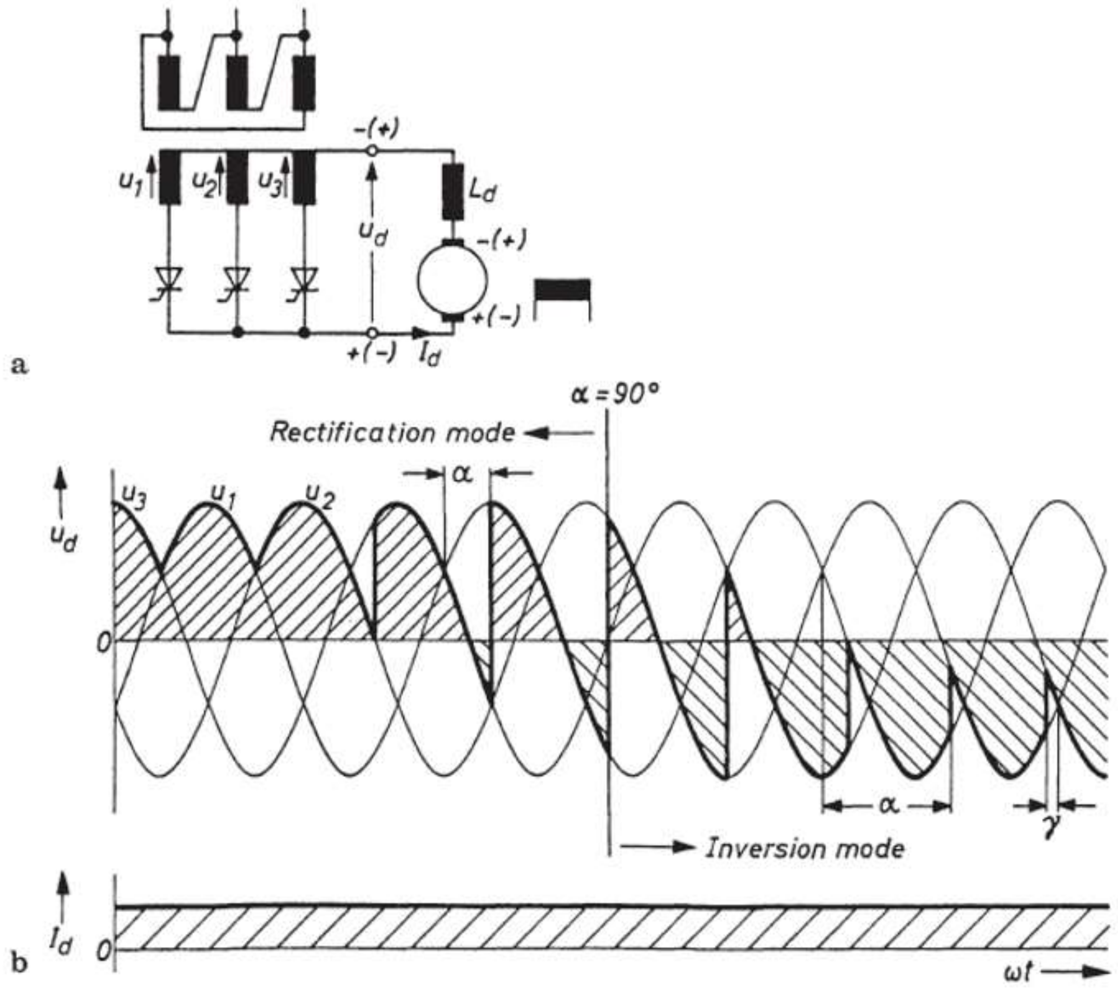
Single-Phase or Three-Phase: These rectifiers use Insulated Gate Bipolar Transistors (IGBTs), which are a type of fast-switching, high-efficiency transistor.

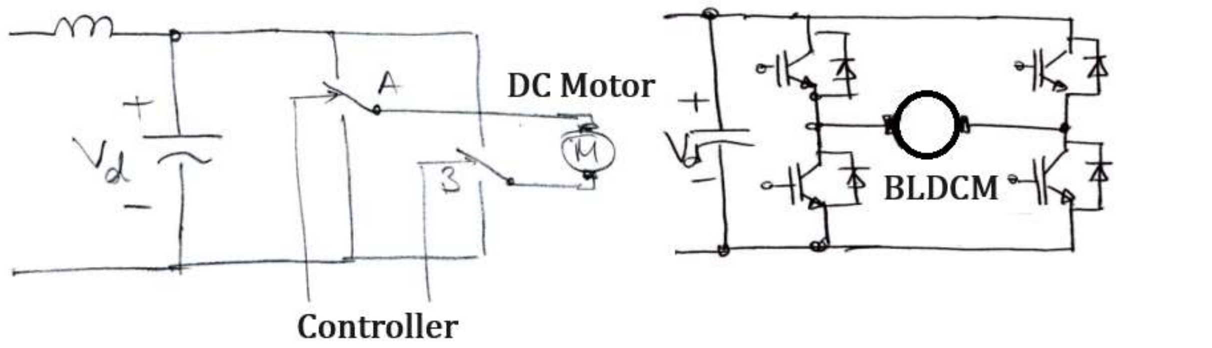
Advantages: IGBTs combine the high-speed switching capability of MOSFETs with the high current and low saturation voltage capability of bipolar transistors. This makes them suitable for high-frequency and high-efficiency applications.

Application: Commonly used in high-performance servo systems where precise control, efficiency, and fast response are required.

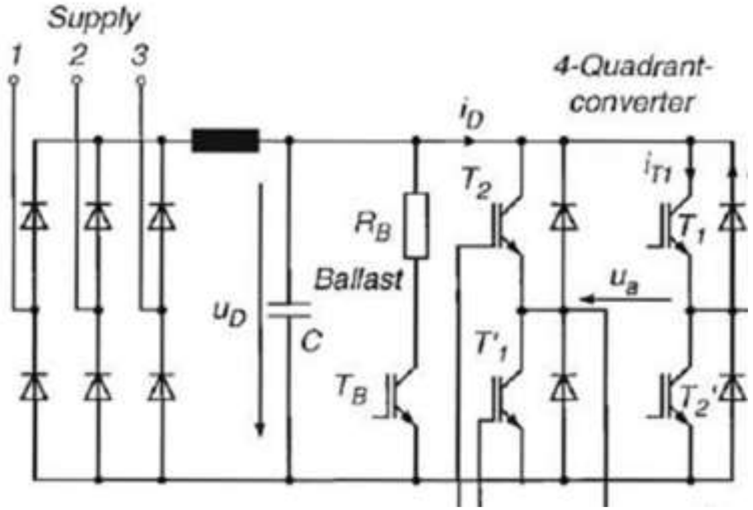
Modulation from operation in the rectifier mode into operation in the inverter mode.

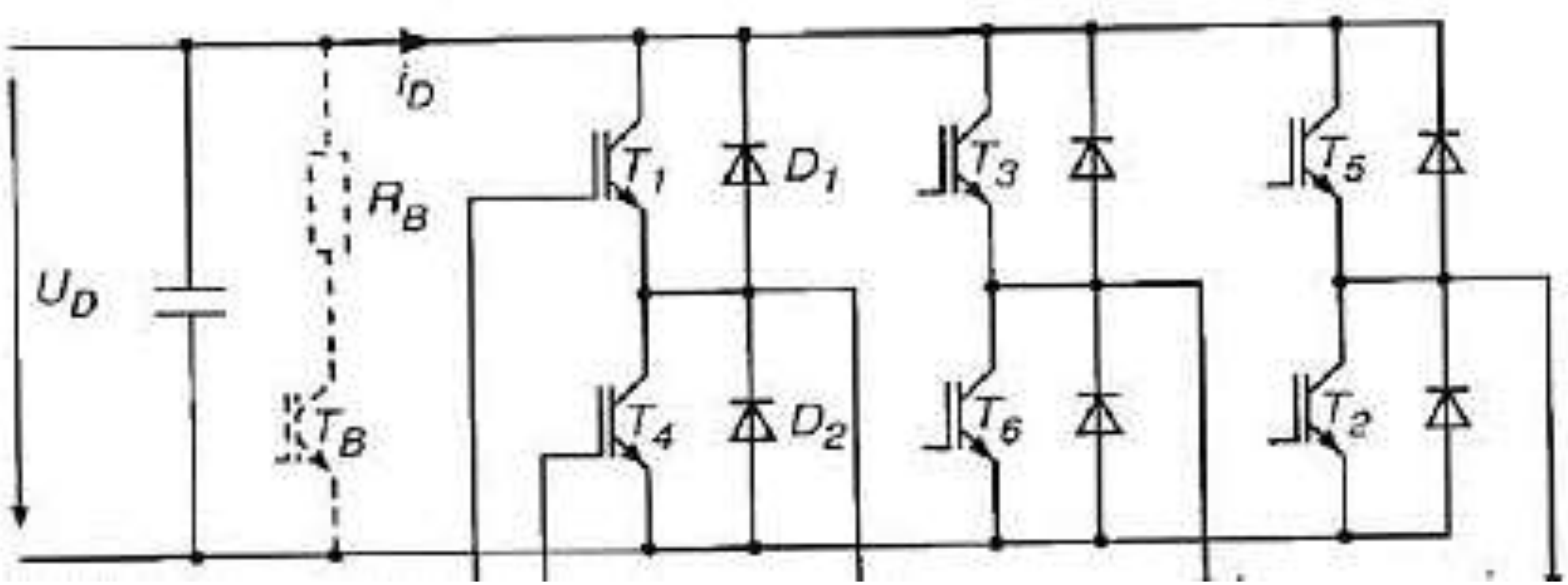
- a) **Three-pulse center tap connection.**
- b) **voltage and current waveforms.**



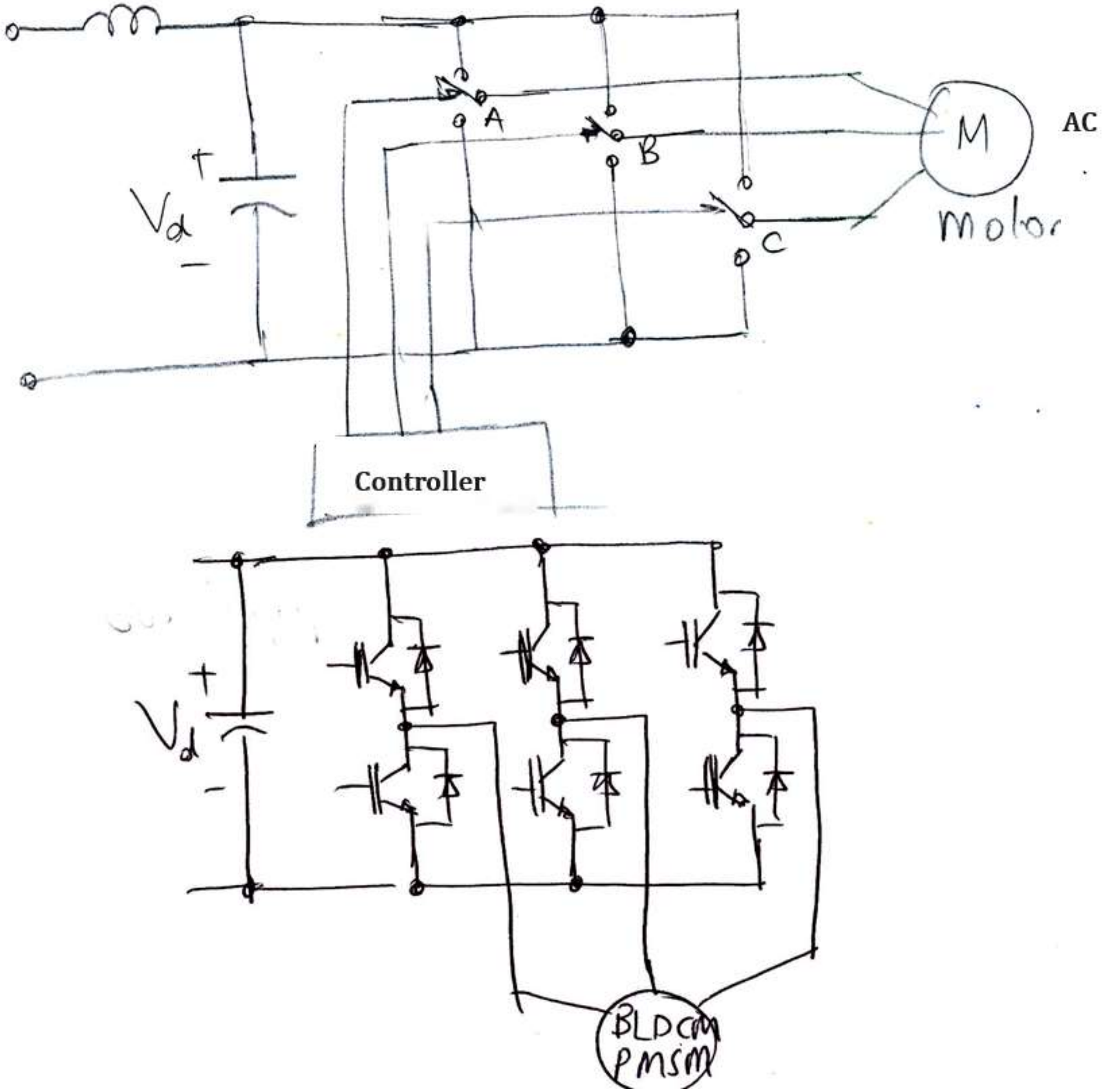


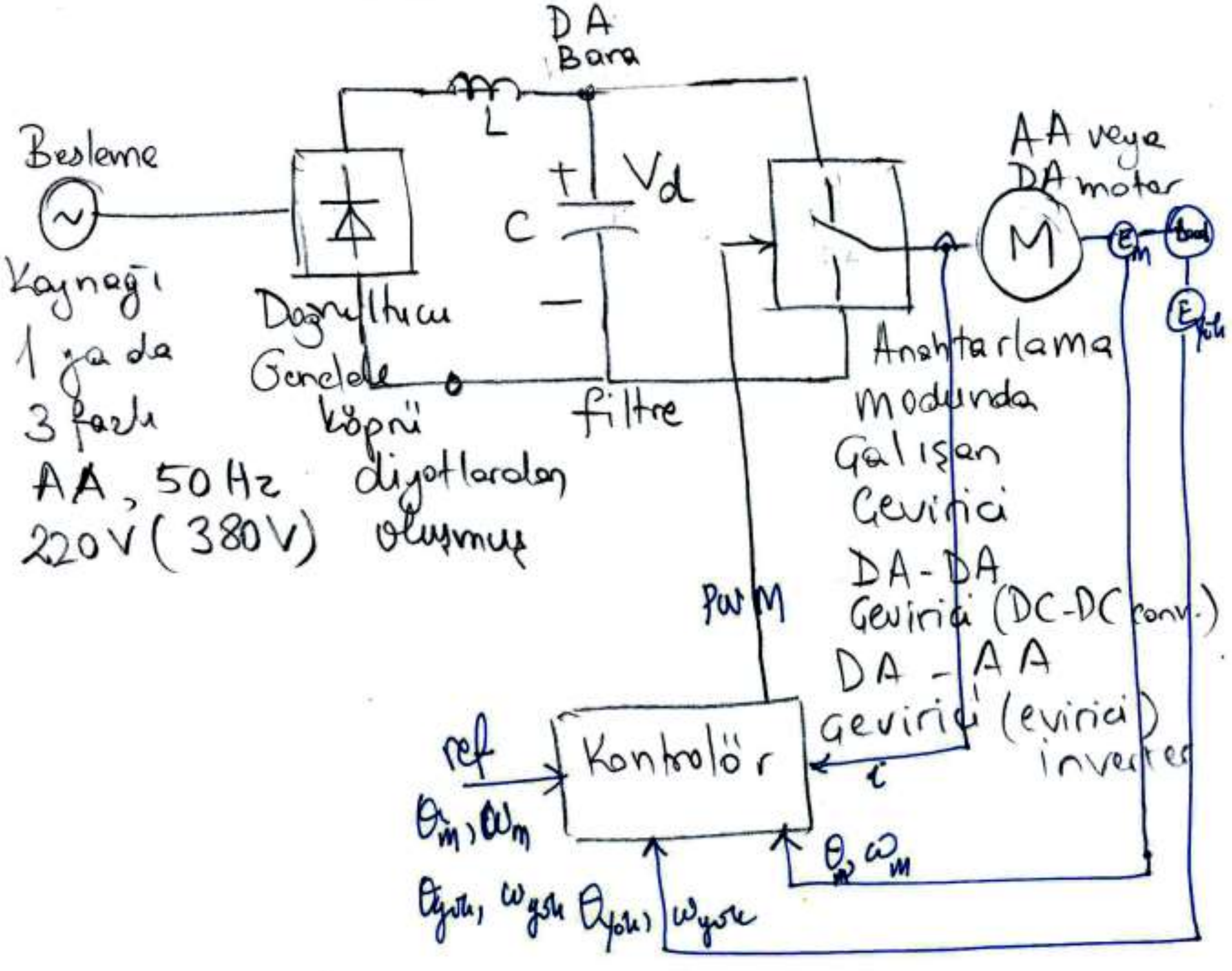
Switched mode inverters for DC and AC motors



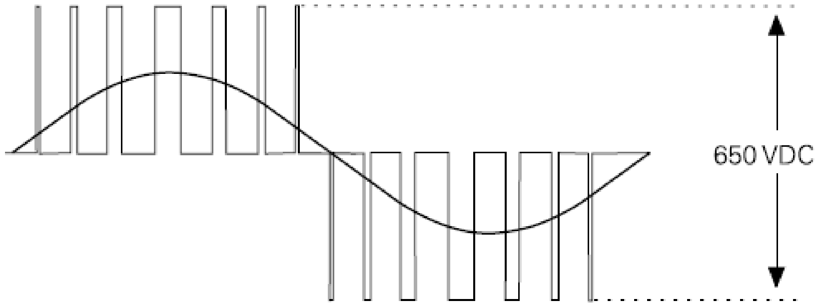


Power electronics circuit inverter that produces variable amplitude and frequency fed from a DC source

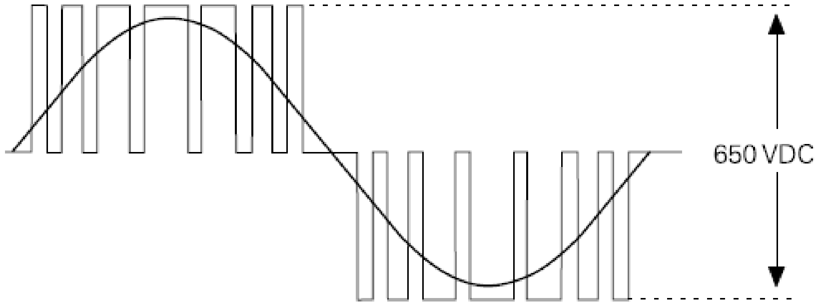

AC
M
motor
A
B
C
Controller
BLDCM
PMSM



DA Bara
L
Besleme
Kaynağı
1 fazda
3 fazlı
AA, 50 Hz
220V (380V)
Doğrultucu
Genelde
köprü
diyotlardan
oluşmuş
C
+
V_d
−
filtre
AA veya
DA motor
M
E_m
Load
$E_{yük}$
Anahtarlama
modunda
Çalışan
Çevirici
DA - DA
Çevirici (DC-DC conv.)
DA - AA
Çevirici (evirici)
inverter
PWM
ref
Kontrolör
i
θ_m, ω_m
$\theta_{yük}, \omega_{yük}$
θ_m, ω_m
$\theta_{yük}, \omega_{yük}$



Shorter "On" Duration, Lower Voltage



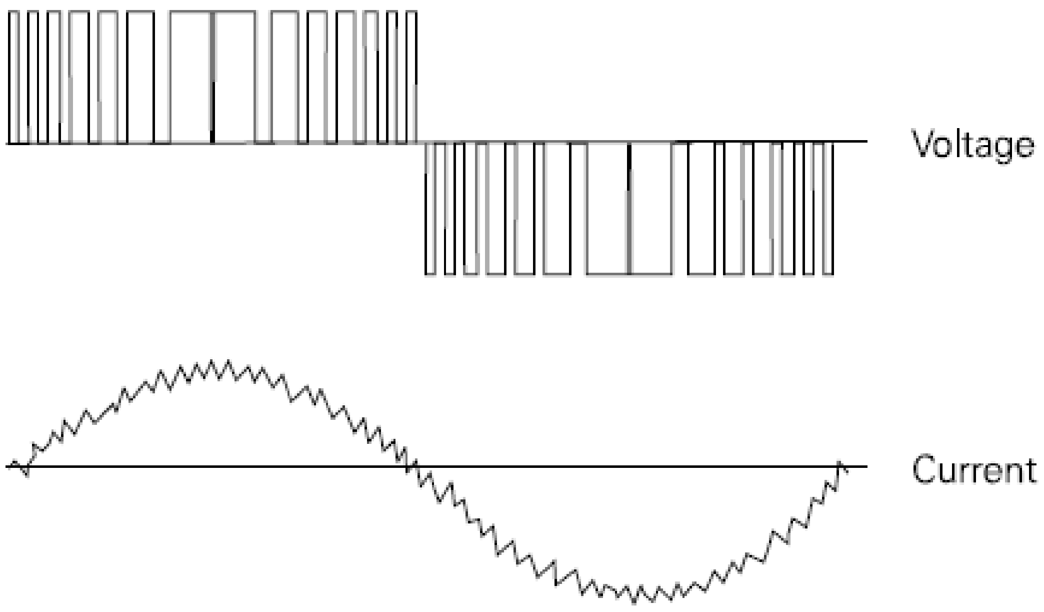
Pulse Width Modulation (PWM) in Power Electronics

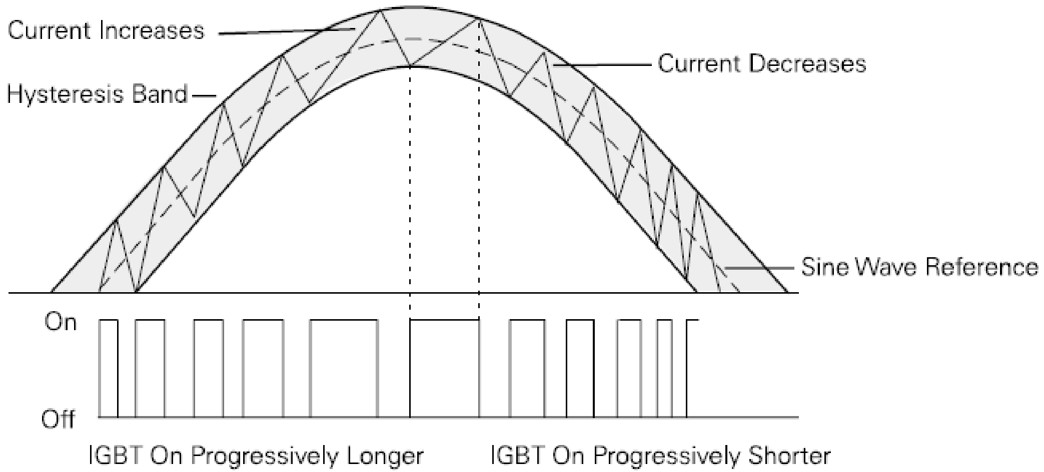
PWM is a versatile method widely used in power electronic circuits to control the power delivered to electric motors, including servo motors. It involves varying the width of pulses in a pulse train to control the average power delivered to a load.

Principle of PWM: The basic idea behind PWM is to switch the power supplied to a device on and off at a rapid rate. By adjusting the duration (or width) of the 'on' time in each cycle, the effective power output can be precisely controlled.

Application in Servo Motor Control: In servo motor control systems, PWM allows for fine control of the motor's speed and torque by adjusting the voltage and current fed to the motor. The rapid switching of the power transistor elements (like IGBTs, MOSFETs) in the PWM method can efficiently regulate the power without significant losses.

Exclusion of Thyristors: It's important to note that thyristors (used in source commutated circuits) are not typically driven using PWM. This is because thyristors, once triggered, remain conducting until the current through them falls to zero. Instead, PWM is more suited for devices that can be turned on and off with control signals, such as IGBTs, MOSFETs, or BJTs.


Voltage
Current


Current Increases
Hysteresis Band
Current Decreases
Sine Wave Reference
On
Off
IGBT On Progressively Longer
IGBT On Progressively Shorter

Advantages of PWM

Efficiency: PWM is highly efficient as it minimizes power loss in the switching devices.

Control Precision: It provides precise control over the motor's operation, which is essential in applications requiring exact positioning and speed control.

Flexibility: PWM can be easily adapted for different control strategies and is compatible with digital control methods.

Implementation: In practice, PWM is often implemented using microcontrollers or digital signal processors (DSPs), which generate the PWM signals based on the control algorithm requirements. These signals then drive the power transistors in the motor control circuitry.

Sensors

Types of Sensors in Motor Control Systems

1. **Position Sensors**
    1. **Potentiometers**: Used for basic position sensing. They provide a variable resistance proportional to the position.
    2. **Optical Rotary Encoders**: Offer high precision by using light to detect the movement of a disk with coded patterns.
    3. **Resolvers**: Similar to encoders but use electromagnetic induction to detect the position. They are robust against environmental factors like dust and moisture.
2. **Speed Sensors**
    1. **DC Tachometers (DC Generators)**: Generate a voltage proportional to the rotational speed of the motor, providing real-time speed feedback.
3. **Current Sensors**
    1. **Shunt Resistors**: Provide a low-resistance path for current measurement, translating the measured voltage drop across the resistor to current.
    2. **Current Transformers**: Used for measuring alternating currents, offering isolation and safety in high-current applications.
    3. **Hall Effect Current Sensors**: Utilize the Hall effect to measure current flow, offering electrical isolation and suitability for both AC and DC currents.
4. **Torque Sensors**
    1. These sensors measure the torque on a rotating system, such as a motor shaft, either directly or indirectly.
5. **Proximity Sensors**
    1. **Limit Switches**: Mechanical switches that detect the presence or absence of objects.
    2. **Optical Proximity Switches**: Use light to detect objects without physical contact.

1. **Load Sensors**
    1. **Strain Gauges**: Measure the strain on an object, often used for weight measurement.
    2. **Semiconductor Force Strain Gauges**: Provide higher sensitivity and are used in precision load measurements.
    3. **Force Sensors**: Directly measure the force applied to an object.
2. **Pressure Sensors**
    1. Used to measure the pressure of gases or liquids.
3. **Temperature Sensors**
    1. **Bimetal Temperature Sensors**: Use two metals with different expansion rates to measure temperature.
    2. **Thermocouples**: Measure temperature using the junction of two different metals.
    3. **Resistance Temperature Detectors (RTDs)**: Use the resistance changes in a material due to temperature changes.
    4. **Thermistors**: Similar to RTDs but use semiconductor materials.
    5. **IC Temperature Sensors**: Integrated circuits designed for temperature sensing, often with digital output.
4. **Fluid Flow Sensors**
    1. **Orifice Plates, Venturis, and Pitot Tubes**: Measure the flow rate by inducing changes in fluid pressure.
    2. **Turbines**: Use a rotating turbine within the flow to measure fluid speed.
    3. **Magnetic Flowmeters**: Measure the flow rate of conductive fluids using a magnetic field.
5. **Liquid Level Sensors**
    1. Can be either discrete (indicating specific levels) or continuous (providing a continuous measurement of the liquid level).

Feedback Devices

- Tachometers
- Hall Sensors
- Encoders
- Resolvers

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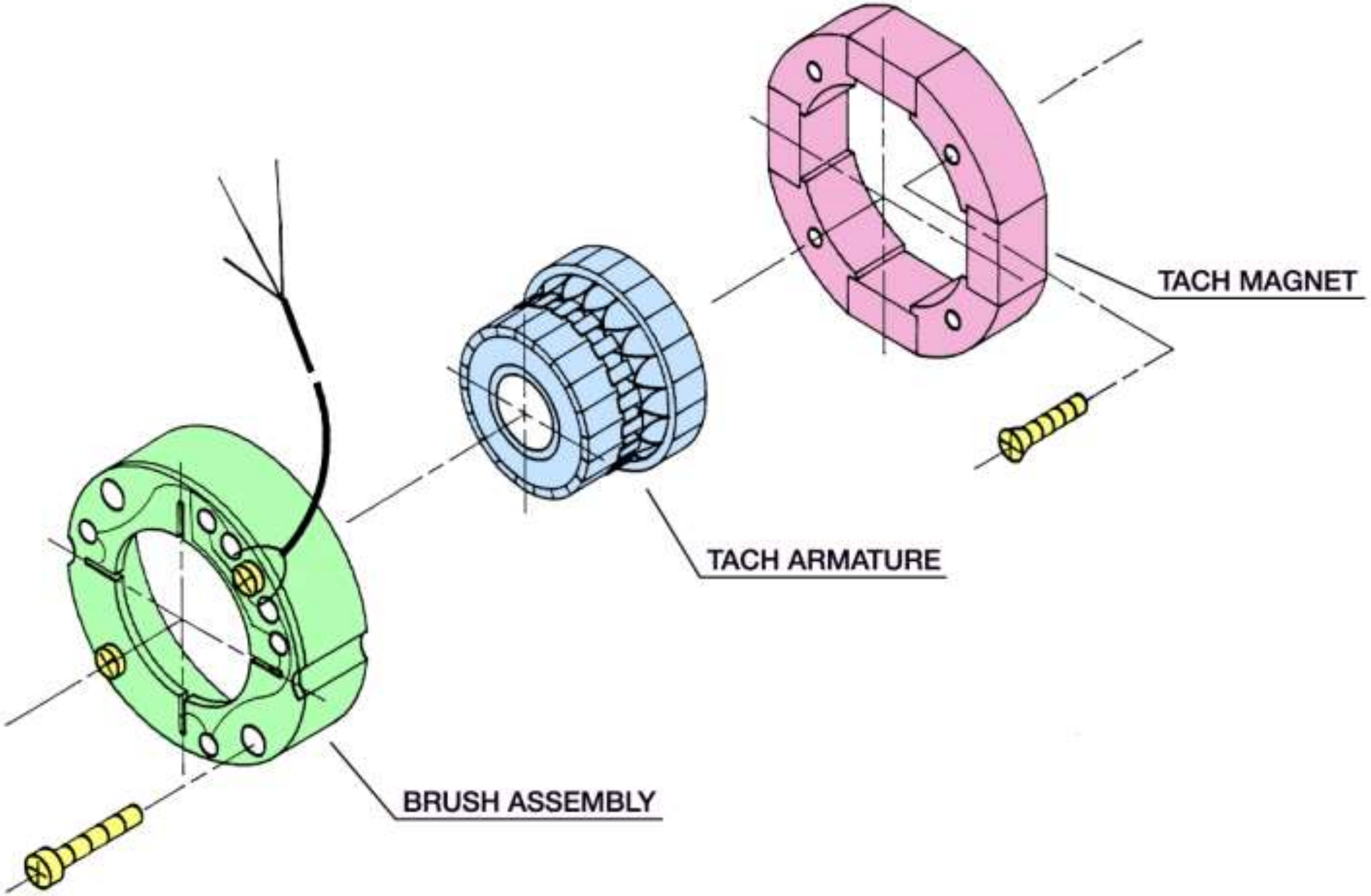
Tachometer Assembly



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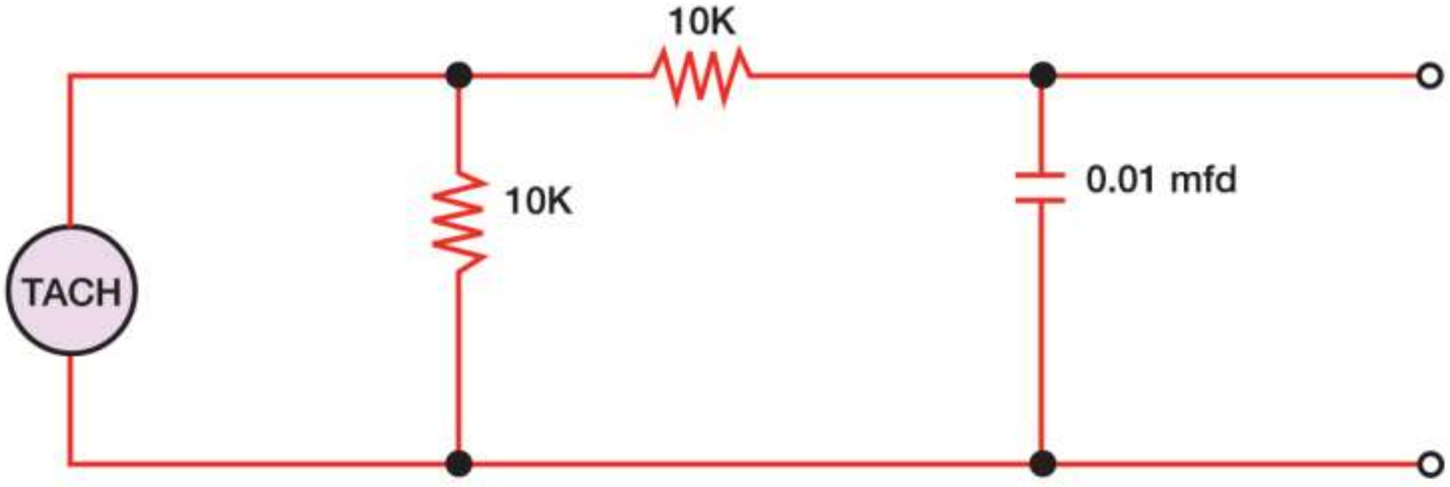
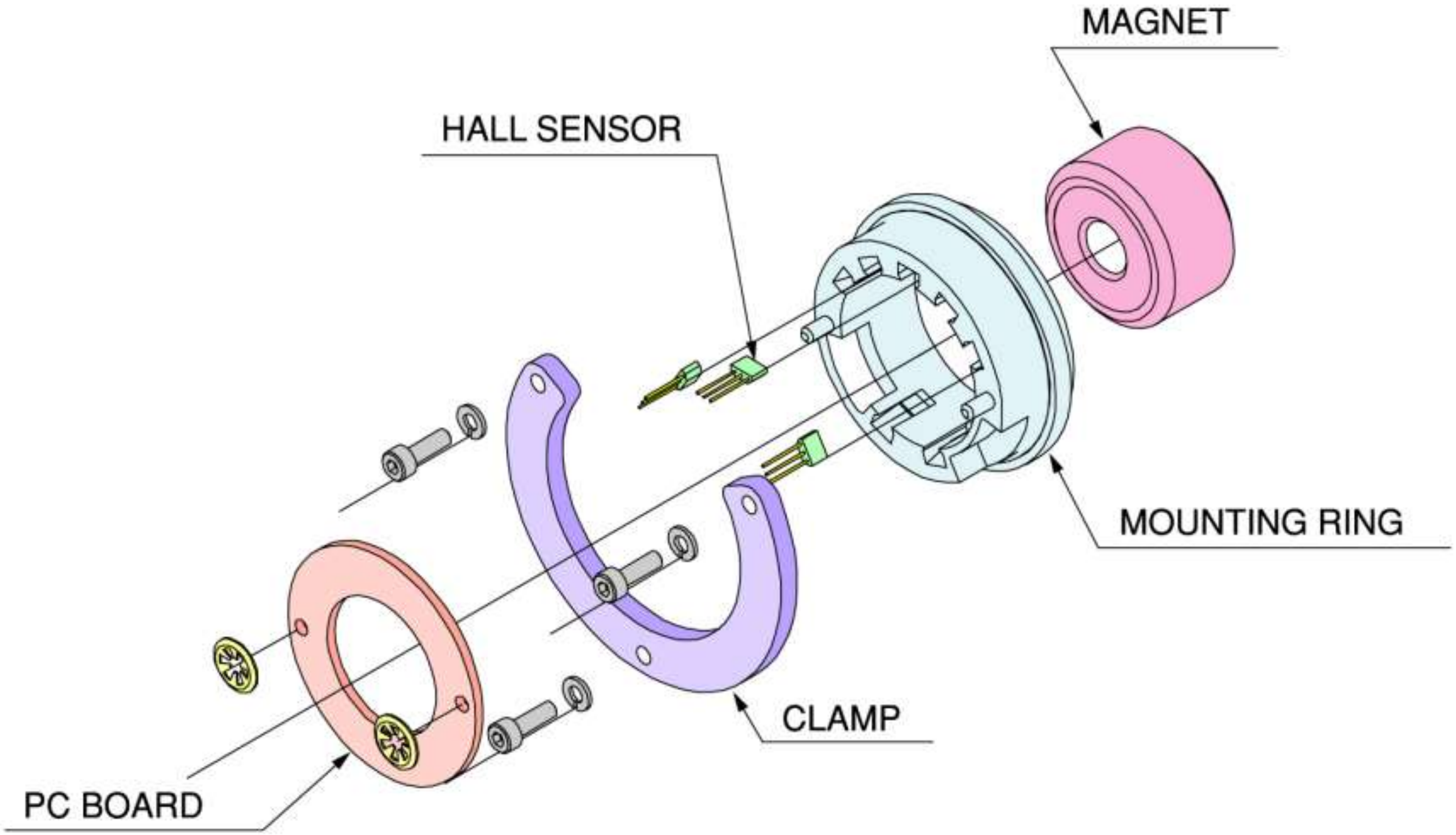
Tachometer Terminology

- Voltage Constant
- Ripple
- Linearity
- Max Speed
- Min Load
- Temperature Stability

Tachometer Filter



Hall Sensor



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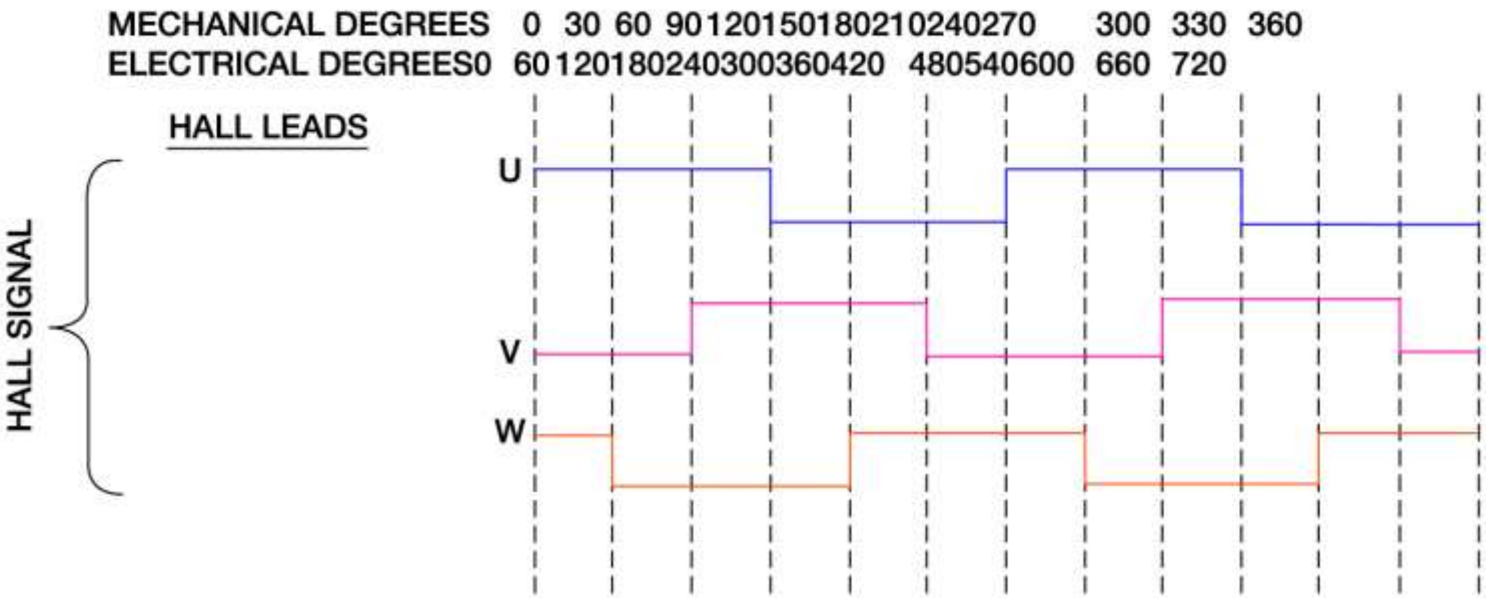
Hall Sensors



Hall Effect Sensors for Current Measurement

Principle of the Hall Effect:

The Hall effect is a phenomenon observed in a semiconductor material when it is placed in a magnetic field while an electric current is flowing through it. This results in the generation of a voltage perpendicular to both the current and the magnetic field.

In the context of current sensors, this effect is used to measure the current flowing through a conductor without direct electrical contact.

Operation of Hall Effect Current Sensors:

Primary Current (Ip): This is the current to be measured. It flows through a primary conductor, which can be an integral part of the sensor or an external conductor around which the sensor is placed.

Magnetic Field and Semiconductor Material: As the primary current (Ip) flows, it creates a magnetic field. This field interacts with the semiconductor material in the Hall sensor.

Hall Voltage Generation:

Due to the Hall effect, a voltage (Hall voltage) is generated across the semiconductor material, perpendicular to the direction of both the magnetic field and the primary current.

Electronic Circuitry:

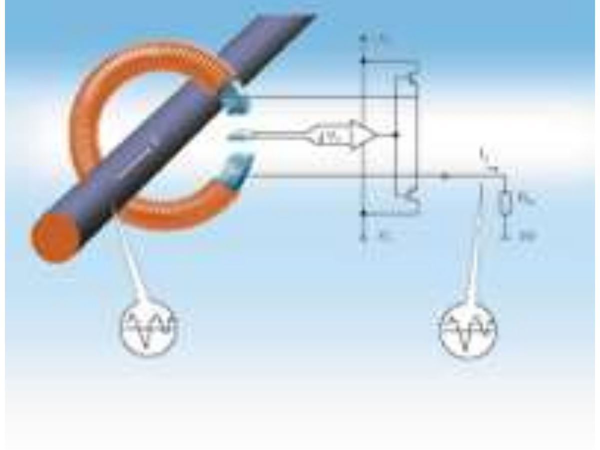
The Hall voltage is typically very small and requires amplification. An associated electronic circuit processes this voltage, amplifying and conditioning it to produce an output voltage proportional to the primary current.

Implementation in Measurement Circuits:

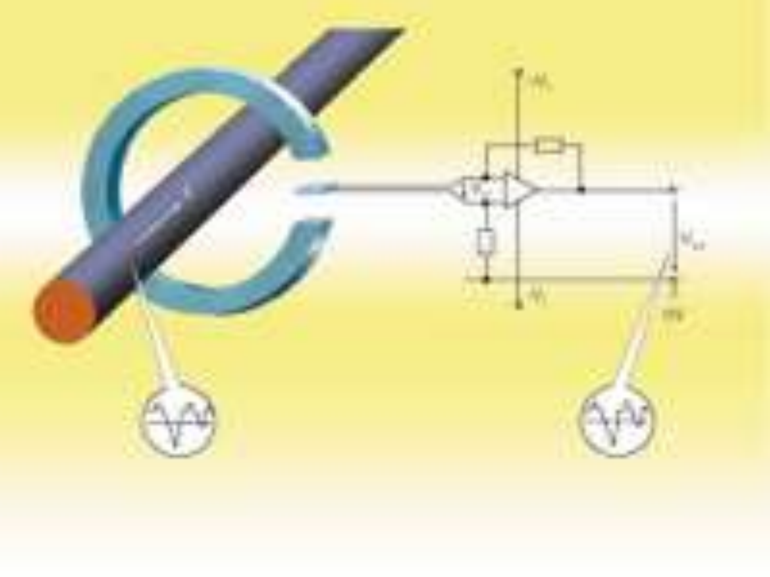
Voltage Measurement Using Series Resistors: When measuring voltage, the current through the primary winding can be controlled using two series resistors connected to the terminals of the voltage source. The current through these resistors creates a magnetic field, which is then used to generate a Hall voltage in the sensor.

Feedback and Calibration: The output voltage from the Hall effect sensor is calibrated to ensure that it accurately represents the primary current or voltage being measured.

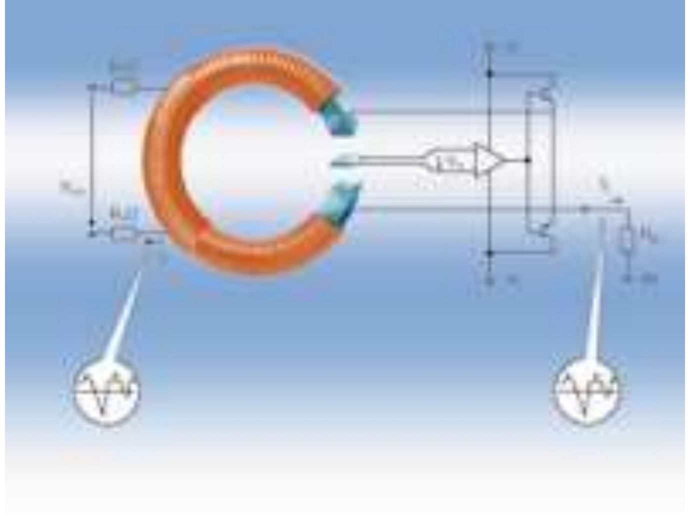
Closed-loop Current Sensor



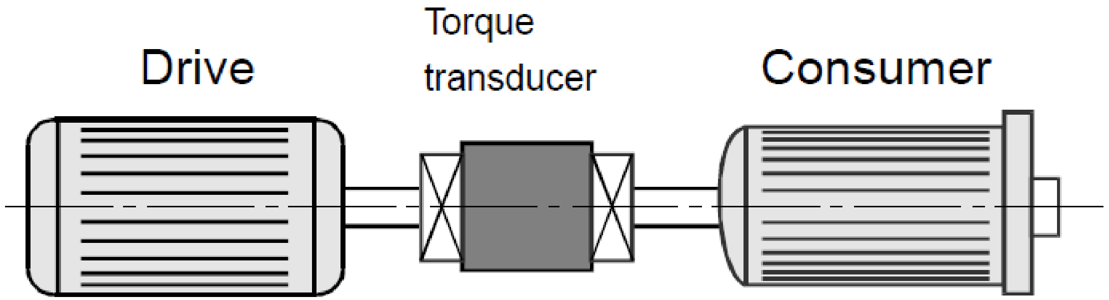
Current Sensor



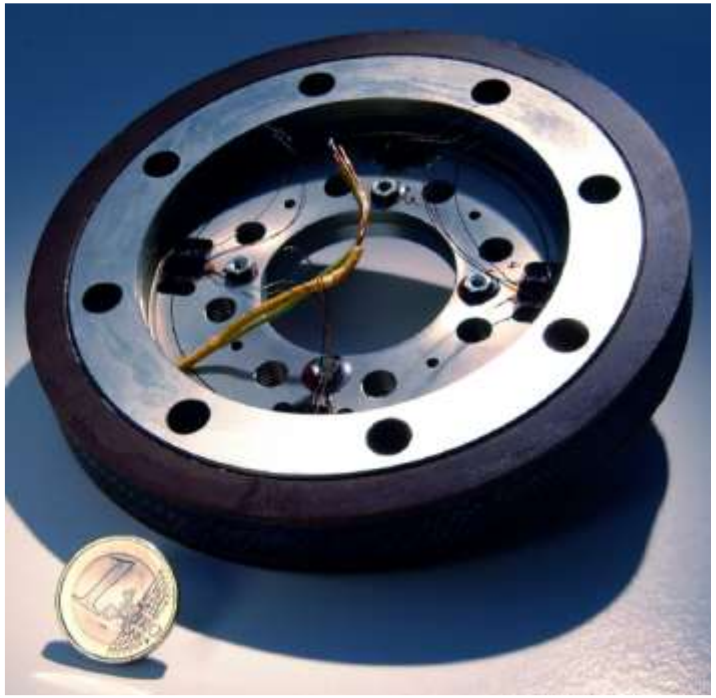
Voltage Sensor

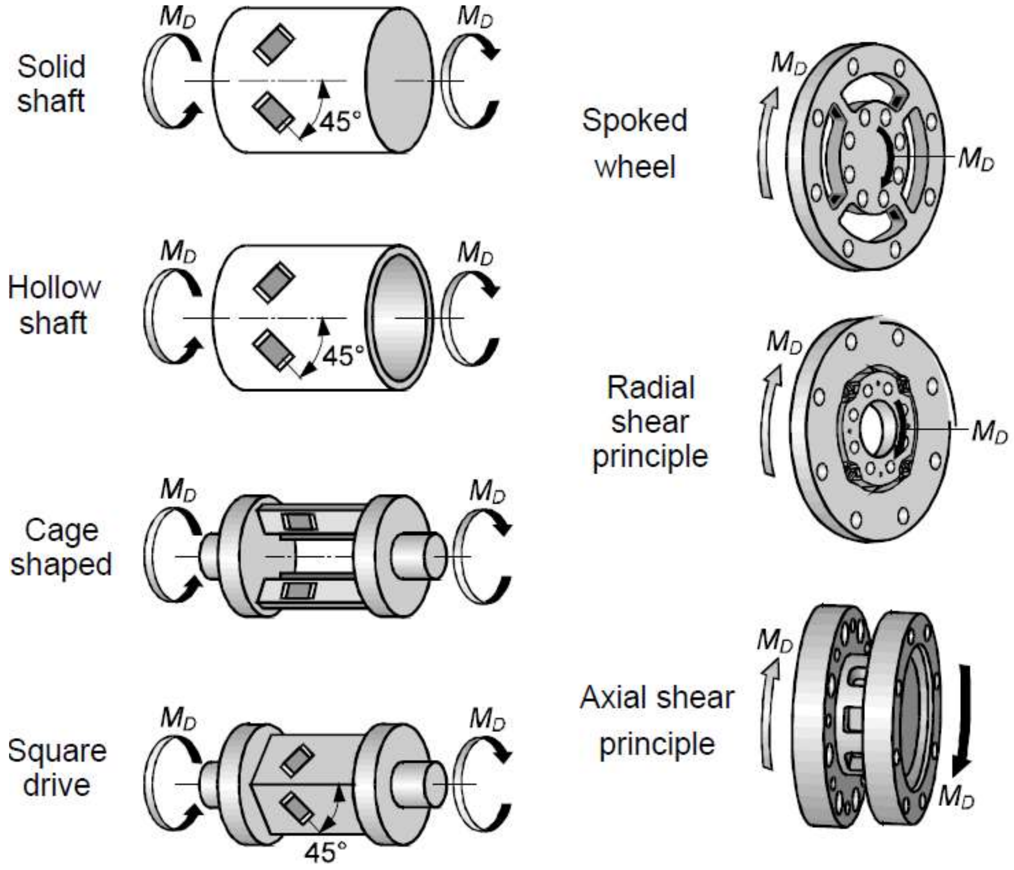


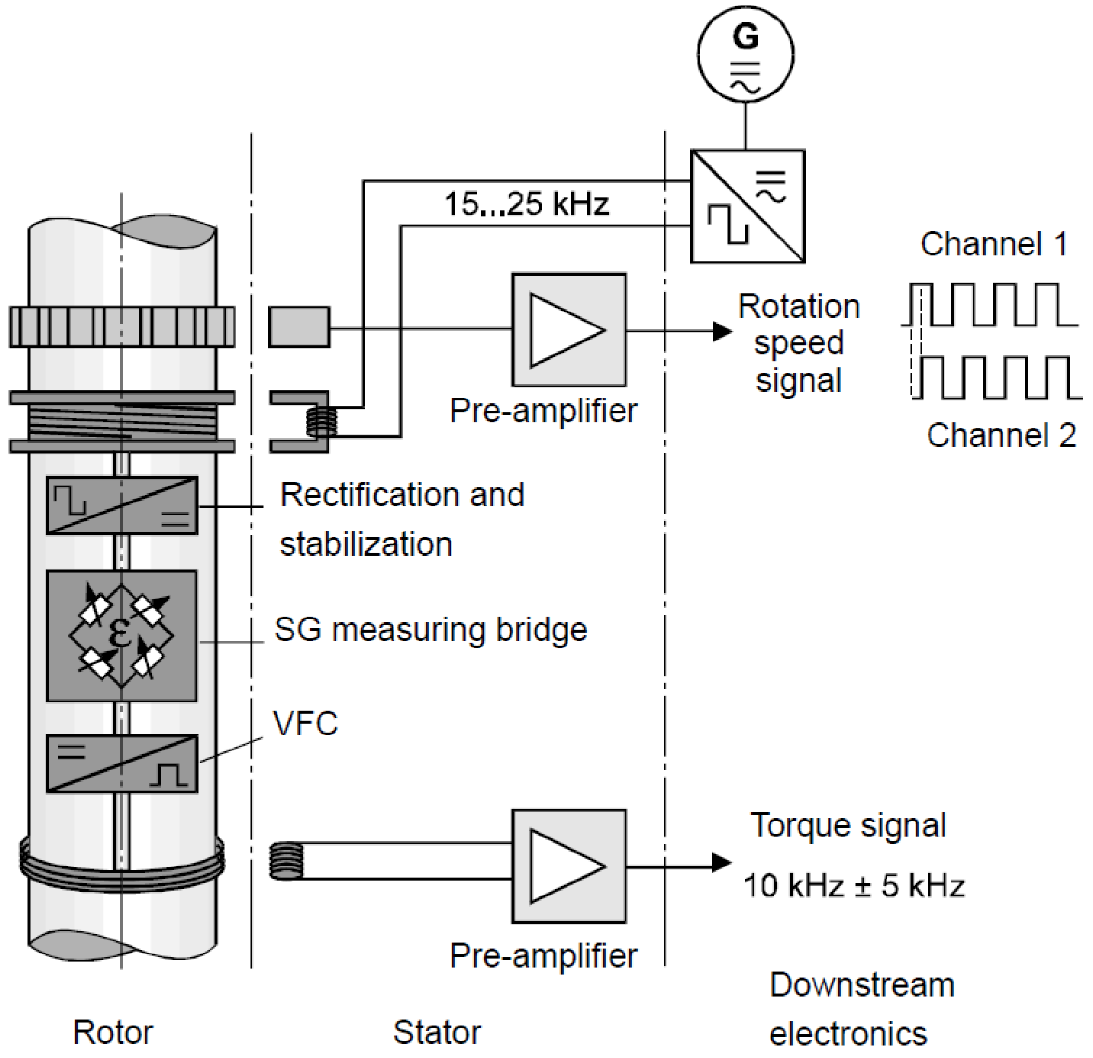
Torque Transducers

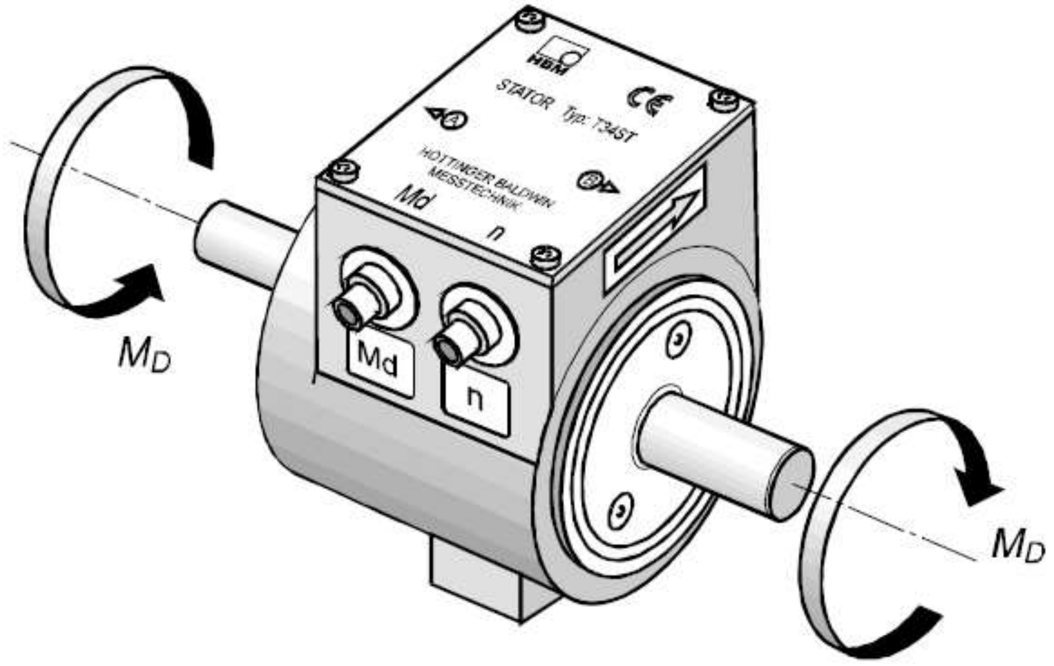


Torque transducer located in the train of shafts

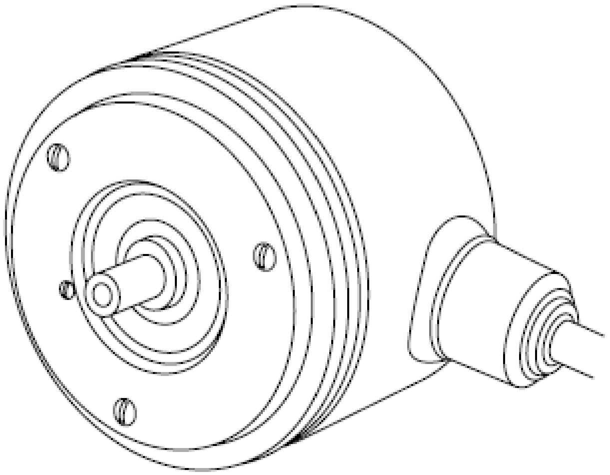


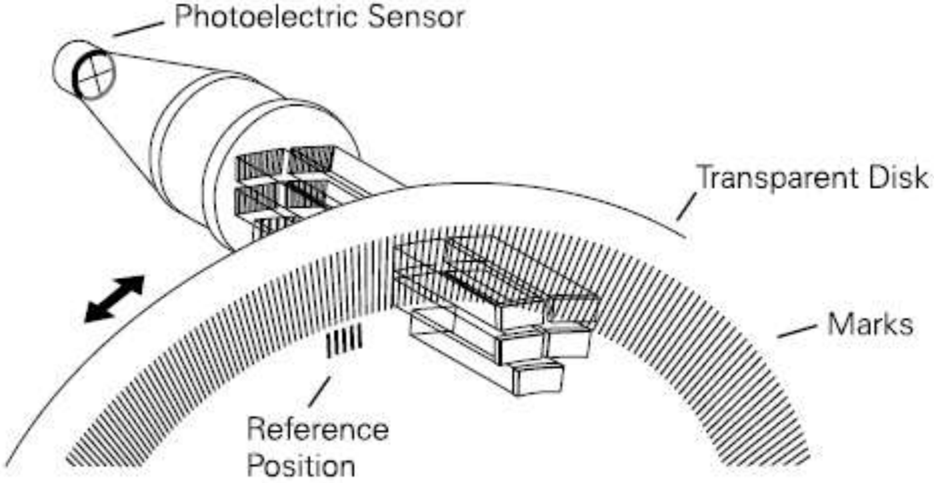


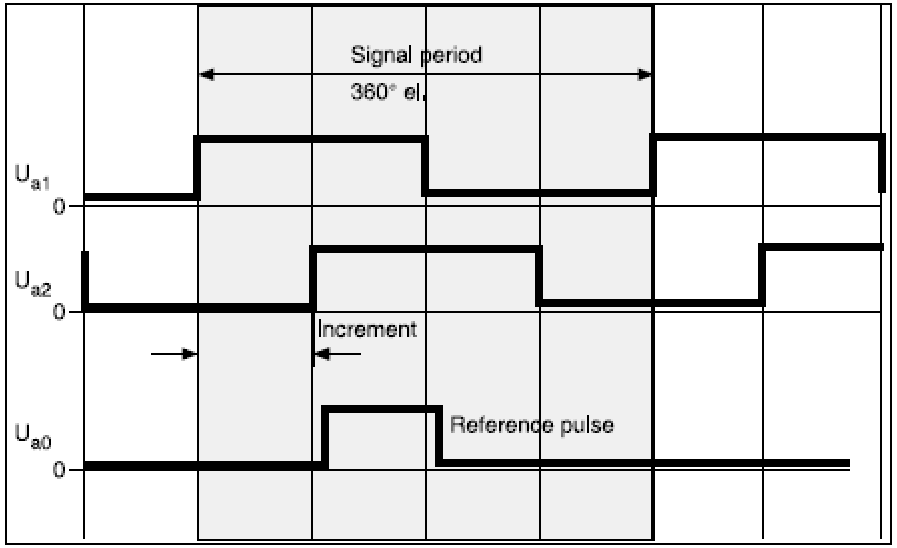

G
15...25 kHz
Channel 1
Rotation speed signal
Channel 2
Pre-amplifier
Rectification and stabilization
SG measuring bridge
VFC
Torque signal
10 kHz ± 5 kHz
Pre-amplifier
Downstream electronics
Rotor
Stator

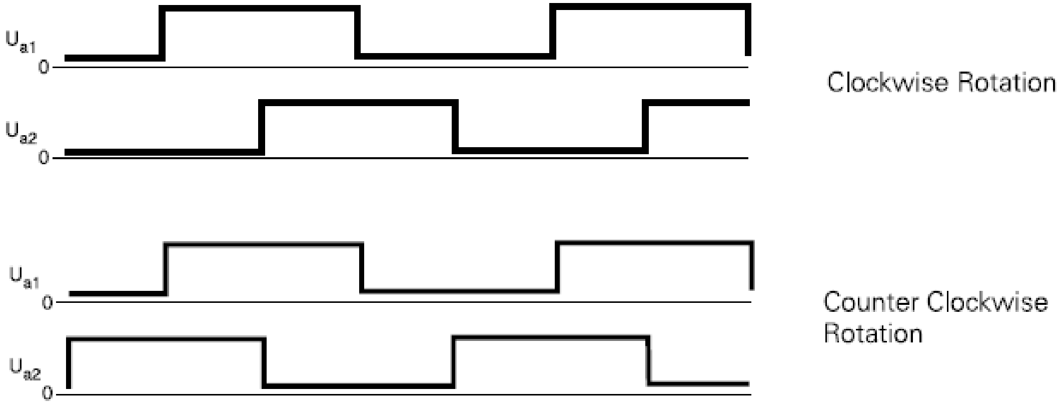

HBM
STATOR Typ: T34ST
HOTTINGER BALDWIN MESSTECHNIK
Md
n
Md
n
M_D
M_D

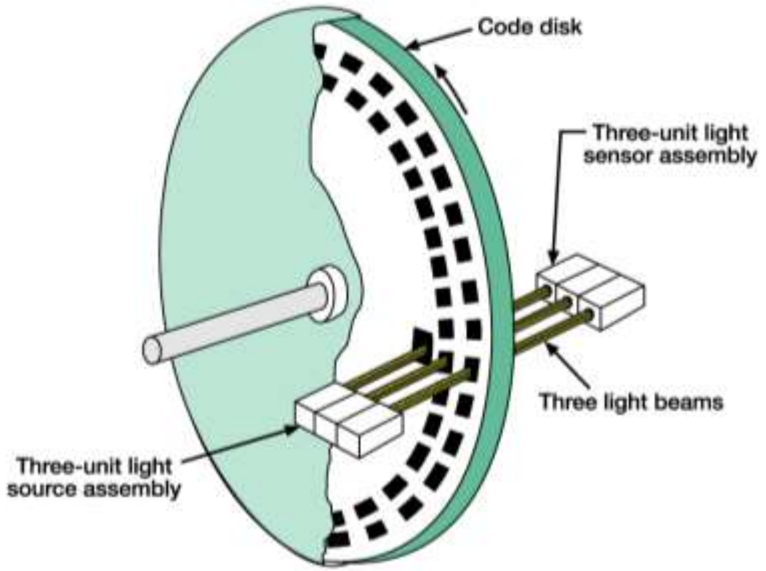
Incremental Encoders

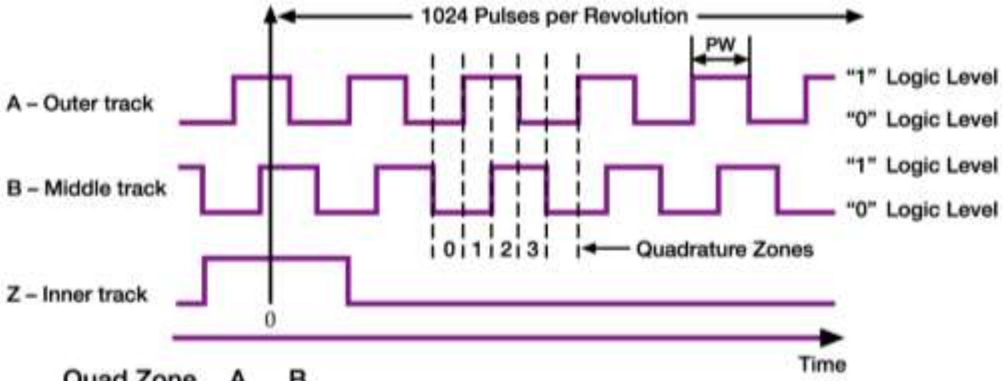






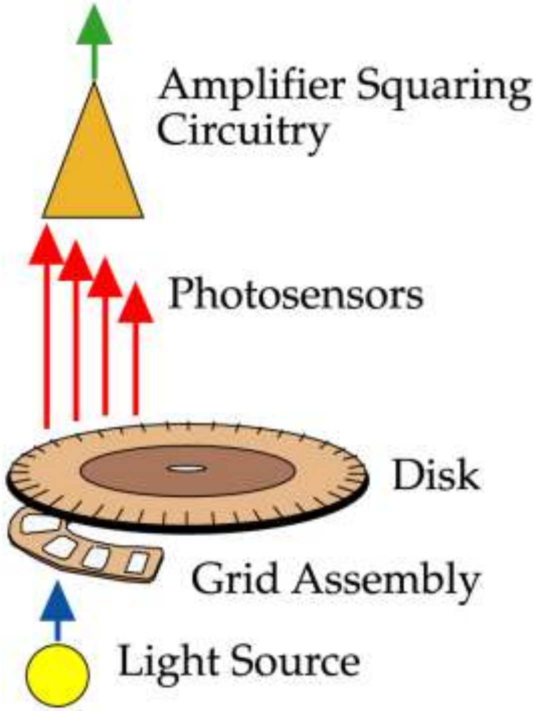


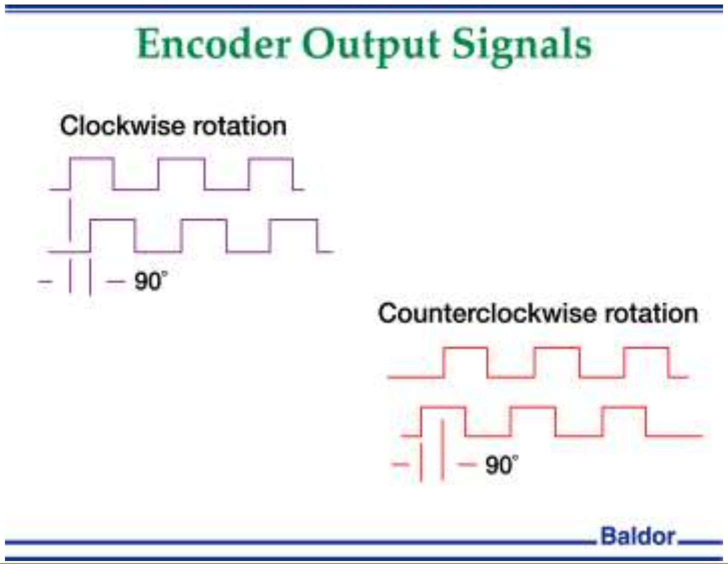




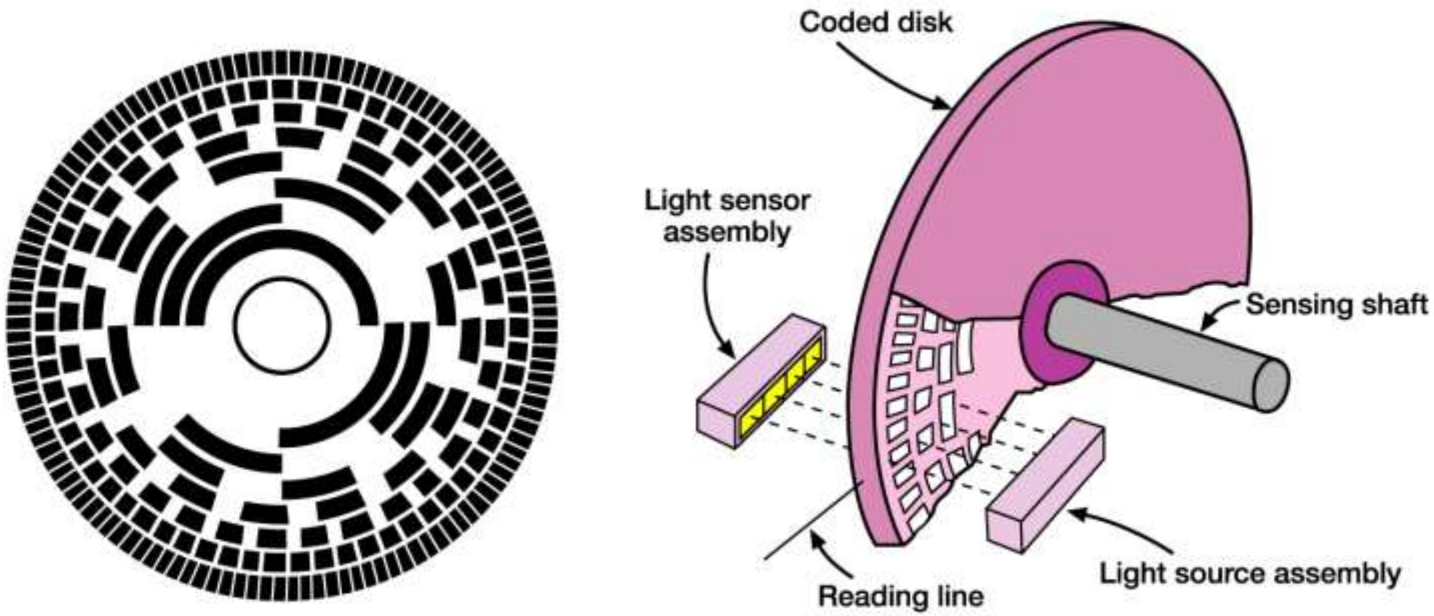
Quad Zone	A	B
0	0	0
1	1	0
2	1	1
3	0	1

Pattern Repeats 1024 Times/Revolution



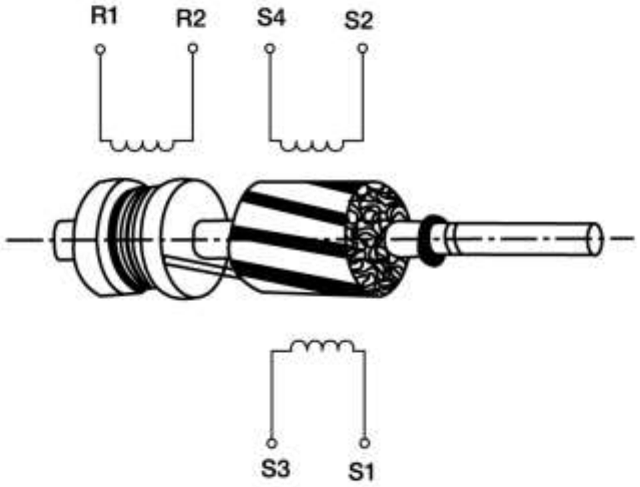


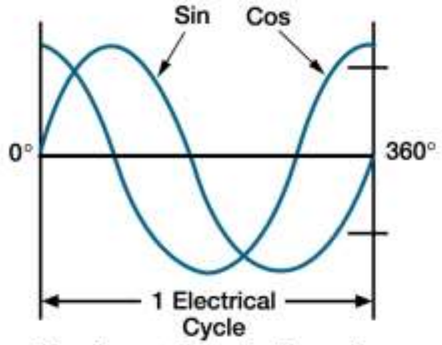
Absolute Optical Encoder



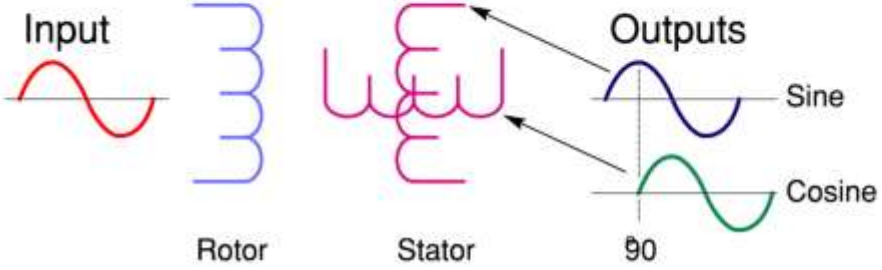
(a) (b)

Resolver





Waveforms from windings of a resolver. Note that forms are always 90° out of phase.



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Summary of Feedback Devices

	Tachometer	Halls	Incremental Encoder	Absolute Encoder SSI	Resolver
Used for	Speed measurement	Electronic commutation	Position, Electronic commutation, Speed	Absolute position, Electronic commutation, Speed	Position, Electronic commutation, Speed
Output	Voltage proportional to speed	On/Off signals	On/Off train pulses	Serial communication	Sinusoidal signal
Output PPR	N/A	6	2500	2048 EnDat 131072 SSI	4096
Accuracy	± 1% set speed	60 degrees	± count	± count	± 10 count
Durability	Good	Good	Good	Good	Best
Advantages	Low cost	Lowest cost, No parts to wear	Digital output works easily electronics	Absolute position, digital output, remembers position	No electronic inside, withstands higher temperature