SERVO MOTORS AND MOTION CONTROL SYSTEMS (Introduction&General Information-Lecture 1)

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A **servomechanism (servo)** is an automatic device that uses feedback to correct the performance of a mechanism (position control system).

An actuator that is used as a servo motor can be:

- Electrical (most common)
- Hydraulic
- Pneumatic

- Electrical motors are the most common servo motors compared to hydraulic and pneumatic.
- Hydraulic motors are used where excessive force is needed and pneumatics are used where there is a fire and/or explosion hazard
- In this class, electrical servo motors are the main focus.

What is a servo motor?

- A servomotor is a rotary actuator that allows for precise control of ***angular position, velocity, and acceleration.***
- It consists of a suitable motor coupled to a ***sensor for position feedback.*** It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors.
- Servomotors are not a specific class of motor although the term servomotor is often used to refer to a motor suitable for use in a ***closed-loop control system.***
- Servomotors are used in applications such as robotics, CNC machinery, or automated manufacturing.

Servo motors, quintessentially, serve as drive elements or actuators in position control or servo systems. These systems are integral to a vast array of applications, ranging from robotics to aviation and automotive industries. The evolution of these motors from DC to AC types, especially with the advent of high-power MOSFETs and IGBTs, marks a significant technological leap. Nowadays, permanent magnet brushless synchronous motors are increasingly supplanting DC motors in many servo applications.

Key Components and Their Functions:

Controller: The brain of the position control system, often a microcontroller or a DSP-based digital system, executes position control algorithms.

Sensor/Detector: Vital for feedback, these are usually linked mechanically to the motor shaft. Devices like incremental encoders and resolvers play a crucial role in measuring the position and/or speed of the servo motor.

Mechanical System: This encompasses the mechanical load on the motor shaft and its subsystems, crucial for translating the motor's rotational motion into the desired mechanical action.

Driver/Power Amplifier: These amplify control signals and channel them to the motor's windings, with the circuitry often comprising IGBTs, power transistors, or power MOSFETs.

Characteristics and Control:

It's noteworthy that a significant portion of electrical energy is consumed by systems converting electrical to mechanical energy. Servo motors, in particular, are essential in applications requiring adjustable ***speed and torque***.

Servo motors are characterized by their ***high torque-to-inertia ratio, peak torque capacity, and ability to achieve swift speeds with rapid acceleration and deceleration.*** Furthermore, they can operate at zero speed without thermal issues.

The concept of servo control, also known as motion control or robotics, is fundamental in industrial setups. These systems, whether pneumatic, hydraulic, or electromechanical, are selected based on ***power, speed, precision, and cost*** considerations.

Electromechanical systems, favored for their ***flexibility, efficiency, and cost-effectiveness***, are widely used for high-precision, medium-power, and high-speed tasks.

Feedback Mechanism:

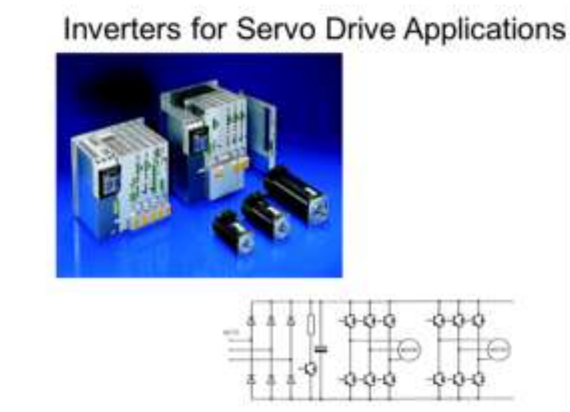
Servo systems rely on feedback mechanisms to control position, velocity, or acceleration. Controllers and drives contain algorithms for loop regulation, and managing machine interfaces. Drives or amplifiers act as power converters based on controller signals. Feedback devices like encoders and resolvers are critical for maintaining loop integrity.

Advanced Motion Controls:

This area of servo technology focuses on crafting servo drives and amplifiers for precision-demanding motion control applications. These drives transform low-energy controller signals into high-power outputs, dictating motor voltage and current. The shift towards digital drives in some scenarios reflects ongoing advancements in this field.


State of the Art: AC Servos
High Speed Spindle
(Siemens)
DSD Servo
(Baumüller)
High Torque Motor
(Baumüller)
Spindle Motor
(Franz Kessler)

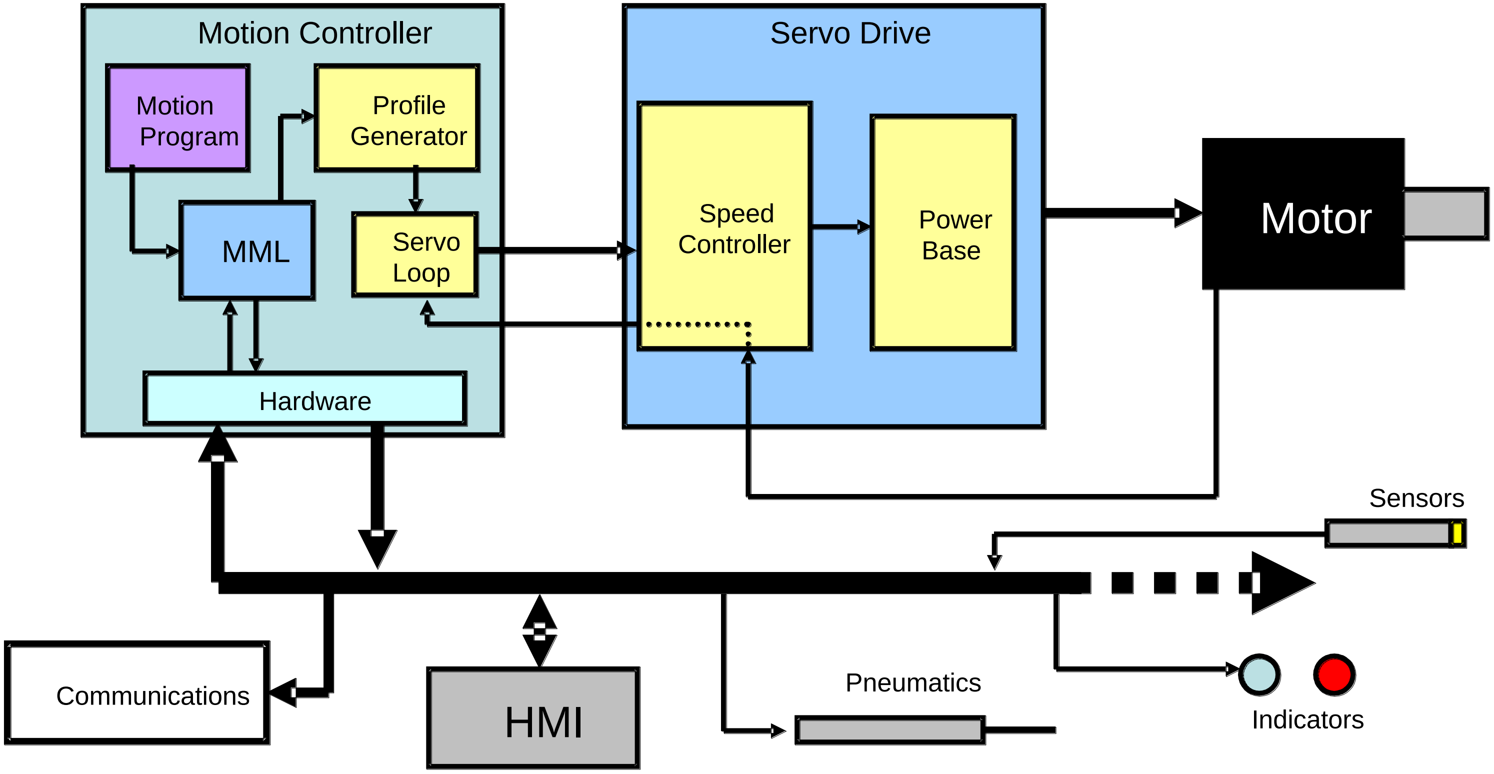

Encoders
Advantages
• low cost
• high accuracy
Disadvantages
• elastic effects
and back lash


Inverters for Servo Drive Applications

A Servo Is . . .

Servo Mechanism

A system of devices used to control the position, direction, and/or speed of a load.



The elements of the position control system

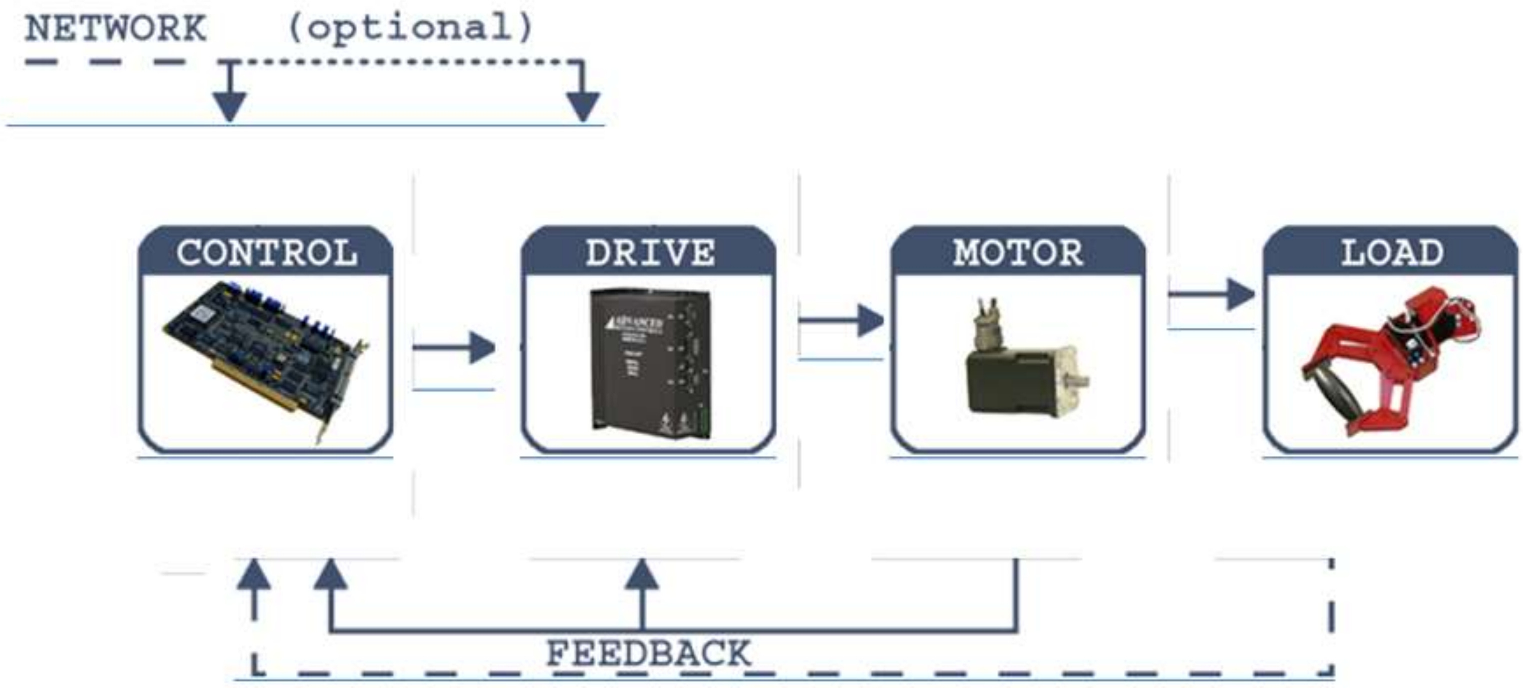
Controller (Commonly, a microcontroller or DSP-based digital system)

Sensor and transducer (Usually coupled to the shaft of the motor: incremental or absolute encoder, resolver, etc., measures the speed or position of the shaft)

A mechanical system (Load, gearbox, belt, pulley, pinion and rack, ballscrew for linear motion, four-bar linkage). The motor shaft is mounted to the mechanical load

Power Amplifier, driver (IGBT, power transistor, or power MOSFET-based power electronic circuit to energize servo motor windings). Varies based on the motor type (structure and power)

Motor (DC or AC servo motors)


NETWORK (optional)
CONTROL
DRIVE
MOTOR
LOAD
FEEDBACK

Controllers

Definition and Functions

Central Intelligence: The controller is the brain of a servo system, responsible for generating ***motion paths*** and ***adapting to external changes.***

Key Functions: It directs movement through signals sent to the drive and analyzes feedback from the motor and load, adjusting the system accordingly. Controllers can close velocity and position loops, a task sometimes performed by amplifiers.

Types

Microcontrollers: These are cost-effective and require expert programming, often used for delegating loop closures to the amplifier.

Programmable Logic Controllers (PLCs): Evolved for simplifying relay circuits, PLCs are more robust and versatile than microcontrollers and allow for modular expansion.

Motion Controllers: Specifically designed for motion control, these controllers provide user-friendly interfaces and advanced tuning capabilities, albeit at a higher cost.

Other Types: This includes connections like CANopen, Synqnet, USB, and RS232, which enable direct computer amplifier connections for more sophisticated control.

The Drive (Servo Amplifier)

Role and Evolution

The drive, or servo amplifier, is responsible for converting controller signals into power signals for the motor. Modern drives, in contrast to initial models, power brushless motors and are capable of closing multiple loops, handling feedback mechanisms, and increasingly integrating controller functions.

Industry Demands

There is a growing demand for higher bandwidth, improved velocity and position control, enhanced networking for synchronized operations, and user-friendly universal operation.

The Motor

Purpose and Types

Purpose: To transform electrical energy from the drive into mechanical motion.

Types

Single Phase: Includes simple motors like brushed motors. Utilizes brushes for mechanical commutation.

Magnetic Bearing: Employs electromagnets for levitation, eliminating physical contact.

Three Phase: Comprises brushless rotary and linear motors for high-performance applications.

Load Considerations

The load encompasses the object being moved, the machinery's moving parts, and potential instabilities. **Factors like inertia, friction, and resonances contribute to the motor load** and must be considered for **efficient operation.**

Feedback Mechanisms

Absolute Feedback: Provides a definitive position within a range without movement.

Relative Feedback (Incremental): Offers position updates incrementally, requiring an absolute feedback source for actual positioning.

Common Feedback Devices

Encoders: Used widely for position feedback in motion control.

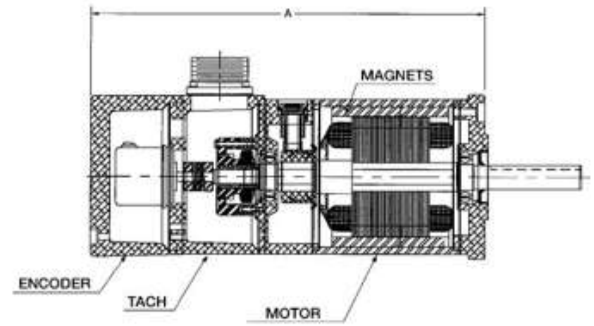
Hall Sensors: Provide low-resolution feedback, mainly for commutation control.

Resolver: Suitable for extreme environments, offering high resolution, temperature, and vibration resistance.

Servo mechanism

- Actuator (Servo Motor)

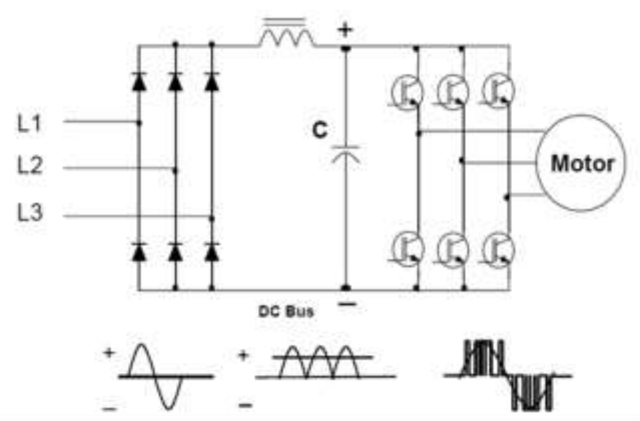
DC Servo Motor



Servomotor

(Baumüller, Shneider, Siemens, Rockwell, Baldor, Yaskawa, Mitsubishi, Beckhoff…)

- Servo Driver



Mechanism

Basic Servomotor Design

Position-Only Sensing

Mechanism: The simplest servomotors operate on position-only sensing, often using a potentiometer. This method allows for basic control of the motor, which either rotates at full speed or remains stationary.

Application: Although this type of servomotor is foundational, it is not widely used in industrial motion control. Its primary application is in simple and inexpensive radio-controlled models.

Advanced Servomotor Design

Enhanced Measurement and Control

Position and Speed Measurement: More sophisticated servomotors measure not only the position but also the speed of the output shaft.

Speed Control: Unlike basic models, these advanced motors can regulate their speed instead of always running at full throttle.

PID Control Algorithm

Integration: These enhancements are typically combined with a PID (Proportional-Integral-Derivative) control algorithm.

Benefits: This combination enables the servomotor to reach its commanded position more rapidly and accurately, minimizing overshooting.

Closed-Loop Servomechanism

Definition and Function

Servomechanism: A servomotor, as the name suggests, is a closed-loop servomechanism. This means it uses position feedback to control its motion and final position.

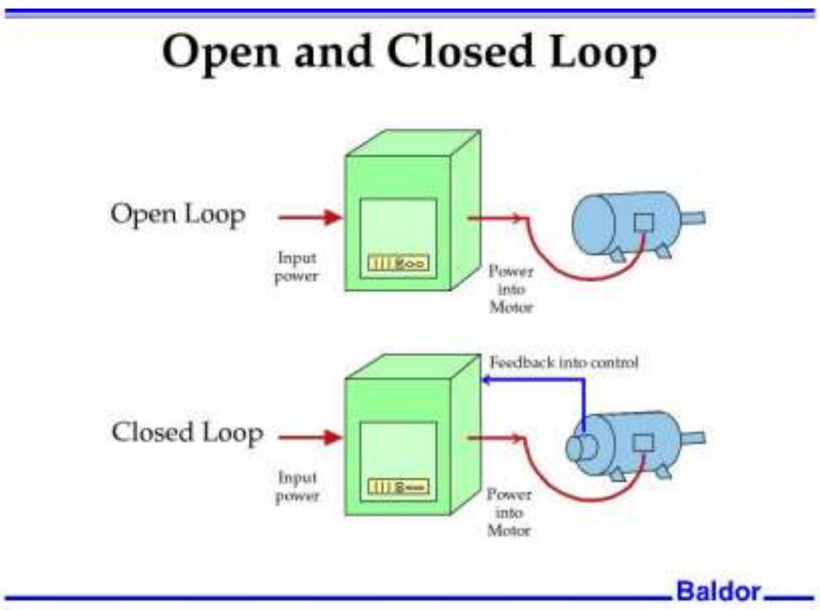
Control Input: The input to its control system can be either an analog or digital signal, representing the desired position for the output shaft.

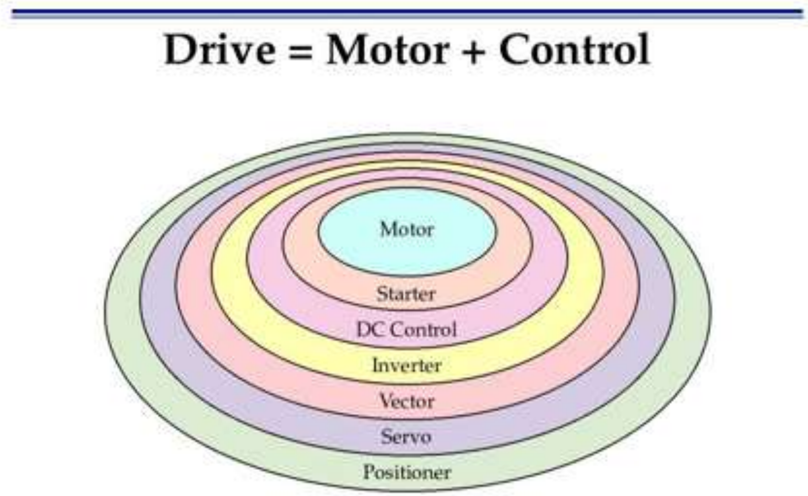
Encoder Pairing and Feedback Loop

Encoder Integration: The motor is paired with an encoder to provide position and speed feedback. In the simplest systems, only the position is measured.

Feedback Process: The measured position of the output is compared to the commanded position. If there is a discrepancy, an error signal is generated, prompting the motor to adjust its rotation to align the output shaft with the desired position.

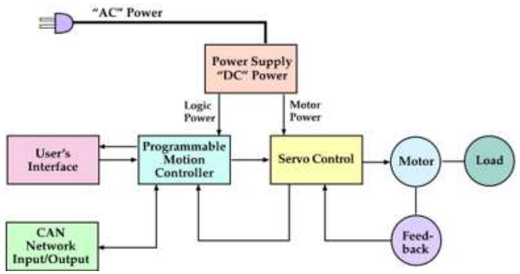
Error Signal Reduction: As the actual and commanded positions converge, the error signal diminishes, eventually reaching zero, at which point the motor halts.

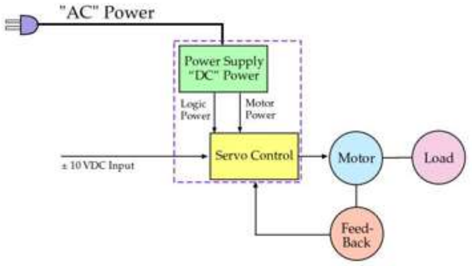

Open and Closed Loop
Open Loop
Input power
Power into Motor
Feedback into control
Closed Loop
Input power
Power into Motor
Baldor


Drive = Motor + Control
Motor
Starter
DC Control
Inverter
Vector
Servo
Positioner

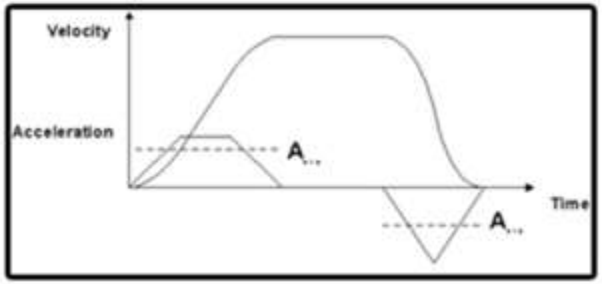
What Makes a Servo Motor Different . . .

- Diameter
- Feedback
- Manufacturing





Motion Profiles

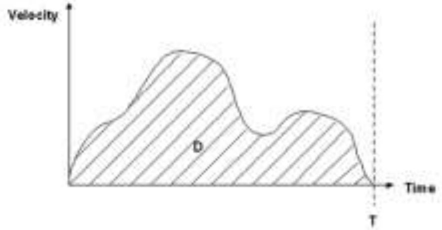


$$d(t) = \int_0^t v(t) \cdot dt$$

$$D = d(T)$$

$$a(t) = \frac{dv(t)}{dt}$$

$$v(t) = \int_0^t a(t) \cdot dt$$



Understanding Motion Profiles in Servo Systems

Definition and Importance

- **Fundamental Concept**: A motion profile is essentially the methodology by which a load is moved within a servo system.

- **Simple to Complex Movements**: It can range from a straightforward move from point A to point B along a single axis to complex, coordinated multi-axis movements.

Calculating Movement and Time

- **Distance Traveled (D)**: This is determined by calculating the area under the velocity-time curve.

- **Total Time Required (T)**: Refers to the duration needed for the complete movement.

- **Acceleration/Deceleration**: The slope of the velocity-time curve at any point signifies the acceleration or deceleration at that instant.

Types of Motion Profiles

1. Constant Velocity

1. **Characteristic**: Maintains a steady velocity between two points.
2. **Limitation**: This is a basic profile, typically not used in precision positioning machines due to real-world constraints like ***velocity change delays***, ***affected by load and system changes.***
3. **Representation**: The dotted line in a graph typically shows the actual velocity path, with ‘ta' and ‘td' indicating the times for acceleration and deceleration, which can vary with load fluctuations.

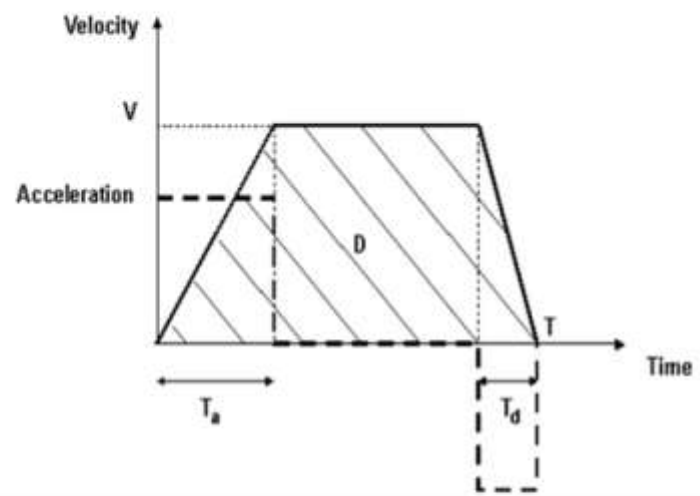
2. Trapezoidal

1. **Design**: Features a sloped velocity curve, establishing predictable acceleration and deceleration rates.
2. **Advantages**: It offers precise and repeatable acceleration/deceleration times, making it more reliable than the constant velocity profile.
3. **Specification**: Here, ‘ta' and ‘td' represent specified values, as opposed to the variable nature seen

$$D = V \cdot (T - \frac{t_a}{2} - \frac{t_d}{2})$$

$$accel = \frac{V}{t_a}$$

$$decel = \frac{V}{t_d}$$



Trapezoidal Motion Profile

Efficiency in Power Use

- **Balanced Acceleration/Deceleration**: If the times for acceleration (ta) and deceleration (td) are each one-third of the total time (T), the overall power usage is minimized. This balance ensures efficient energy consumption during the move.

Overshoot Error

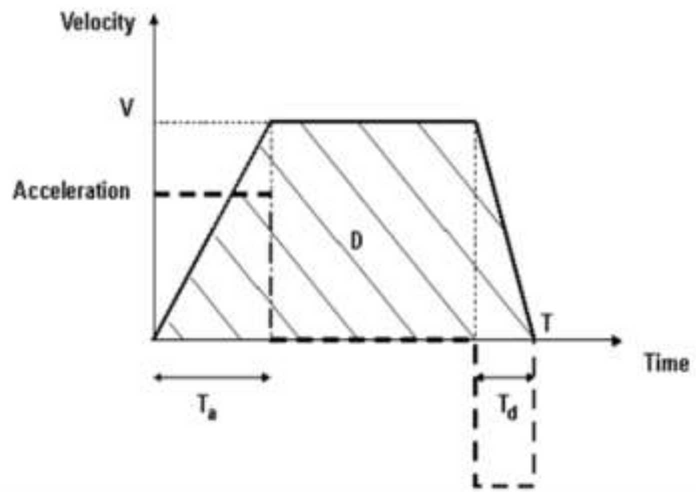
- **Existence of Error**: While overshoot error is present in a trapezoidal move, it is generally negligible for many systems.

- **System Impact**: For most applications, this small degree of error does not significantly affect performance, but it is a factor to consider.

$$D = V \cdot (T - \frac{t_a}{2} - \frac{t_d}{2})$$

$$accel = \frac{V}{t_a}$$

$$decel = \frac{V}{t_d}$$



S-Curve Motion Profile

Gradual Acceleration Change

- **Design Principle**: The S-curve profile is characterized by a gradual change in acceleration, which is crucial for reducing or eliminating overshoot problems.
- **Mechanical Vibration Reduction**: This gradual acceleration and deceleration significantly reduce mechanical vibrations within the system.

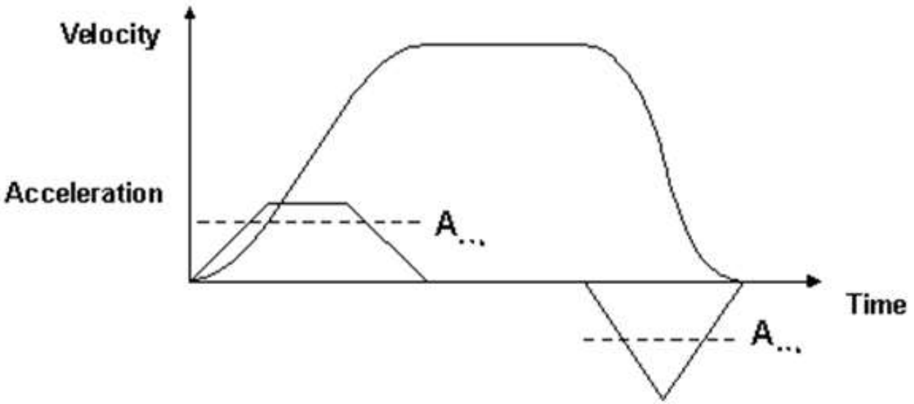
Acceleration Characteristics

- **Minimum Acceleration Points**: These occur at the beginning and end of the acceleration period.
- **Maximum Acceleration**: Found between the minimum points, this design facilitates a motion profile that is both fast and accurate, particularly advantageous for high-precision machines.

$$V = \int_0^{t_a} a(t) \cdot dt = a_{avg} \cdot t_a$$

$$a_{avg} = \frac{1}{t_a} \int_0^{t_a} a(t) \cdot dt$$

$$a_{avg} \leq a_{peak} \leq 2 \cdot a_{avg}$$



Proportional Relationships

- **Velocity**: Proportional to $1/T$, indicating its relationship with the total time.
- **Acceleration**: Proportional to $1/T^2$, highlighting how acceleration rates are influenced by the square of the total time.
- **Power (Peak)**: Proportional to $1/T^3$, demonstrating the cube relationship with the total time.

Critique and Insights

While discussing these profiles, it's important to understand their practical applications and limitations. The constant velocity profile, while basic, illustrates the foundational concept of motion control but falls short in high-precision scenarios due to its inability to account for instantaneous velocity changes and load variations. In contrast, the trapezoidal profile, with its defined acceleration and deceleration phases, offers greater control and predictability, making it more suitable for applications requiring precision and repeatability.

Torque and Power Calculations in Servo Systems

Fundamental Relationships

- **Torque and Current**: Torque is directly proportional to the current flowing through the motor.

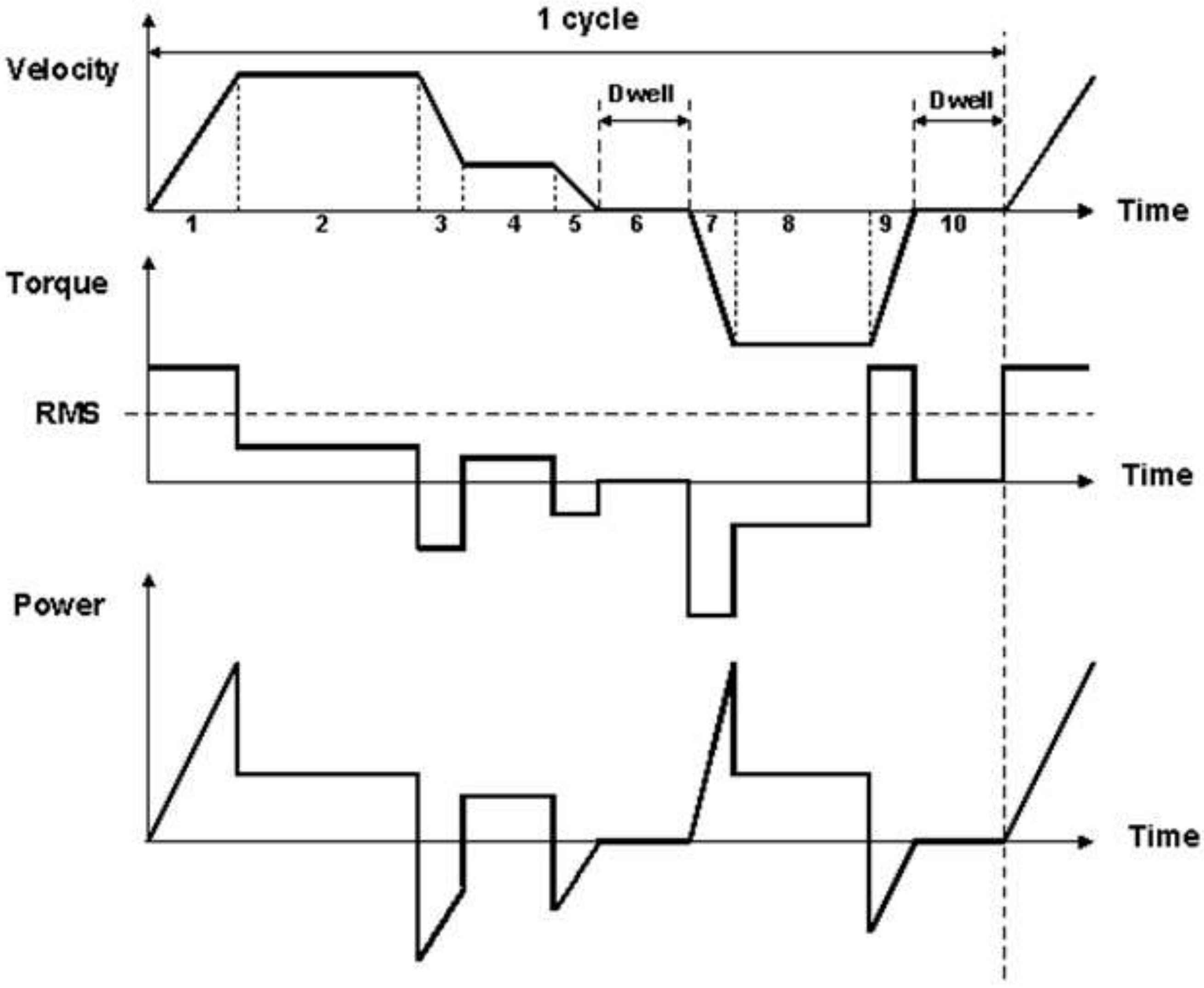
- **Power Equation**: The product of torque and speed equals power, encapsulating the dynamic interaction between these variables in servo systems.

Constants and Considerations

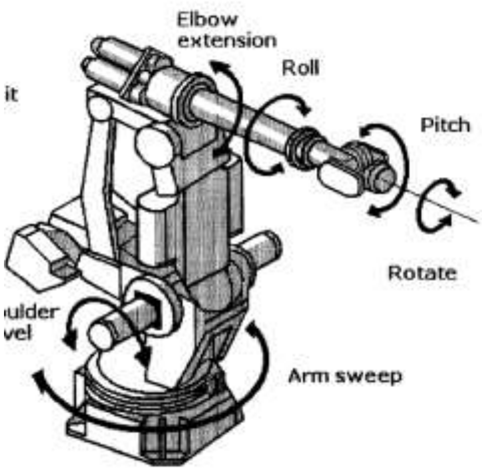
- **Torque Constant (Kt)**: Defined as the torque per unit current (typically expressed in lb-in/A), this constant is a key factor in motor design and control.

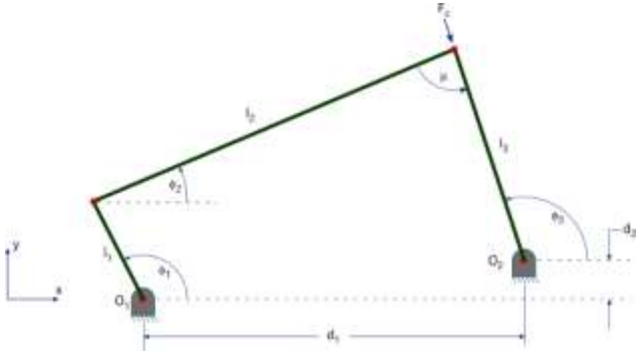
- **RMS Torque**: Root Mean Square (RMS) torque is crucial for supply and thermal considerations in servo systems, as it represents the effective torque value over time.

$$T_{RMS} = \sqrt{\frac{\sum_i T_i^2 \cdot t_i}{\sum_i t_i}}$$


1 cycle
Velocity
Dwell
Dwell
Time
1
2
3
4
5
6
7
8
9
10
Torque
RMS
Time
Power
Time

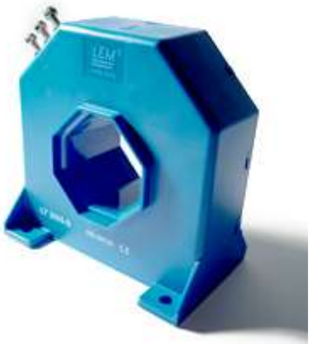
Mechanism (mechanical system that is being moved)

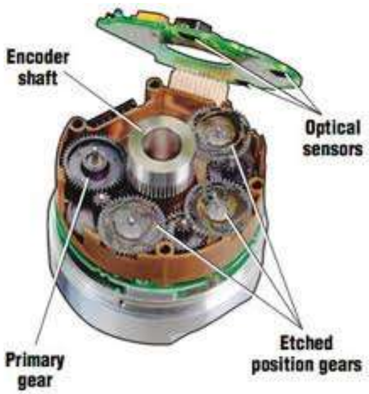


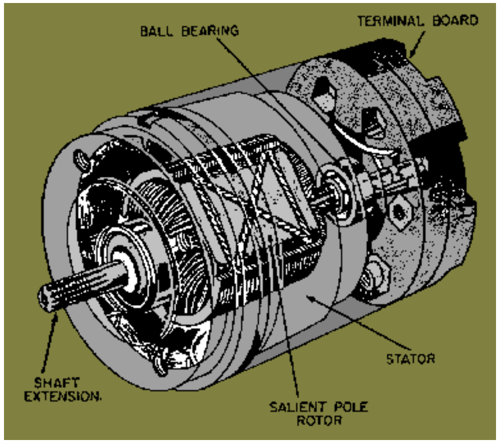


Sensors (Measurement and feedback)

Position, velocity, current sensors and transducers







Currently, servo systems are employed in:

i. Robotics

ii. Aviation

iii. Automotive

iv. Flexible manufacturing systems

v. Household devices

vi. Antennas

vii. Defense industry

viii. Medical areas

Medical science

Hand-held surgical devices

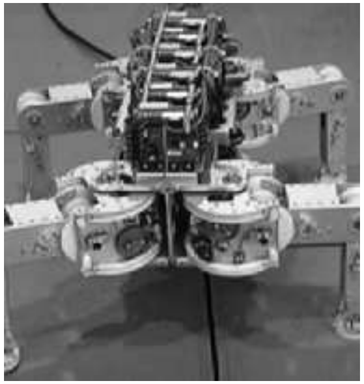
Surgical robots

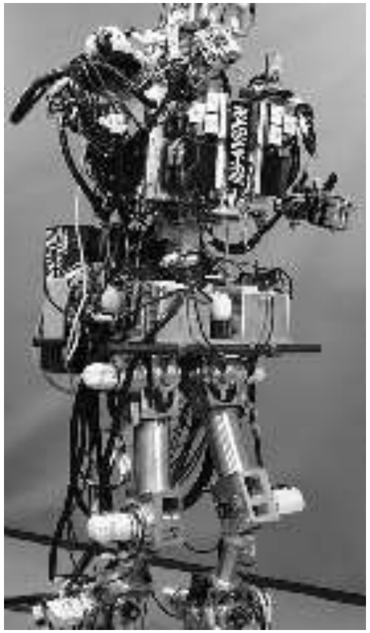
Micro-pumps

Dialysis systems

Dosing systems

Radiation equipment





Robotics

Humanoid robots

Service robots

Educational robots

Industrial automation

Positioning systems
Handling systems
Conveyor belts
Industrial robots

Electronics / Semiconductor technology

Feeders
SMT placement equipment
Lithography systems
Wafer processing systems

Security technology

Mobile inspection systems
Surveillance cameras
Access and lock systems
Automated gates

Instrumentation

Microscopes
Laser leveling systems
Precision scales
Climate analyzers

Communications

Antenna adjustments
Copiers / Printers / Plotters
Recording systems
Professional cameras

Automotive

Adjustable shock-absorbers

Exhaust reduction systems

Power steering

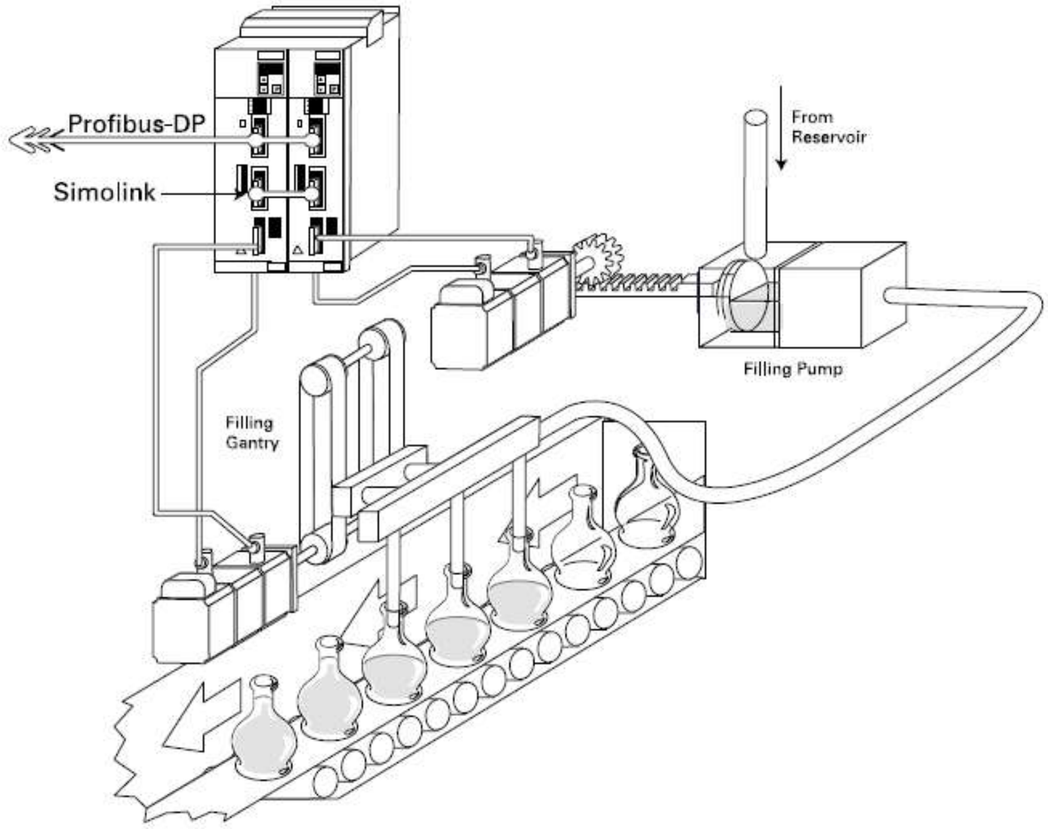
Electrical Car

Unmanned land vehicles

Aerospace

Seat adjustments
Flight recorders
Autopilots
Air conditioners
Space robot

Unmanned aerial vehicles



Container Filling Systems

2 axis synchronized systems

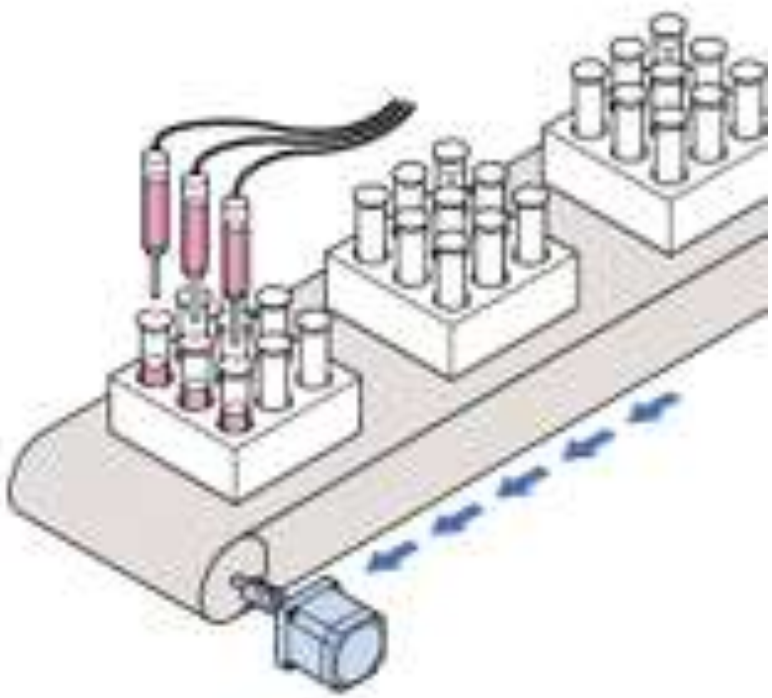
Some bottle-filling applications, such as cosmetics, require the distance between the filling pipe and the liquid level in the bottle to be kept constant. In addition, the filling pump must maintain a constant flow.

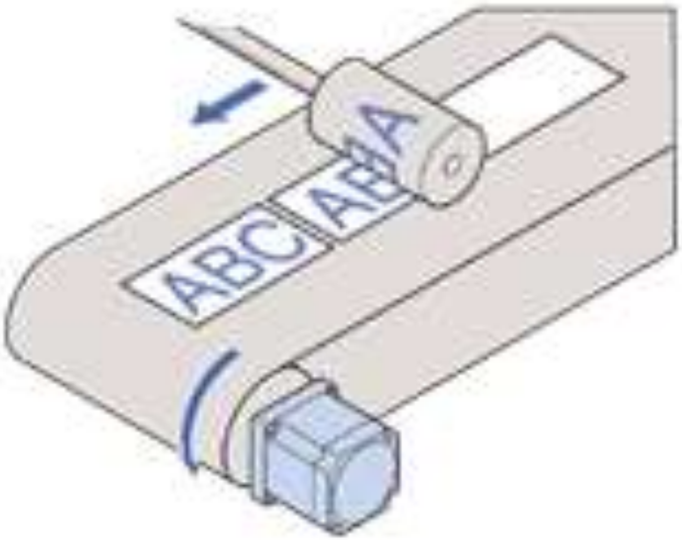
In this application, the pump drive acts as the master, and the filling gantry acts as the slave. As the pump provides a constant flow of product, the filling gantry movement is synchronized, through a cam profile that corresponds to the bottle contour.

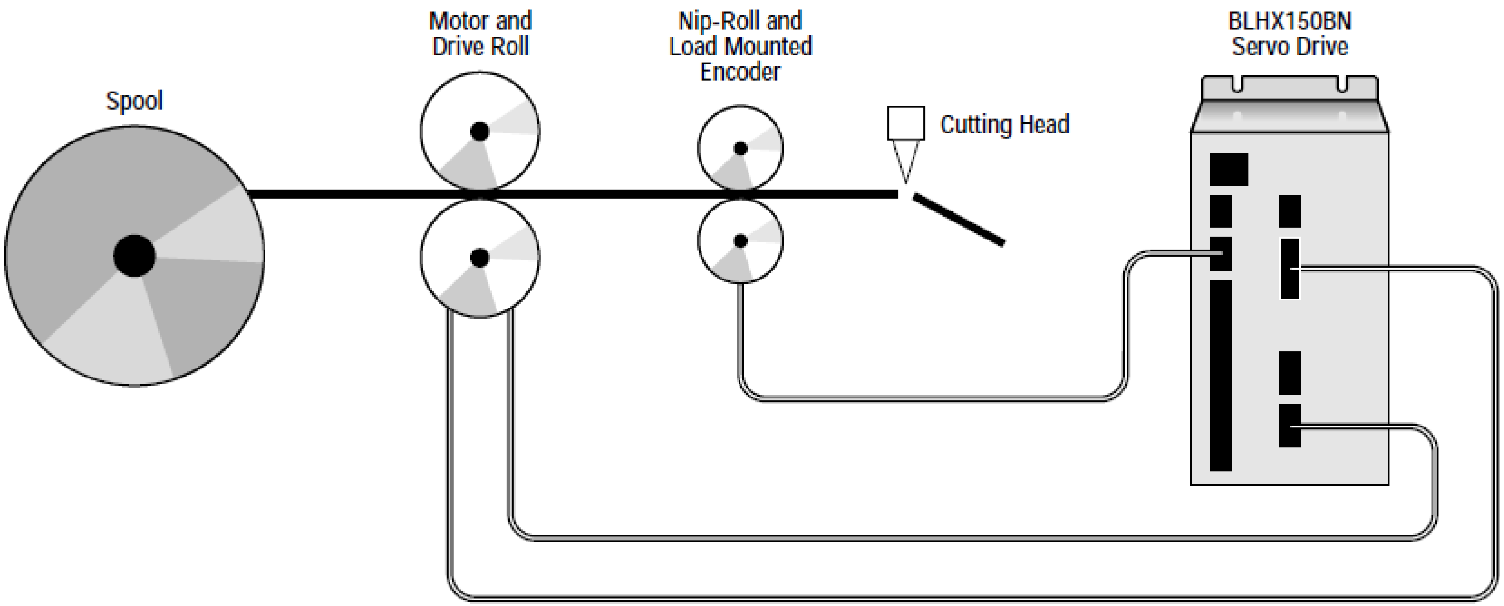
This maintains a constant filling pipe to liquid distance.

Fluid Injection

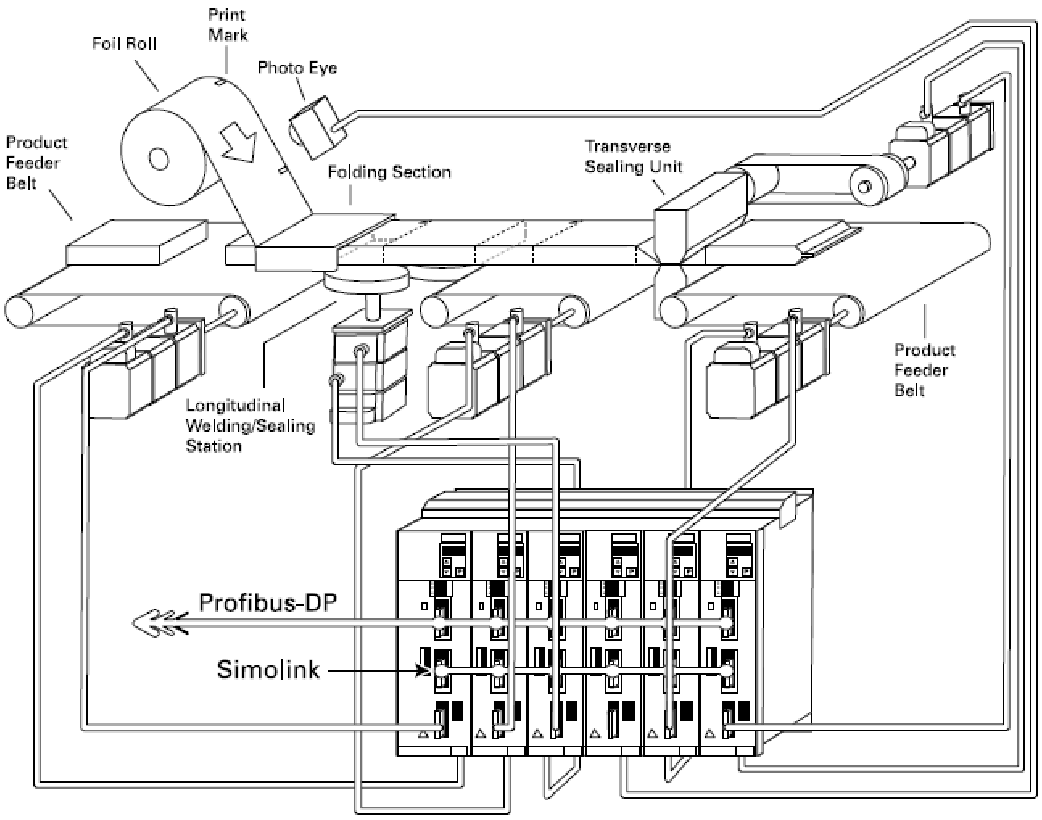
Printing Media







The process involves cutting steel rods

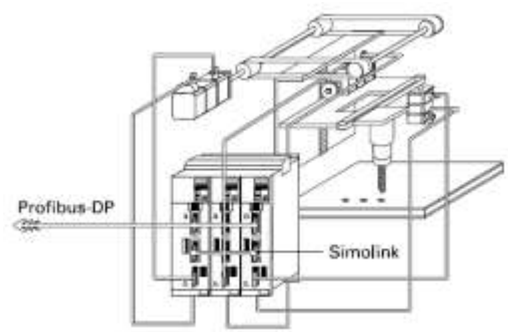


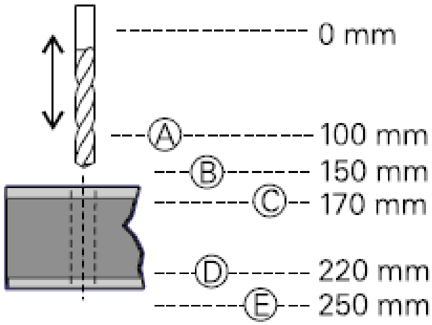
Packaging

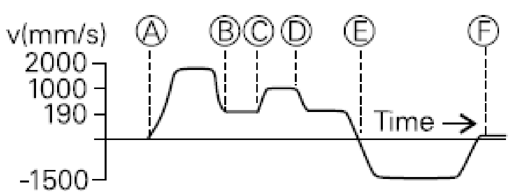
This application involves a continuous roll of foil for horizontal bagging. The sealing station handles the foil transport. Electronic line shaft and print mark registration ensure the foil is synchronized with the products being packaged. Electronic line shafting also ensures the product feeder belt and the foil are in continuous position synchronization. Print mark registration will accelerate or decelerate the foil to make up for a possible stretch. This ensures that printed labels on the foil will be correctly positioned on the package.

The transverse sealing station must travel with the line to achieve continuous packaging. This is accomplished with the servodrives's electronic line shaft and electronic cam functions. The sealing station is accelerated with the electronic line shaft function to the speed of the product (x-axis). The electronic cam function closes the sealing jaws (y-axis) while the sealer moves across and simultaneously seals the package.

Composite Drilling



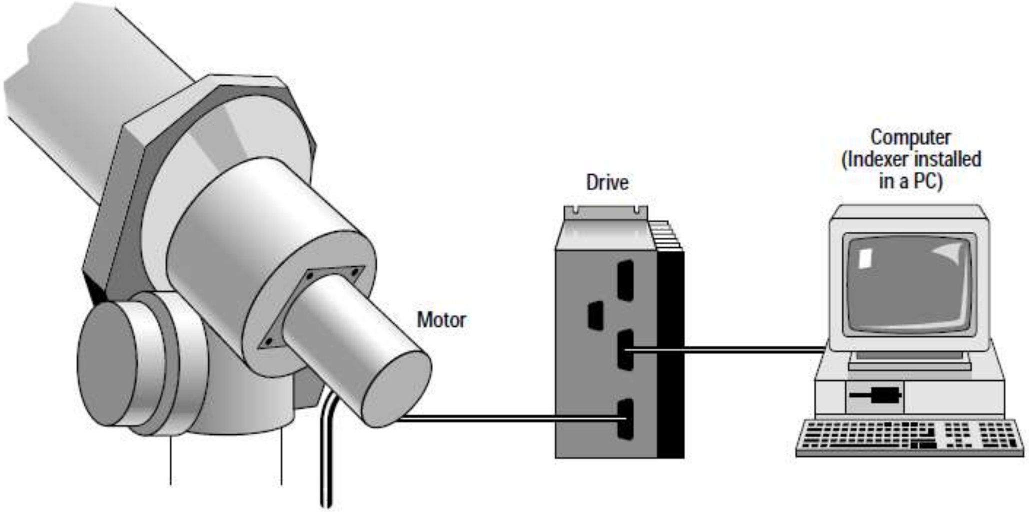




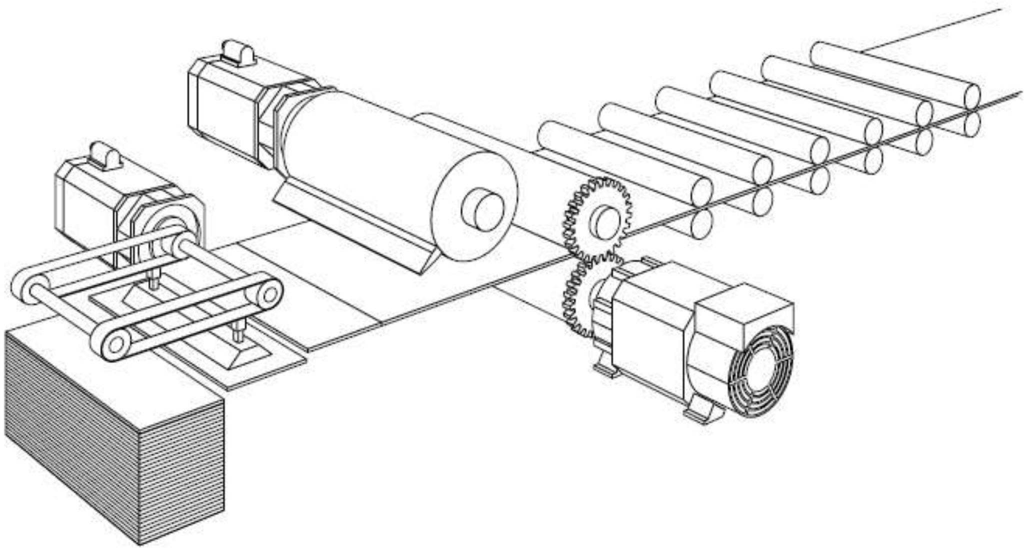
Positioning the x- and y-axis to locate the drilling tool can be accomplished with the manual data input (MDI) mode. Once the drilling tool has reached the desired location, the automatic function takes over and controls the movement of the z-axis. The following instruction set is an example of a drilling profile:

- Moving from A to B the drilling gantry rapidly traverses to just in front of the board and starts to reduce the feed velocity.
- At point B the drill reaches the reduced feed velocity to drill through a plastic laminate.
- Moving from B to C the drill slows to drill through the laminate.
- Moving from C to D the drill increases to normal velocity to drill through the core.
- Moving from D to E the drill reduces velocity to drill through bottom laminate.
- Moving from E to F the drill returns with increased velocity.

Telescope Driver

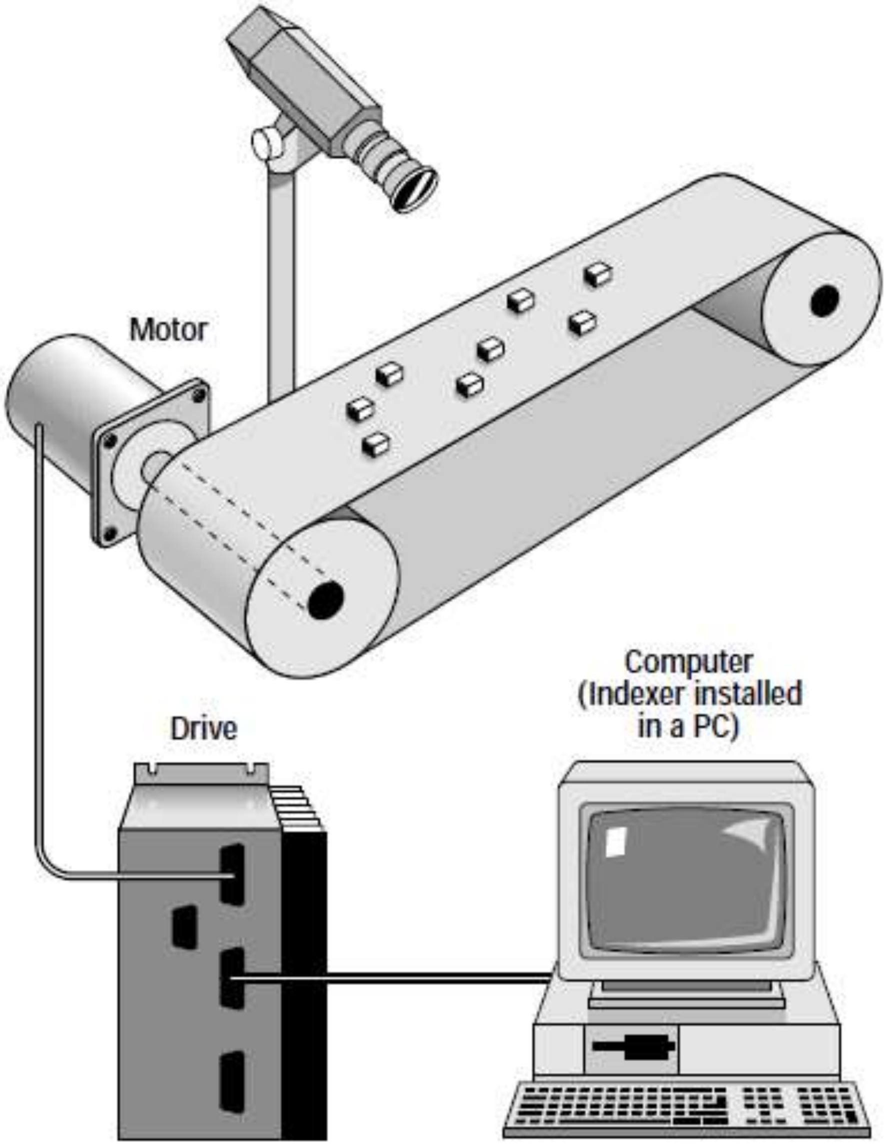


Cut to Length Rotary Knife/Sheater

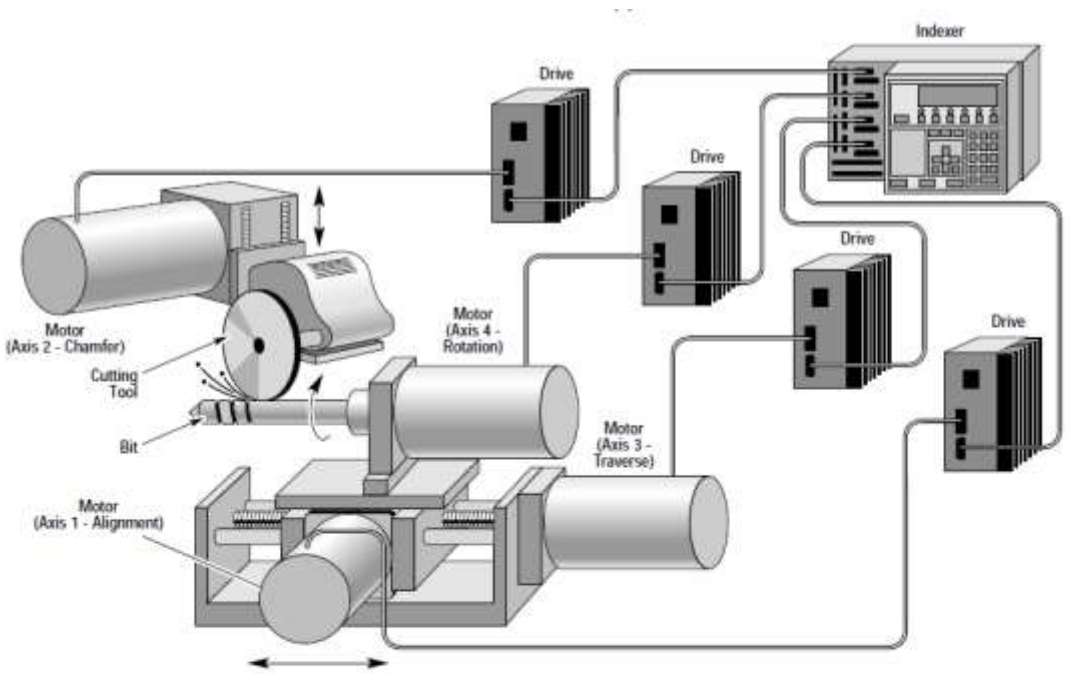


In Cut to Length applications, the purpose is to cut material to a **Rotary Knife/Sheater precise length. For a fixed cut length, and a knife circumference** of the same length, it is simply a matter of maintaining a constant speed between the web and the knife. However, for products that require various cut lengths, the knife's circumference would have to vary to match these new cut lengths. Since this would not be practical, the knife speed is often profiled. By varying the knife speed various cut lengths can be obtained. Furthermore, the rotary knife is accelerated so that as the cutting edge comes into contact with the material it is traveling at the same velocity. This is done to avoid "ripping" the material.

Conveyor

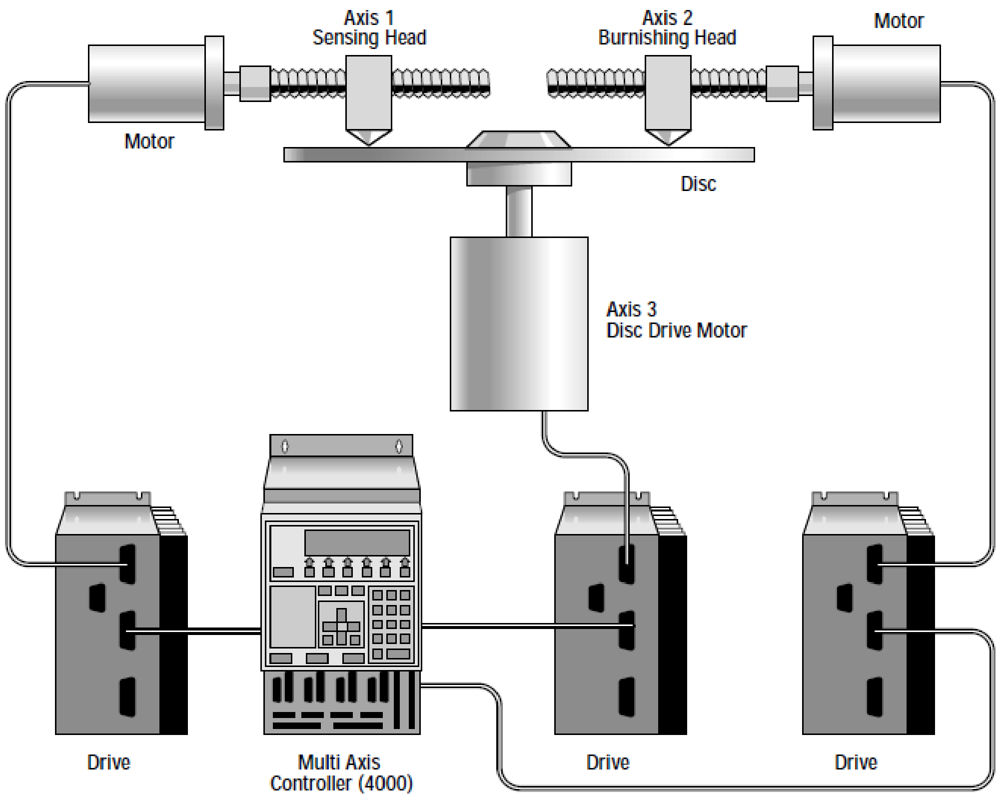


Milling

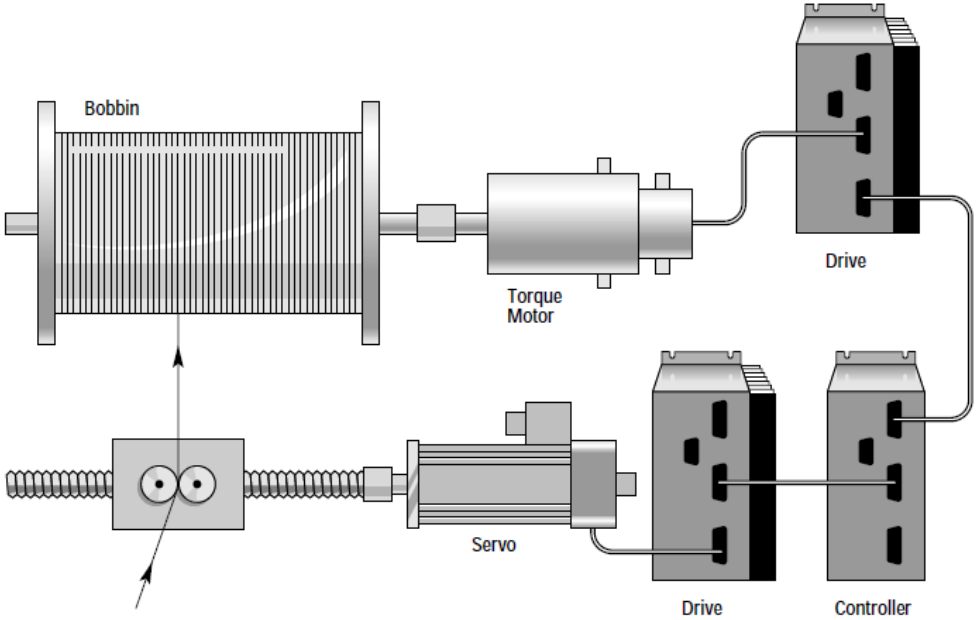


Indexer
Drive
Drive
Drive
Drive
Motor
(Axis 2 - Chamfer)
Cutting
Tool
Bit
Motor
(Axis 4 -
Rotation)
Motor
(Axis 3 -
Traverse)
Motor
(Axis 1 - Alignment)

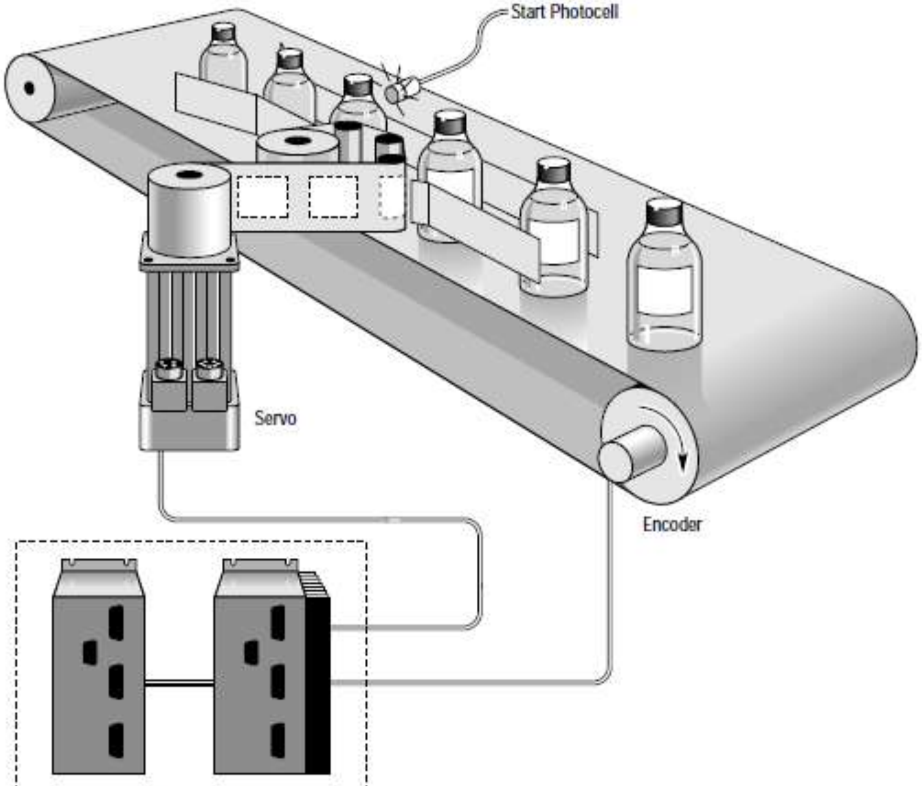
Surface Finishing



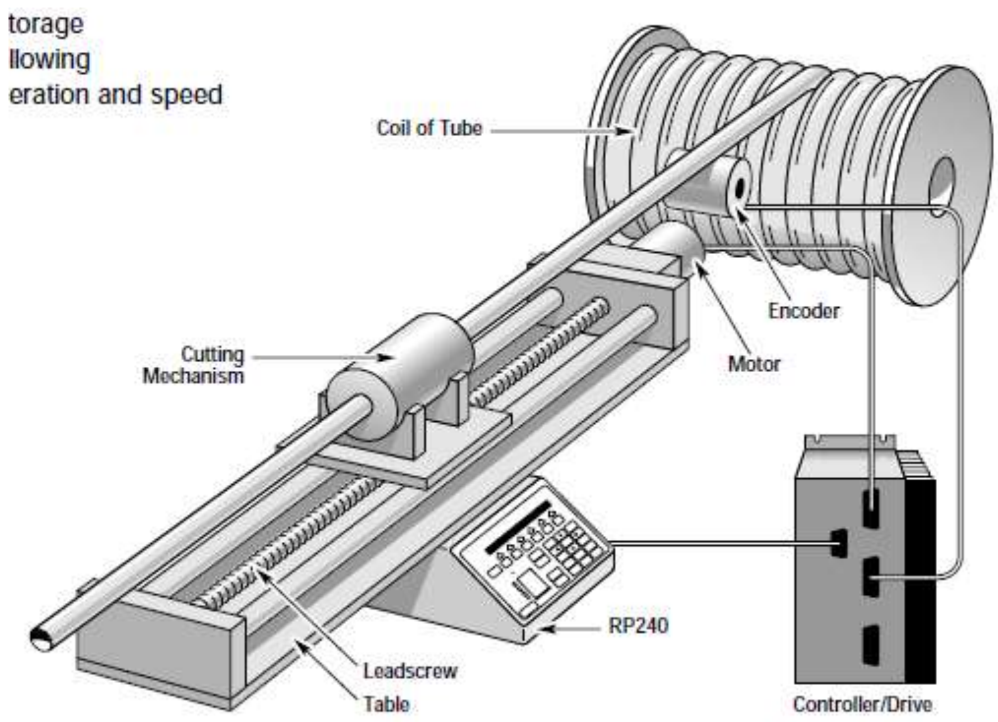
Winder



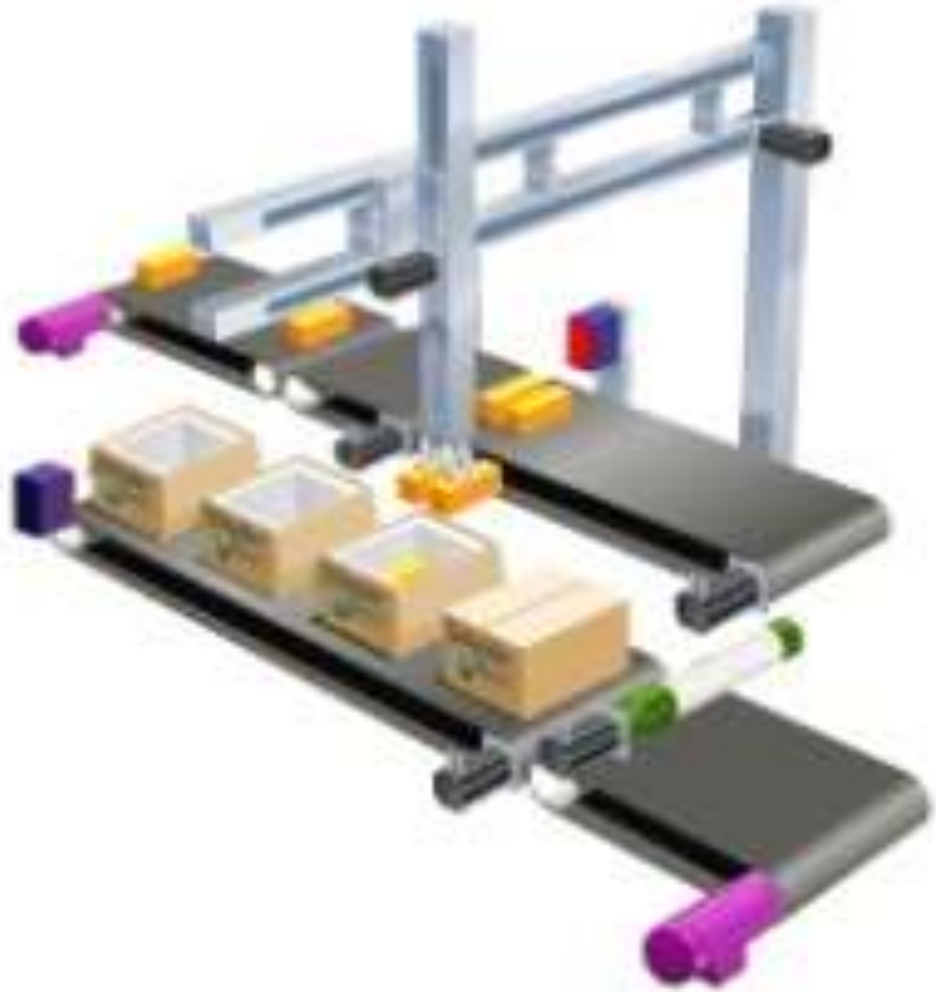
Labeling

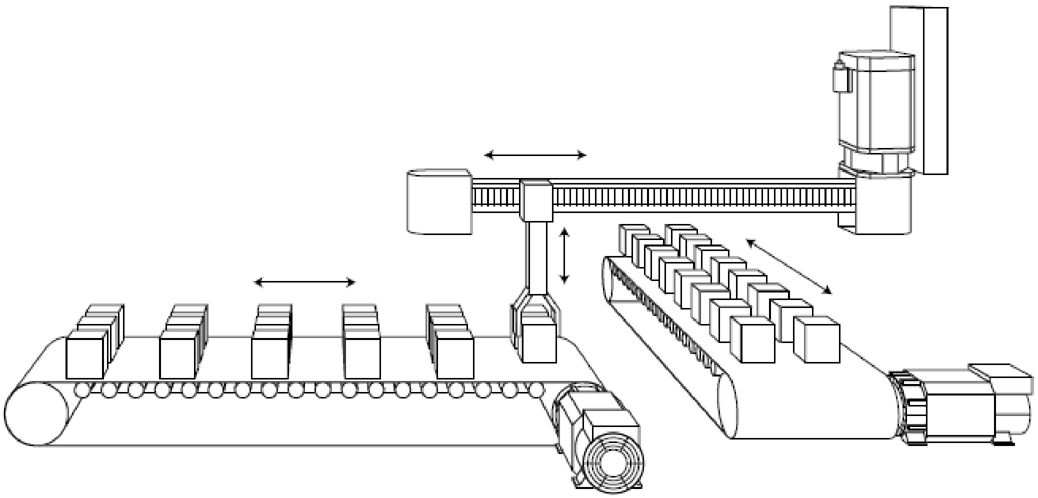


Pipe Cutter


torage
llowing
eration and speed
Coil of Tube
Encoder
Motor
Cutting
Mechanism
RP240
Leadscrew
Table
Controller/Drive

Packaging





Pick and Place

Pick and Place applications involve the precise movement of products from one location to another. Using the Point-to-Point positioning features, this precise movement can be realized. Typically the gripper claw is "homed" to the starting location during the initialization of the system. From that point, as the product is sensed, the gripper closes on it and the Point-to-Point move is made. Once the final destination point is reached the gripper releases the product and the return move to home position is carried out.

Baldor-Cut_to_registration.wmv

Baldor-FlyingShear-Cakes.wmv

Baldor-Labelling.wmv

Baldor-Pick-and-Place.wmv

Baldor-FourColourPrinter.wmv

Baldor-FlyingShear-LinearKnife.wmv

Baldor-FlyingShear-RotaryKnife.wmv

Baldor-WaterJet.wmv

Baldor-Spacing.wmv

LinearMotor.wmv

Servo motor's advantages

High, «torque/inertia ratio» (longer but thinner rotors)

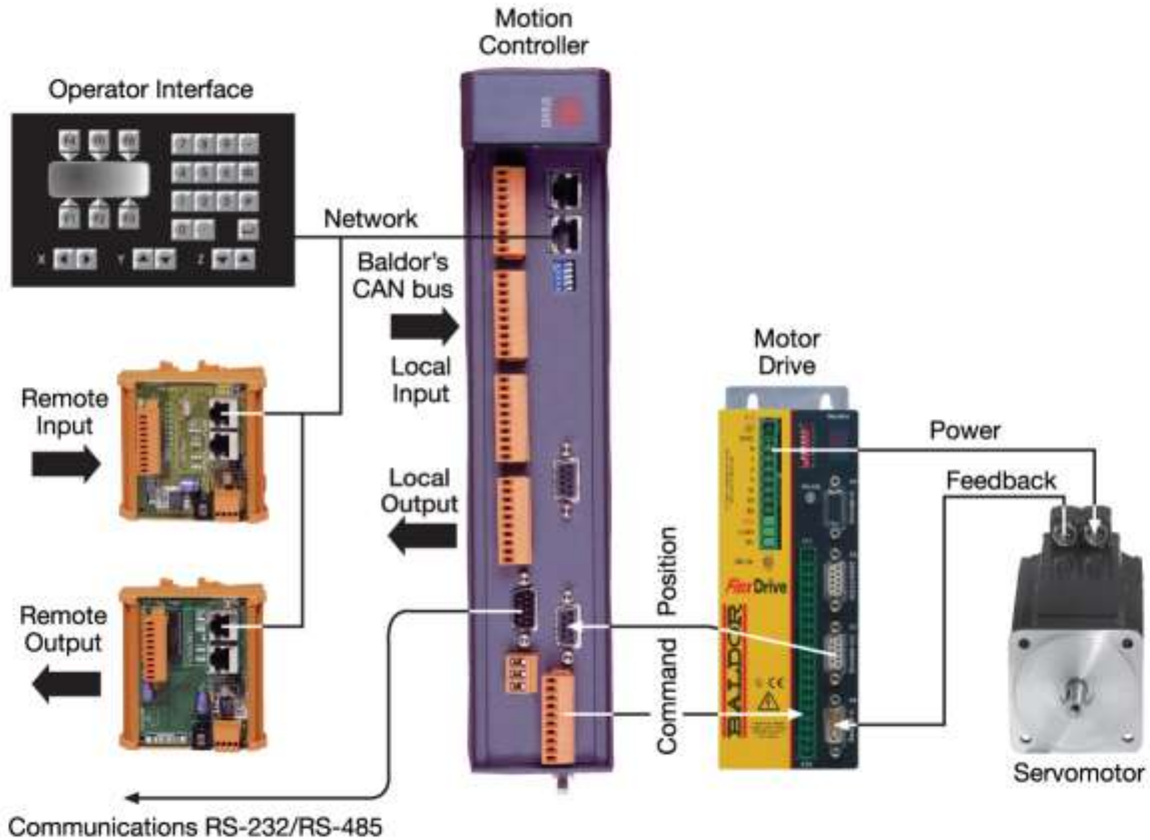
High peak torque

High Speed

Small acceleration and deceleration time constants (fast reaction) $e^{\tau s}$

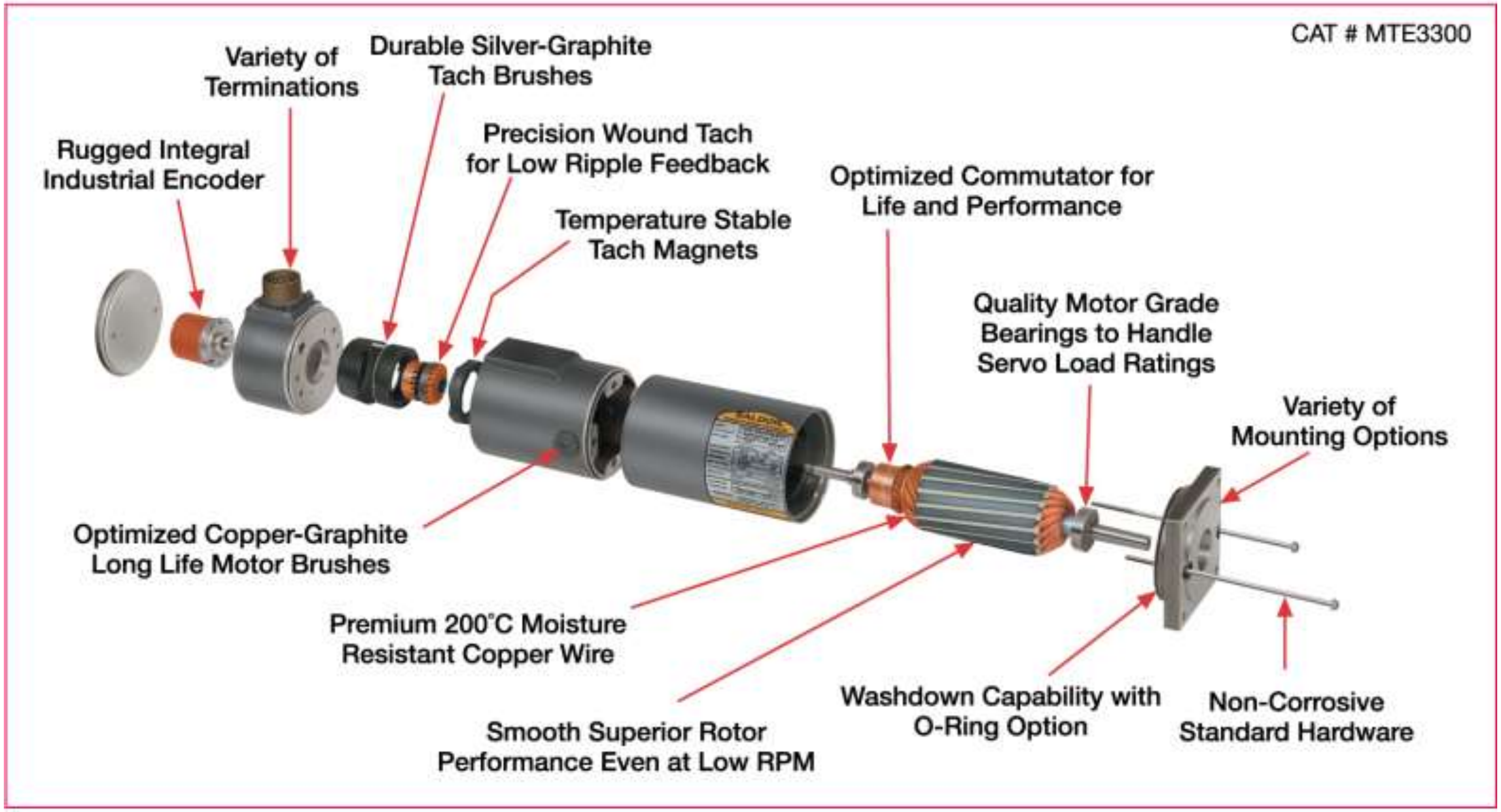
Low-speed operation without overheating

Interface to Servo

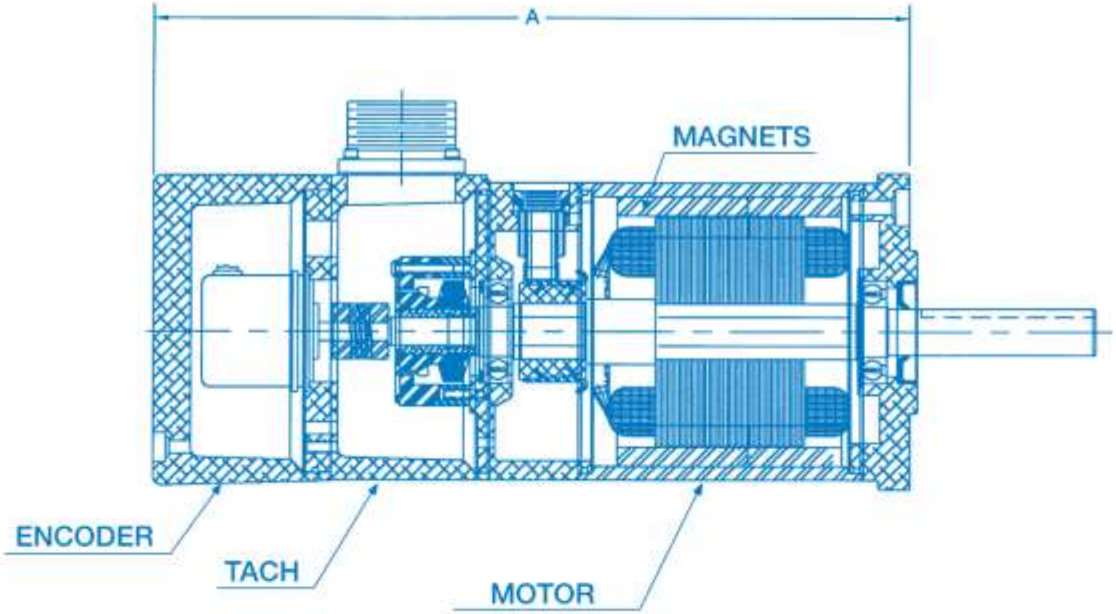


Baldor

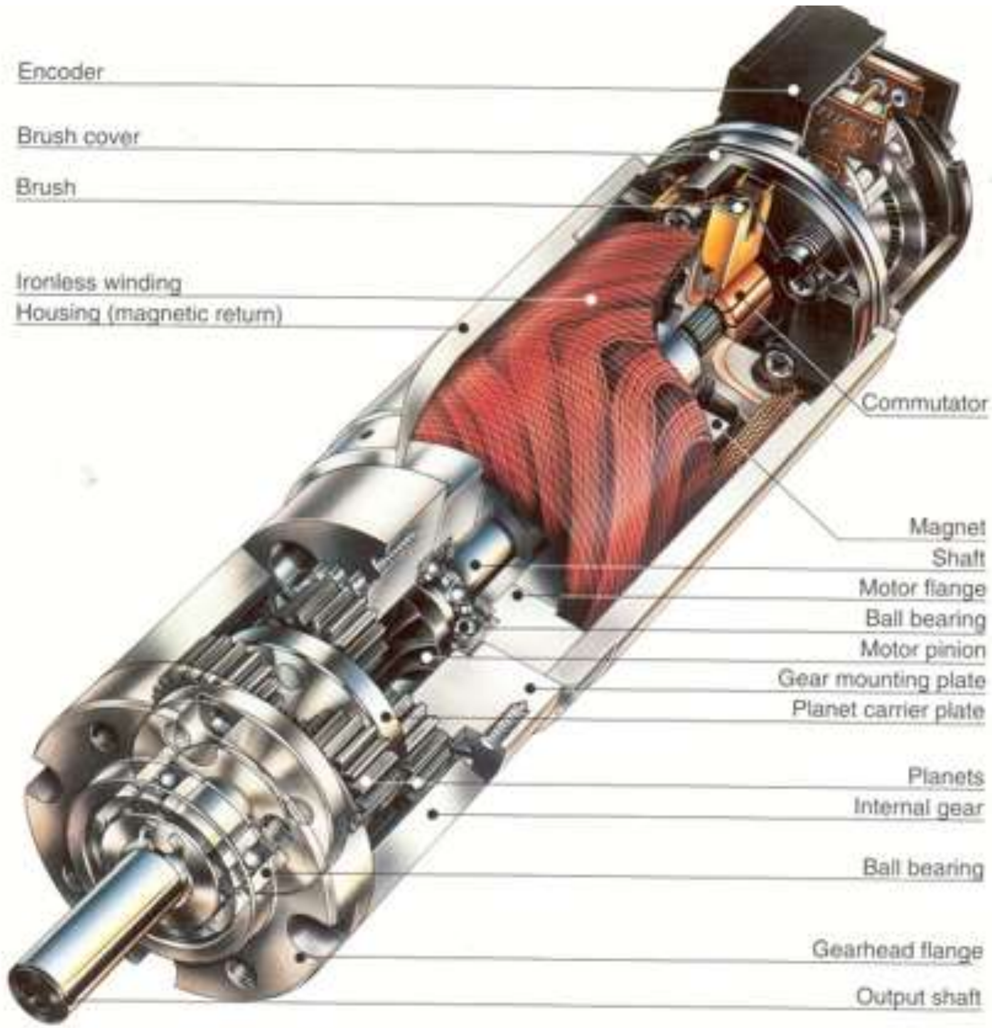
DC PM Servo Motor Construction



DC Servo Motor



Baldor


Encoder
Brush cover
Brush
Ironless winding
Housing (magnetic return)
Commutator
Magnet
Shaft
Motor flange
Ball bearing
Motor pinion
Gear mounting plate
Planet carrier plate
Planets
Internal gear
Ball bearing
Gearhead flange
Output shaft

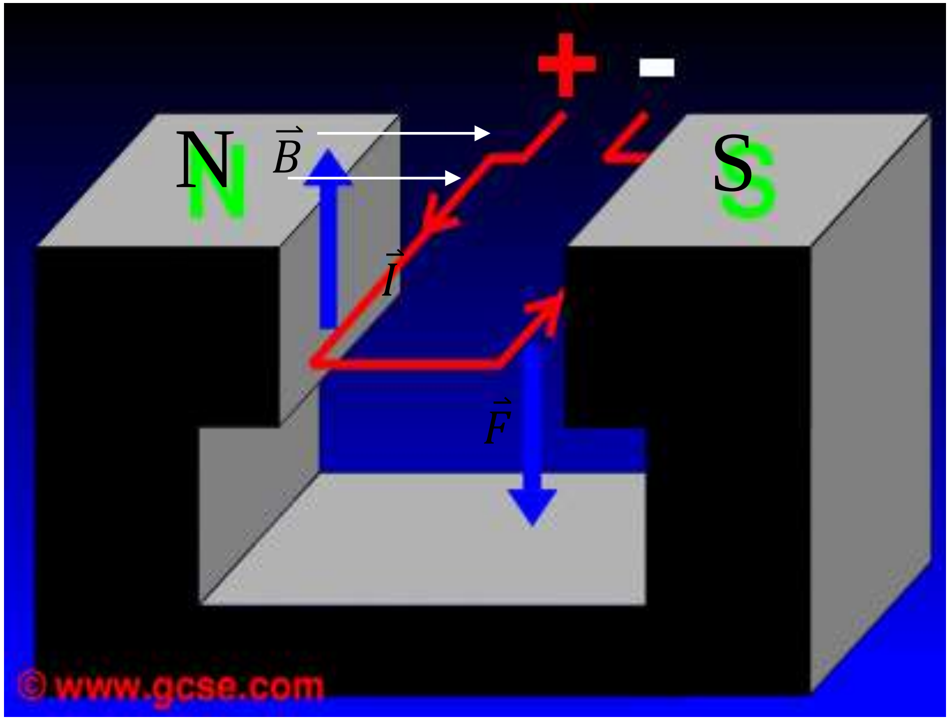
DC Motors

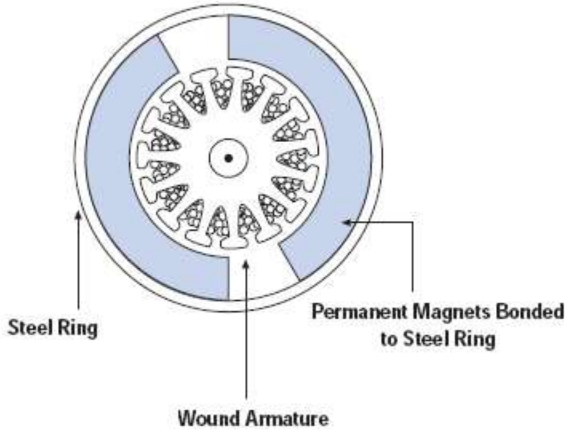
<u>Lorentz Force Law:</u>

F = **I** x **B**

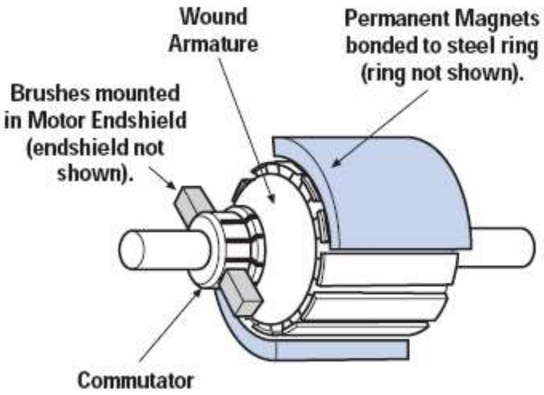
F = force on wire
I = current
B = magnetic field

Right hand rule:
index finger along I,
middle finger along B,
thumb along F.

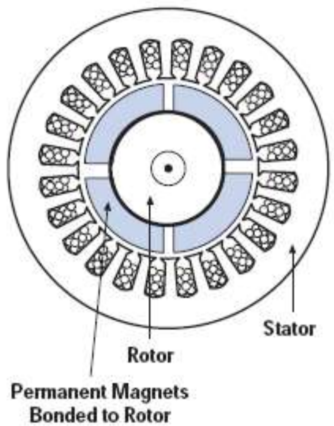




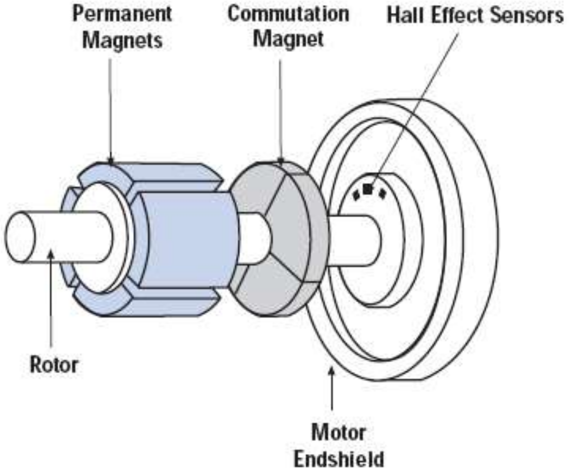
PMDC MOTOR



PMDC MOTOR



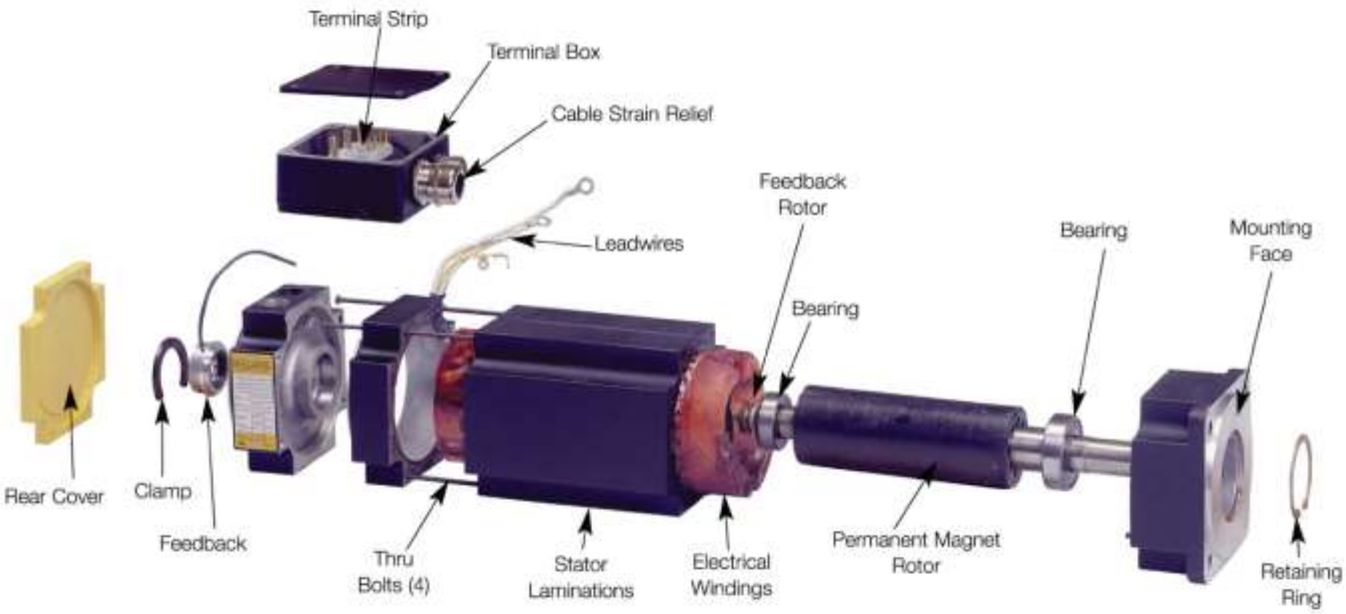
BRUSHLESS MOTOR



BRUSHLESS MOTOR

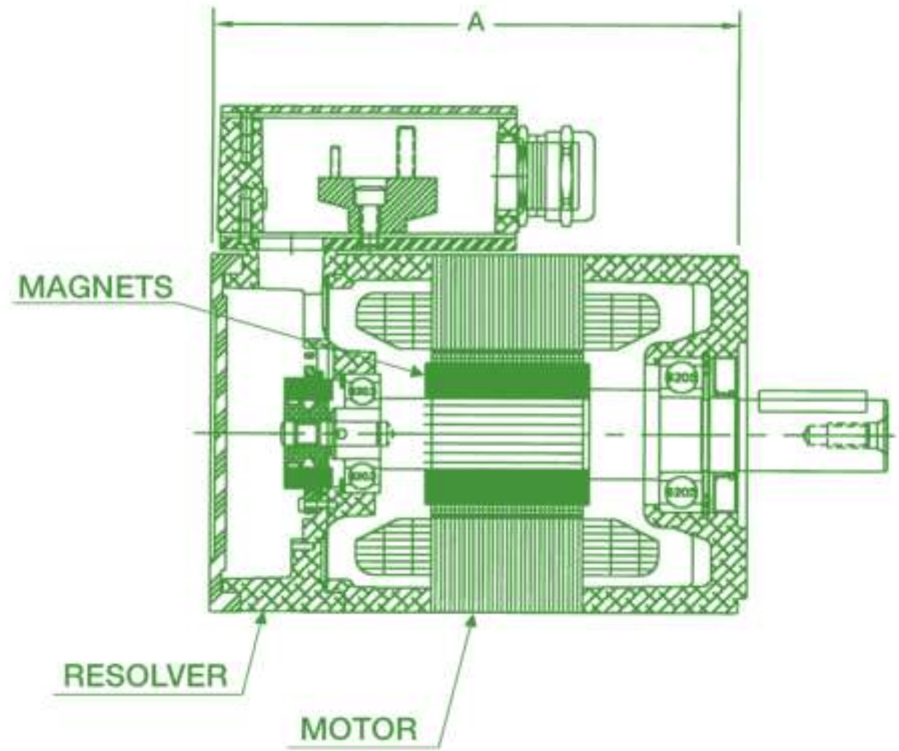
Brushless Servo Motor

Exploded View

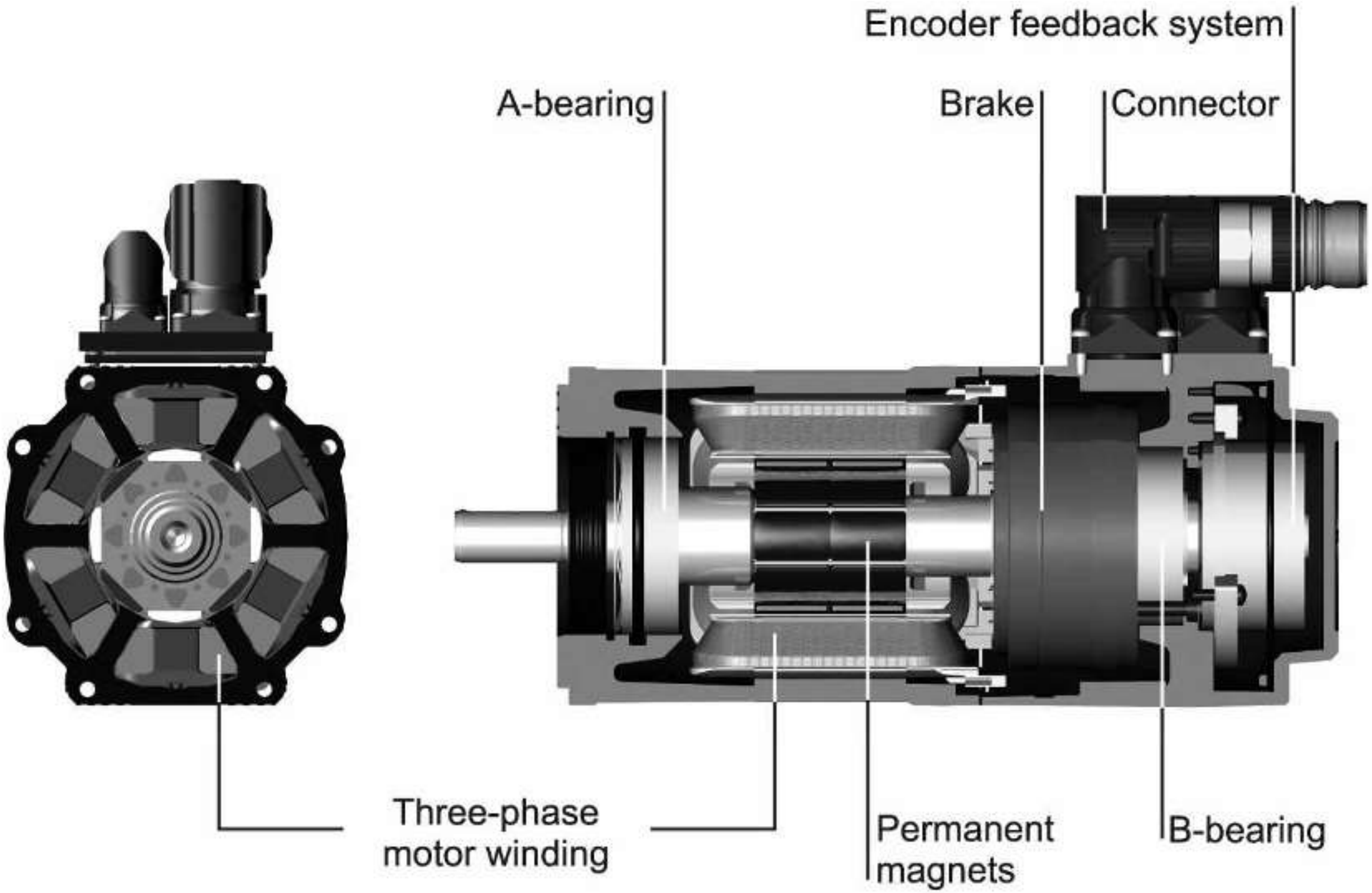


Baldor

AC Servo Motor



Baldor


Encoder feedback system
A-bearing
Brake
Connector
Three-phase motor winding
Permanent magnets
B-bearing

Controls are Available in Various Packages

UMH Servo Control

Controls (amplifiers) originally were designed for a particular application, to handle a specific load. About the late 70's a designer figured that a product could be made available to handle a wide variety of applications if potentiometers were provided for adjustments. Today, digital adjustments via keypad, and with PC setup, are also available.

TSD Servo Controls

H-Series Controls

H2 Controls

Flex+Drive^II^

Programmable Positioners Come in Wide Selection of Configurations...

MintDrive[II]

Programmable motion controls are available in many different configurations. some include the motor control (amplifier) with an internal power supply, and typically control one motor. Other are multi-axis. These are commercially available in enclosures or printed circuit boards, which fit inside a PC.

NextMoveBX[II]

Motion Controller
2, 3, 4 Axes

NextMovePCI

Motion Controller
1-12 Axes PCI Bus

Baldor

Baldor Brushless Servo Motors

- Standard, custom and Stainless Steel motors
- Standard and low inertia models
- Potted stator – superior protection for high voltage and current spikes
- Premium 200°C moisture resistant, multi-coated wire
- Superior bearing grease provides 4 times greater life
- Worldwide acceptable mounting – IEC, NEMA & customs – UL/CSA/CE/BISSC
- Variety of feedback – resolver, encoder, Halls, SSI, EnDat, etc.

Stainless Steel Brushless Servos

- Stainless steel housing
- Non-corrosive
- FDA, BISSC, UL, CSA, CE
- Watertight 1500 psi & IP67
- Potted stator
- Exxon Polyrex®EX Polyurea grease
- Laser etched nameplate

Precision Gearheads for BSM Servos

- Mount directly onto BSM
- Planetary - high efficiency
- Low backlash
- Inertia matching
- Torque multiplication
- GBSM Models
  - Standard 8-15 arc min
  - Higher torque / Lower backlash
  - Right angle

AC Brushless Servo Control

- Rotary or linear brushless servos
- Analog or pulse/direction input
- Intuitive WindowsTM front end provides full auto-tuning
- ActiveX libraries supplied free

MicroFlex

- Cont 3, 6, 9 amp (pk = 2X)
- Anti-resonance filters

FlexDriveII

- Cont 2 - 7.5 amp 1ϕ; 2 - 27.5 3ϕ; (pk=2X)
- 8/3 I/O; 1-14 bit analog input
- Master encoder input for gearing
- DeviceNet, ProfiBus, CANOpen

Motion Controllers

- Coordinated motion control
- Programmable in MintMT Multi-Tasking, or 'C'
- CANOpen for distributed control

NextMovePCI

- 1 – 8 axis servo/stepper
- USB & RS232 communications

NextMoveBX^{II}

- 2 - 4 axis servo
- RS232/485 communications

NextMoveESB

- 3 axis servo / 4 axis stepper
- USB & RS232 communications

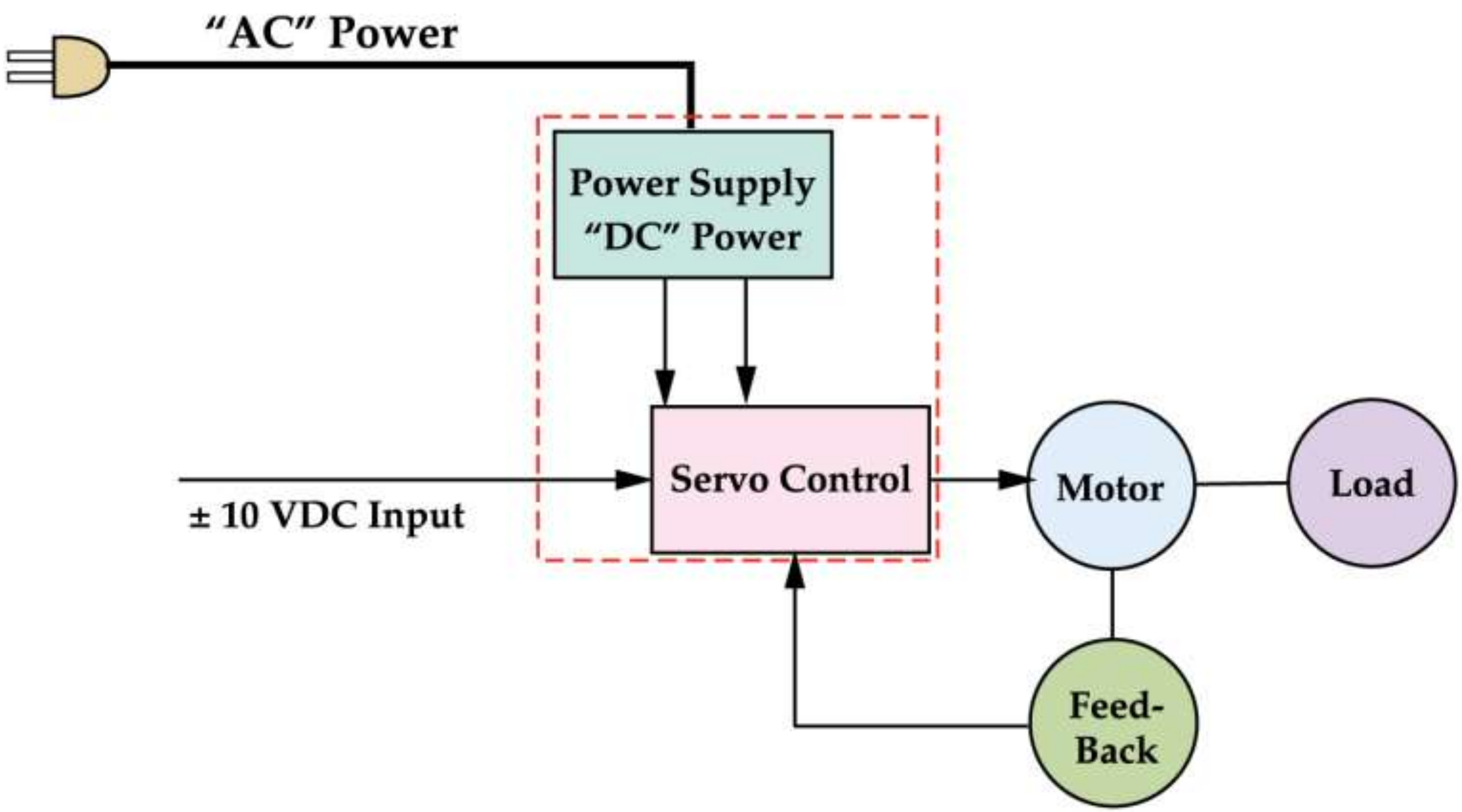
Accessories to Complete the Package

- Cable assemblies

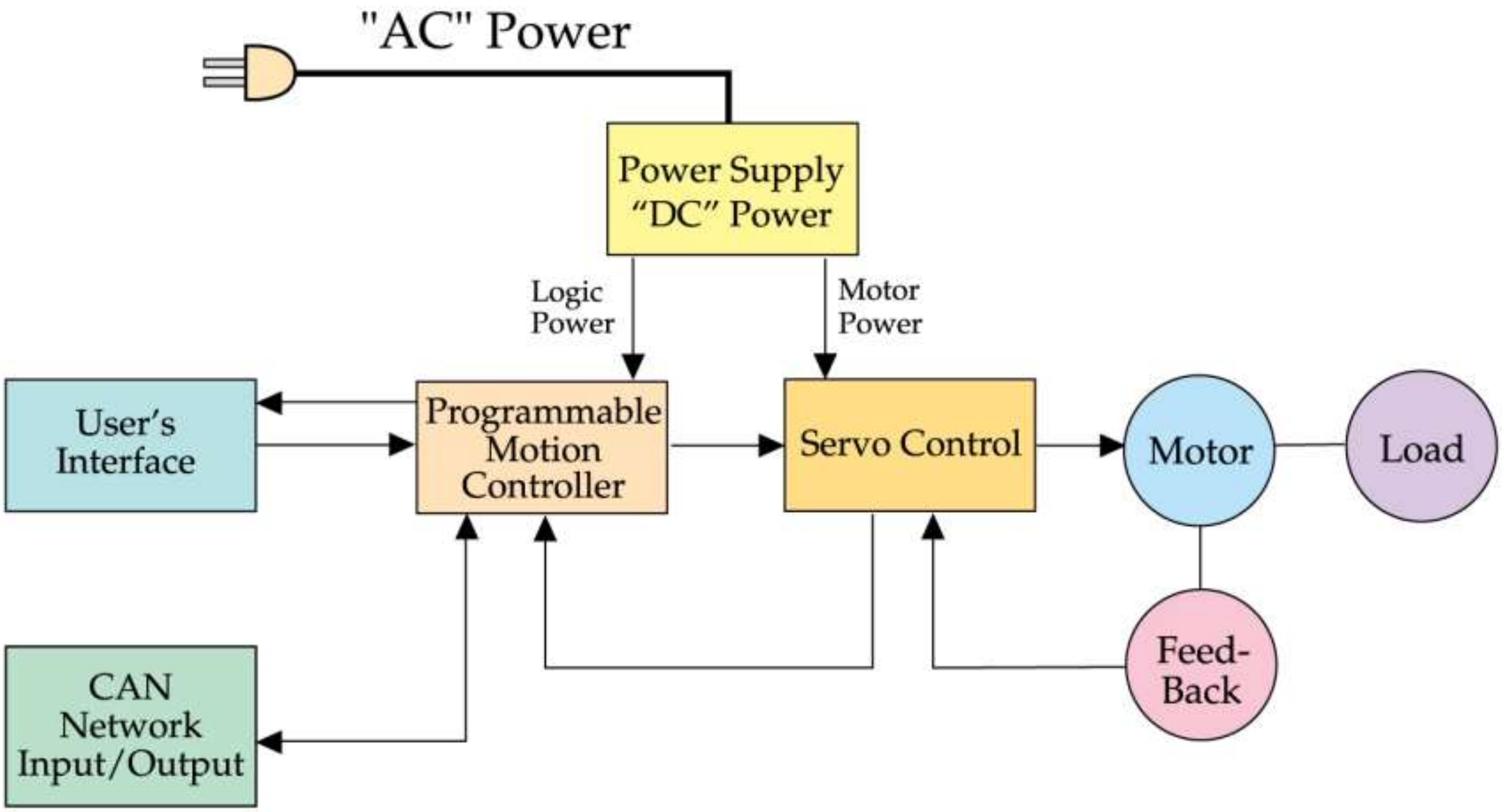
- HMI operator panels

- Auxiliary breakout boards

Servo Components



Servo Components

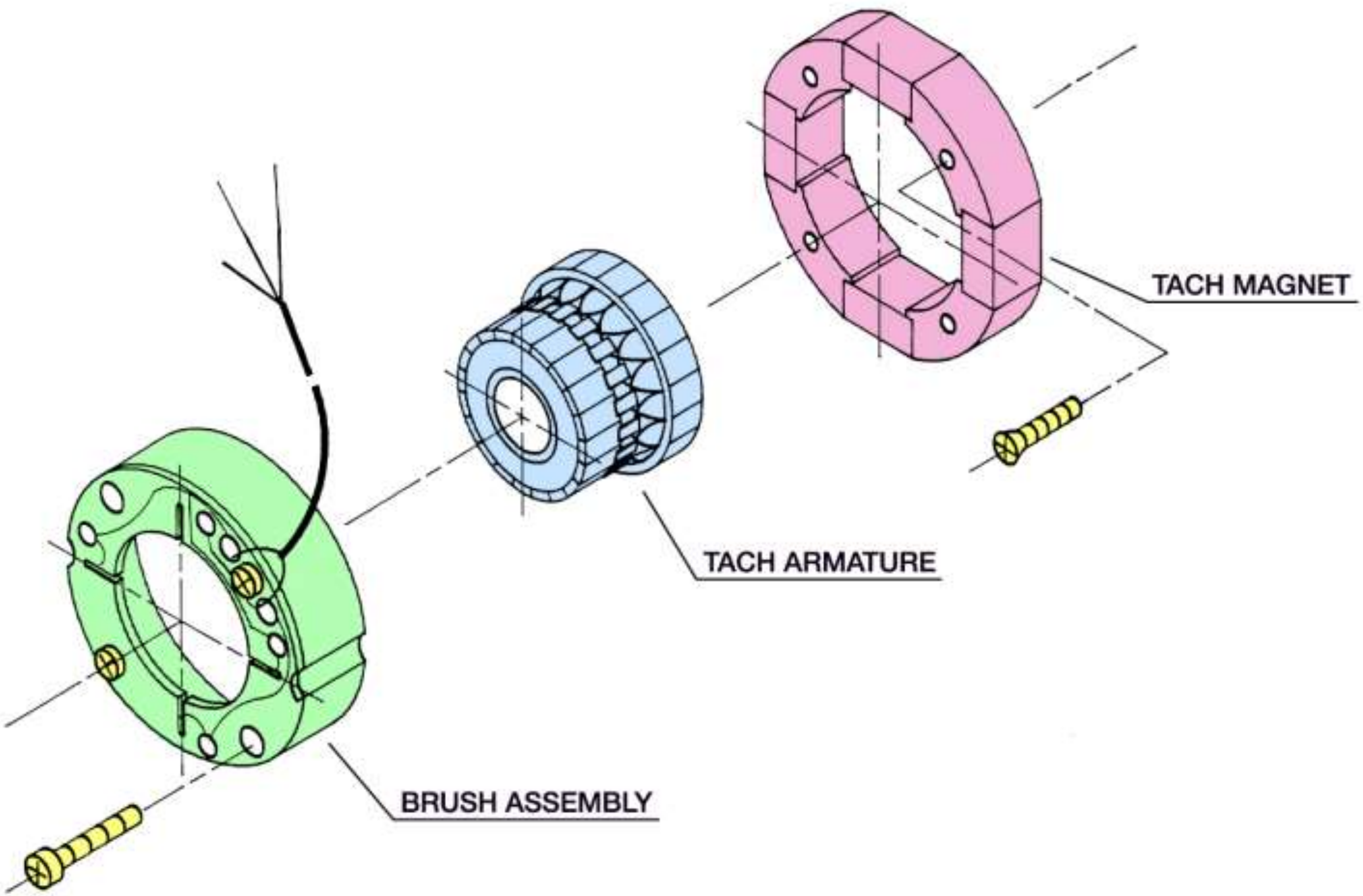


Baldor

Feedback Devices

- Tachometers
- Hall Sensors
- Encoders
- Resolvers

Tachometer Assembly

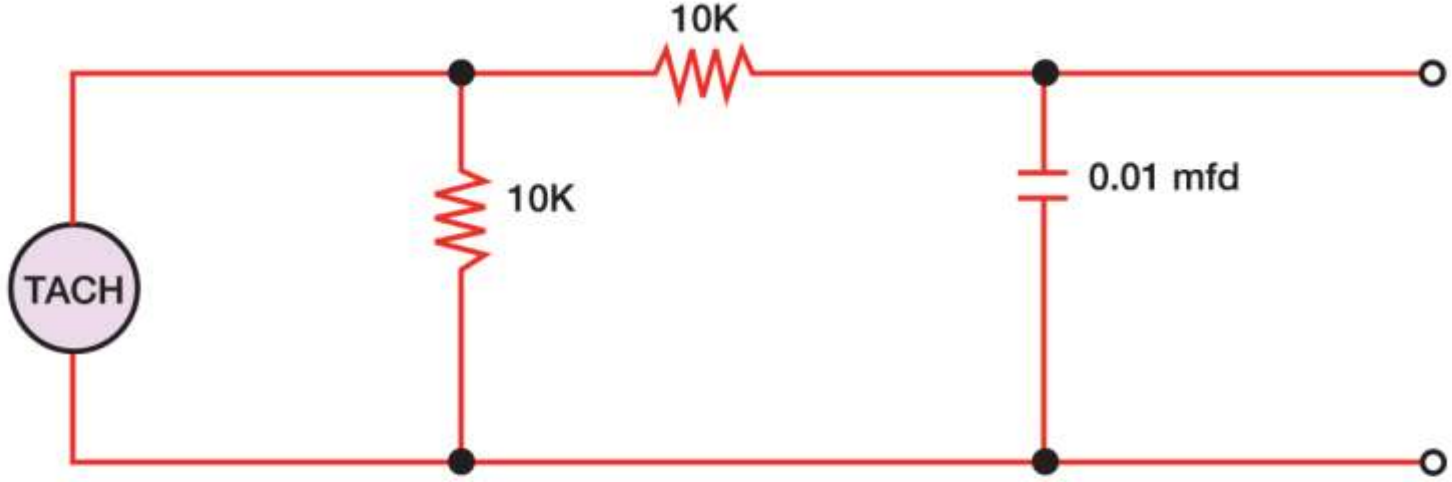


Baldor

Tachometer Terminology

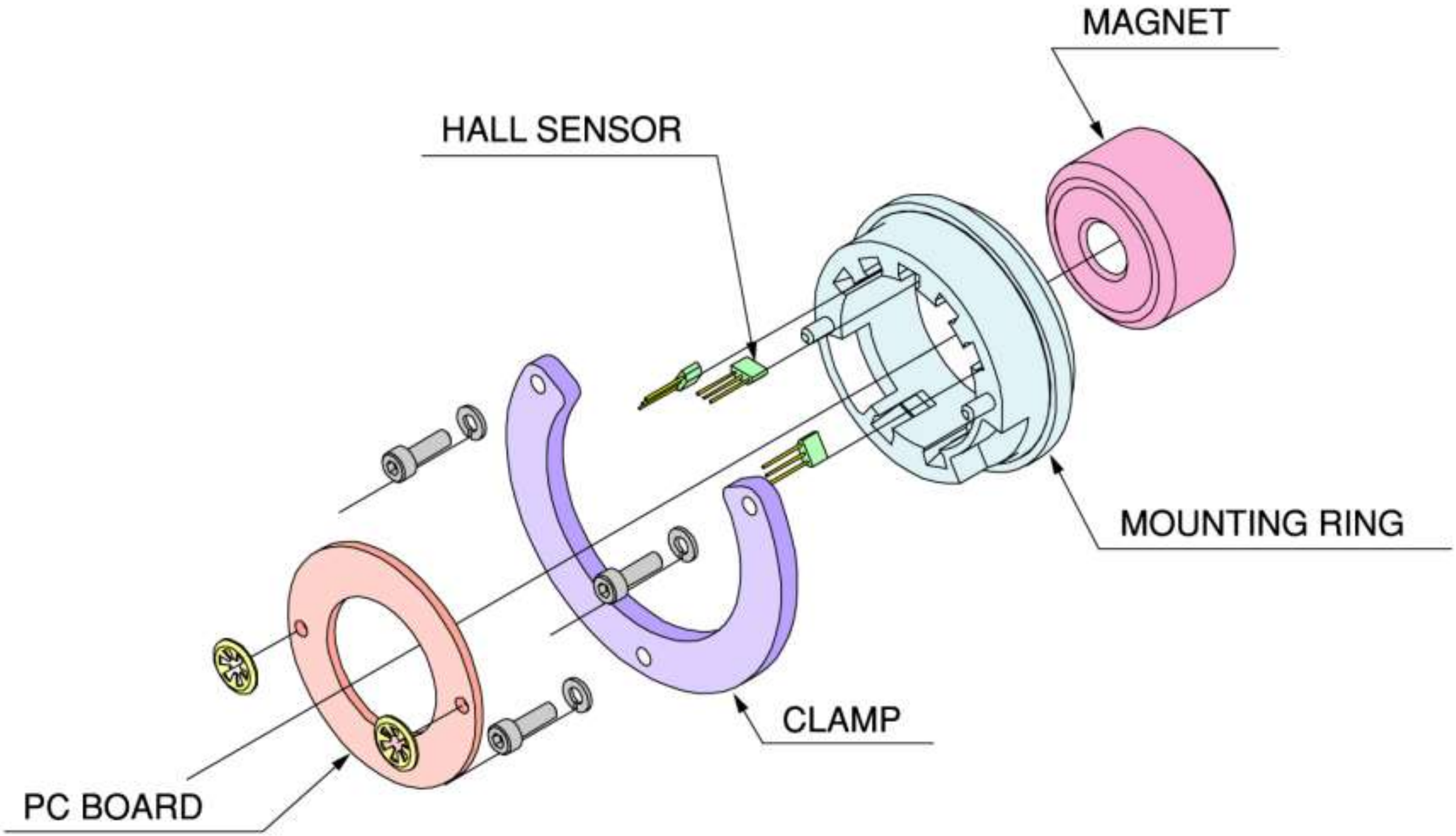
- Voltage Constant
- Ripple
- Linearity
- Max Speed
- Min Load
- Temperature Stability

Tachometer Filter

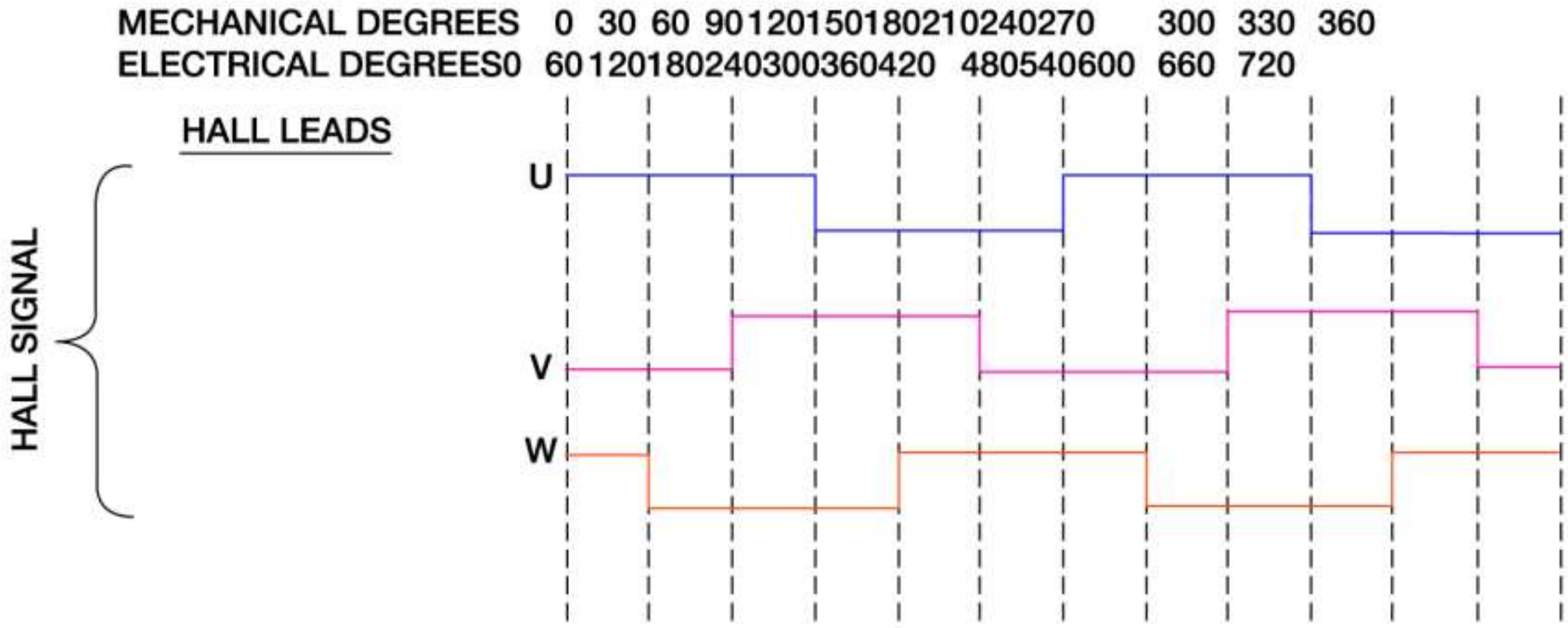


Baldor

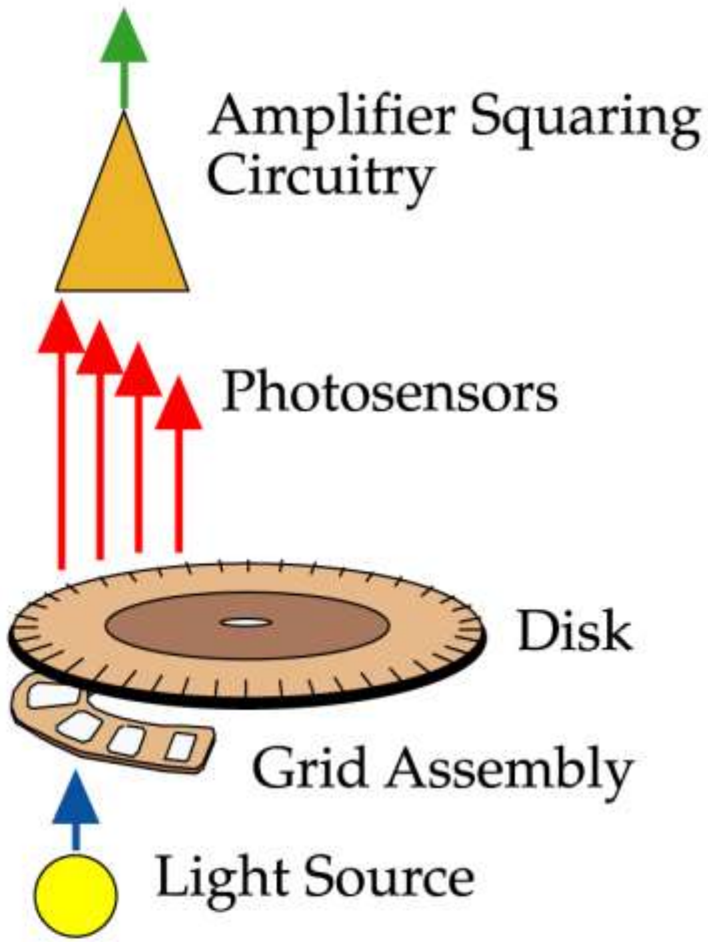
Hall Sensor



Hall Sensors



Encoder


Amplifier Squaring Circuitry
Photosensors
Disk
Grid Assembly
Light Source

Types of Encoders

Incremental Encoders

- **Functionality**: They provide signals indicating position changes or incremental positions rather than absolute positions.
- **Similarity to Pulse Tachometers**: Incremental encoders are akin to pulse tachs but usually offer more advanced features and performance.
- **Terminology**: Terms like incremental encoder, encoder, pulse tach, and digital tachometer are often used interchangeably in industry.

Optical Encoders

- **Most Common Type**: These encoders use light beams transmitted through transparent stripes or slots in a rotating disk.
- **Signal Generation**: The photodetector captures these beams, converting them into a series of pulses, or a pulse train, allowing for very high resolution.

Magnetoresistive Encoders

- **Design**: They have a wheel or disk with alternating north/south magnetic poles.
- **Sensing Mechanism**: A sensing element changes resistance based on the magnetic field and generates pulses corresponding to each magnetic pole.

Absolute Encoders

- **Unique Feature**: They produce multiple binary outputs read as a binary word, indicating the absolute angular position of the shaft.
- **Application**: Primarily used in systems where precise position feedback is required, such as cut-to-length servo systems.

Encoder Characteristics and Features

Direction Indication

- **Quadrature Outputs**: These are two outputs with a 90º phase displacement, used to determine the direction of rotation by detecting the leading signal.

Index Position Indication

- **Index Pulse/Marker Pulse**: This occurs once per revolution at a specific index position, helping to identify when the shaft is in a particular position.

Complementary Outputs

- **Configuration**: Pairs of outputs where one (A) is high when its complement (A) is low, providing differential signals with better noise immunity.
- **Transmission Line**: A differential line driver and receiver connected by a shielded, twisted-pair wire enhances signal protection from electromagnetic interference.

Resolution and Pulse Multiplication

Determining Resolution

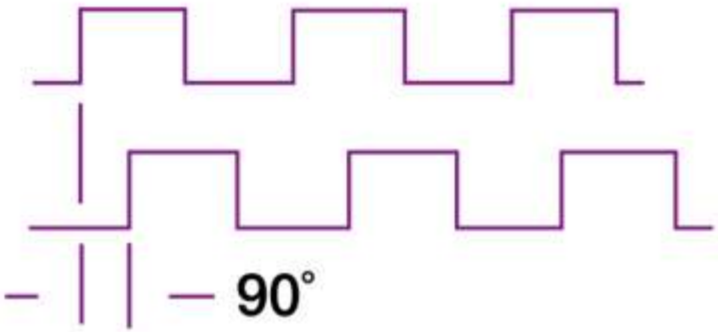
- **Pulses per Revolution (PPR)**: The resolution of an encoder is determined by its PPR, which indicates the smallest amount of rotation detectable.

Enhancing Resolution

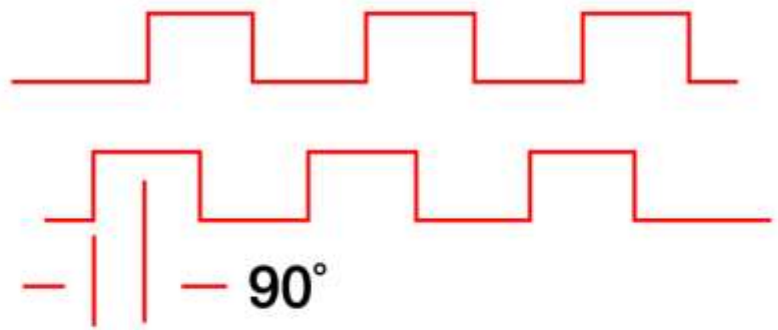
- **Pulse Multiplication**: Techniques like 1X, 2X, and 4X signal generation can improve the effective resolution of an encoder.

Encoder Output Signals

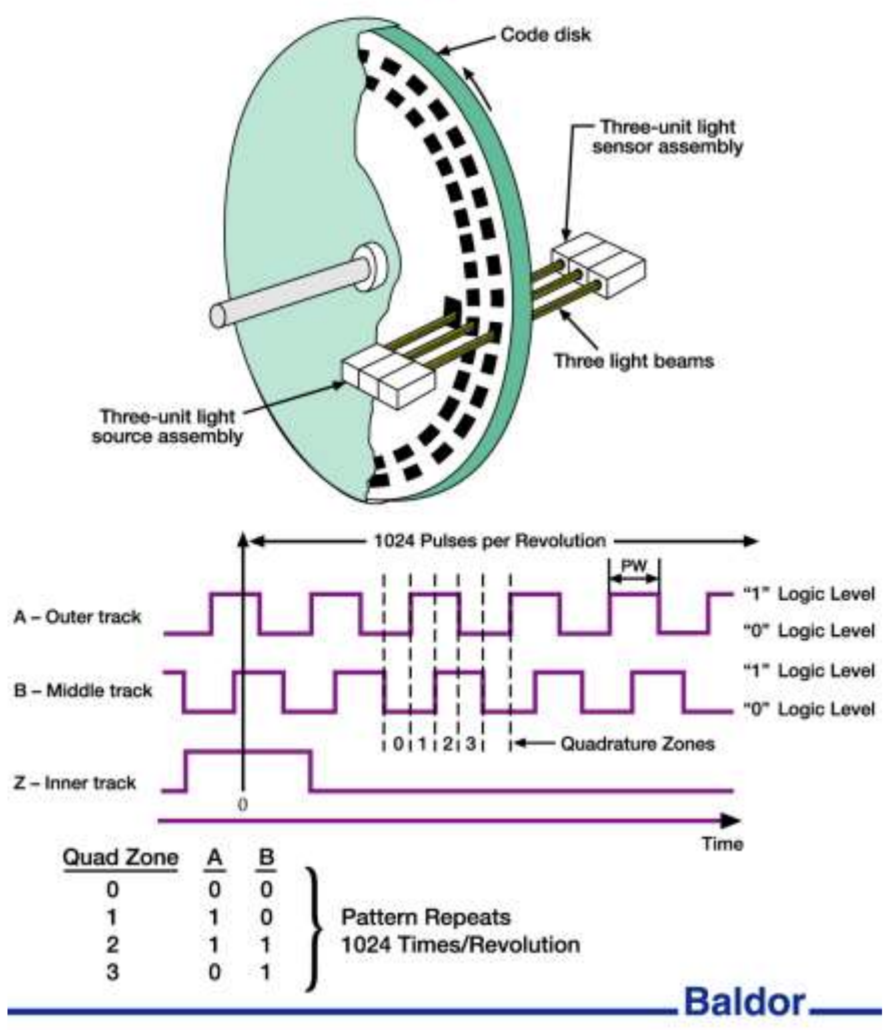
Clockwise rotation



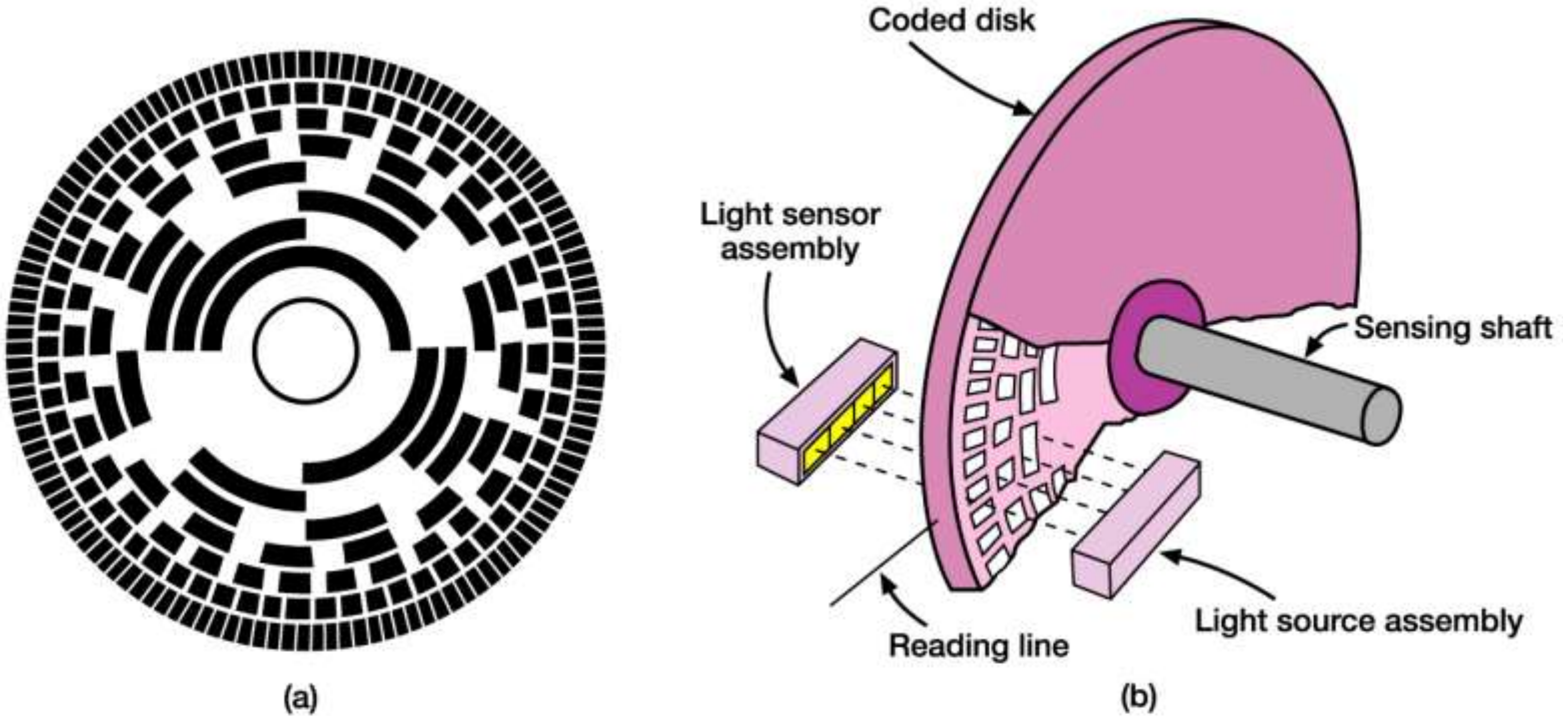
Counterclockwise rotation

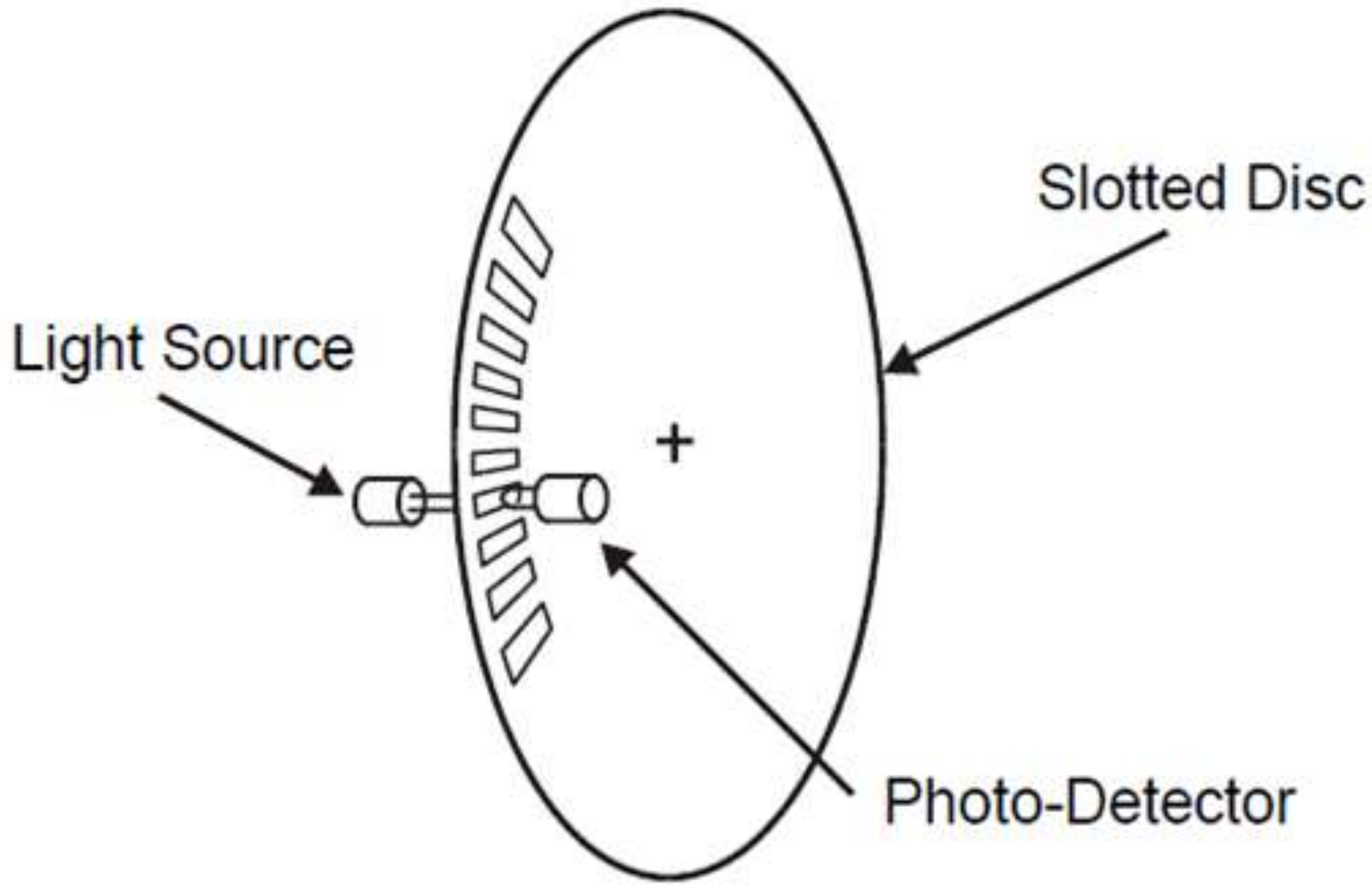


Incremental Optical Encoders

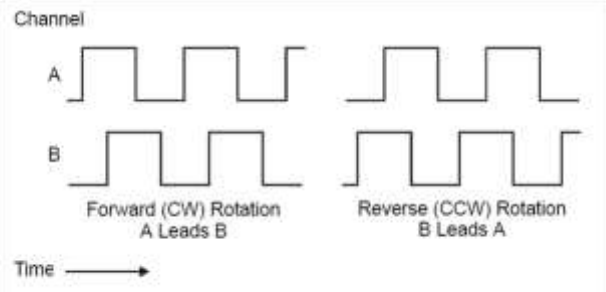


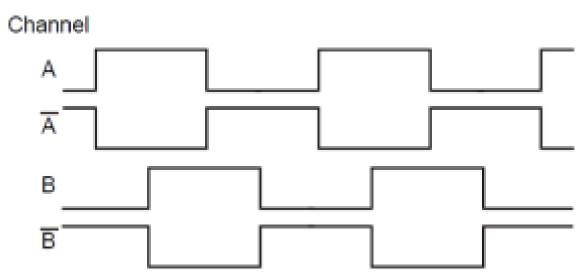
Absolute Optical Encoder

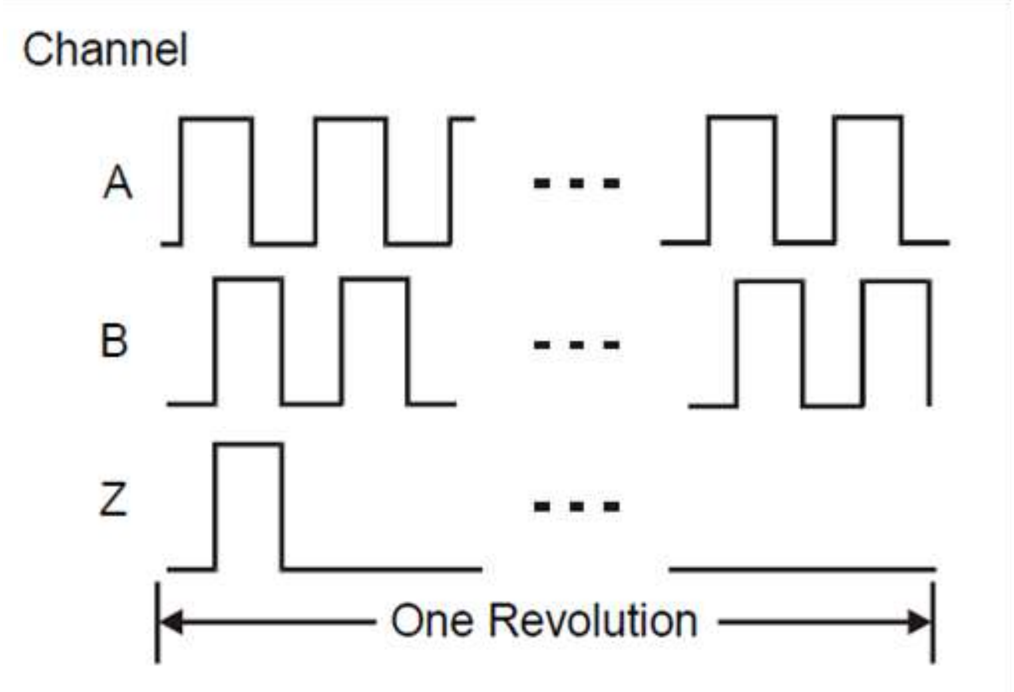


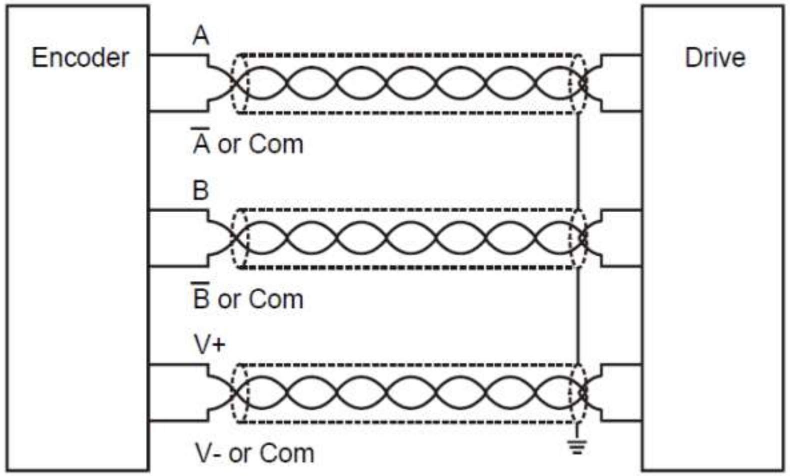


Slotted Disc
Light Source
Photo-Detector

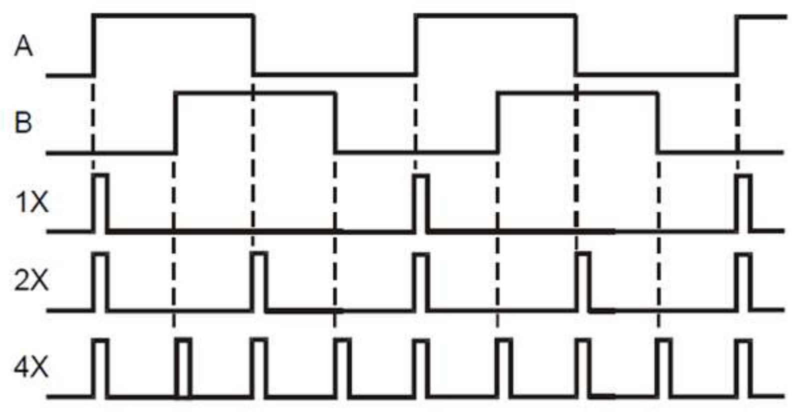

Channel
A
B
Forward (CW) Rotation
A Leads B
Reverse (CCW) Rotation
B Leads A
Time


Channel
A
$\overline{A}$
B
$\overline{B}$


Channel
A
B
Z
One Revolution



Encoder
Drive
A
A or Com
B
B or Com
V+
V- or Com



A
B
1X
2X
4X

Resolution

Pulses Per Revolution (PPR): The most fundamental specification of an encoder is its resolution, defined by the number of pulses generated per revolution of the encoder shaft. High PPR values enable more accurate and frequent speed measurements.

Performance Considerations

Minimum and Maximum Operating Speeds: The encoder PPR must be selected to ensure the pulse frequency is high enough for required performance at minimum speed and does not exceed the maximum output frequency of the encoder or the input frequency capability of the receiving circuitry.

Accuracy and Influencing Factors

Accuracy: It is the maximum variation between actual and theoretical pulse positions. However, the overall speed-measurement accuracy is also influenced by the encoder's timing, counting accuracy, and mechanical factors like backlash in the coupling.

$$\text{Pulse Frequency (Hz)} = \frac{\text{Speed (rpm)} \times \text{Resolution (PPR)}}{60}$$

Output Specifications

Single or Quadrature Outputs: Encoders may have single or quadrature outputs, with or without a zero marker. Complementary outputs can also be provided.

Voltage and Current Ratings: These should align with the circuitry receiving the signal. Most encoders offer square-wave outputs, with some variations available.

Encoder Application in Modern Systems

Preference for Incremental Encoders: Microprocessor-based adjustable-speed drives are designed for use with incremental encoders for optimal performance.

EMI Immunity: Attention to differential signals and wiring can enhance the EMI immunity of encoders to be equal to or better than analog tachometers.

Power Requirements

Voltage Needs: Common requirements are 12 and 24 VDC, with some models operating at 5 VDC.

Considerations for Long Cable Runs: Lower voltage models are not recommended for long-distance installations due to potential signal degradation.

Environmental and Mechanical Specifications

Operating Temperature Ratings: Encoders have specific operating temperature ranges, and exceeding these limits can lead to malfunction or damage.

Heat Considerations: Encoders can be affected by heat conducted from motors or machines.

Housing and Mounting: Various options offer different degrees of protection from environmental factors, with explosion-proof models available for hazardous environments.

Bearing Ratings: Accommodate a range of radial and axial loads.

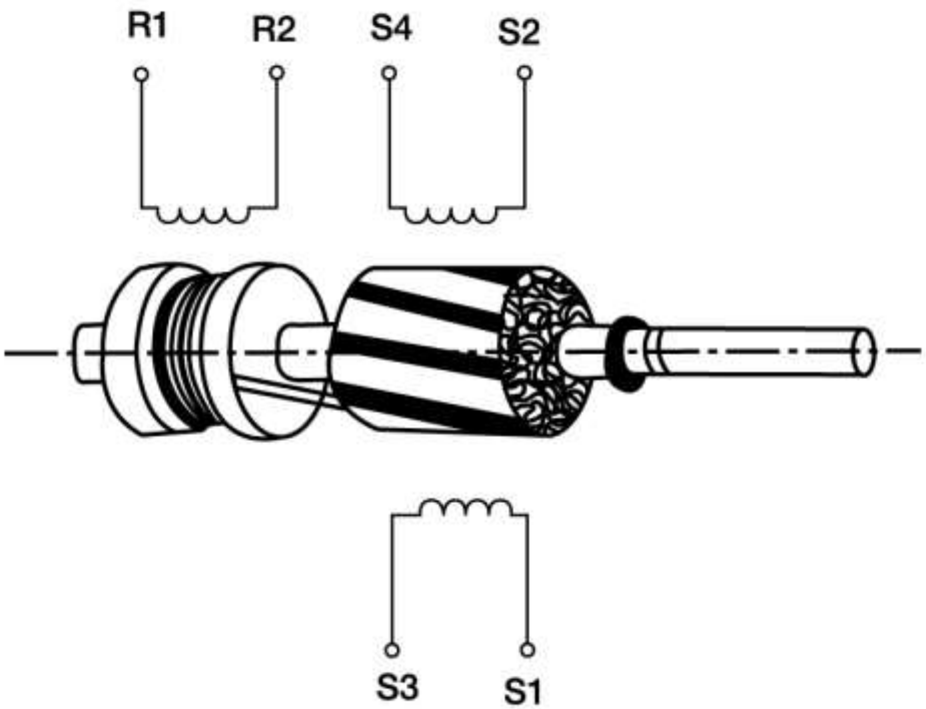
Installation and Wiring

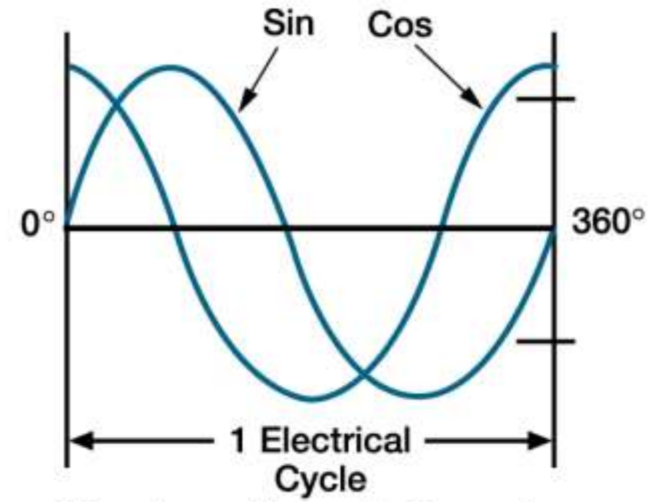
Careful Installation: Following the manufacturer’s installation and alignment procedures is crucial for reliable operation.

Wiring Specifications: Proper wiring, following encoder and drive manufacturer specifications, is essential for optimal performance.

Use of Shielded Twisted-Pair Cables: These are recommended for each output channel and power supply to reduce EMI and noise.

Resolver





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

Resolvers: Fundamentals and Applications

Characteristics

•**Definition**: A resolver is an electromechanical device that functions as a position transducer, resembling a small motor.

•**Primary Use**: It's mainly used in servo motor applications for precise rotor position feedback, critical for system accuracy.

Construction and Function

•**Similarity to AC Motors**: Resolvers are akin to AC induction motors, comprising a single winding rotor and fixed wire coils known as stators.

•**Operation**: A reference voltage applied to the rotor winding induces a voltage in the stator windings, producing an analog output proportional to the rotor's rotation.

•**Robustness**: Being free of electronics, resolvers are better suited for harsh environments compared to encoders.

Advantages

•**Absolute Measuring Instrument**: Resolvers retain their exact location during power outages and can transmit information over long distances with minimal electrical noise interference.

Comparative Analysis of Servomotors

Challenges

•**Diverse Criteria**: Comparing servomotors across different manufacturers is complex due to varied dimensions, torque, speed, voltage ratings, and cooling conditions.

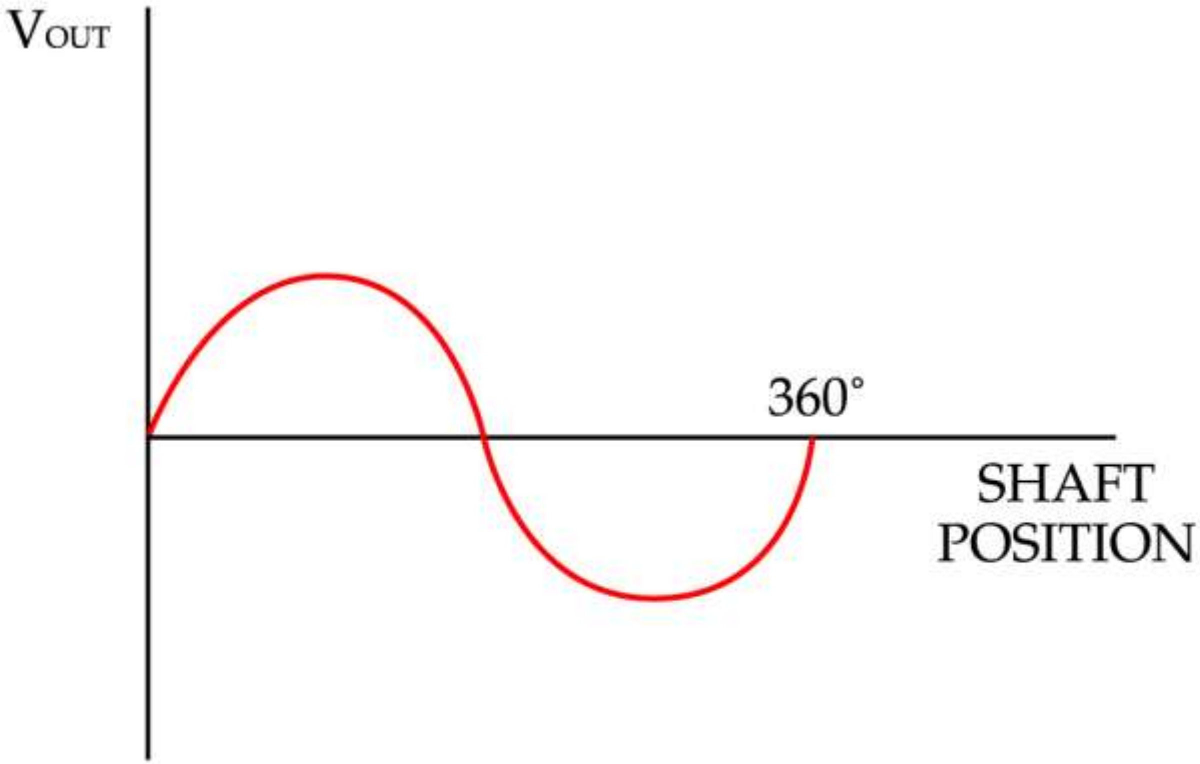
Focus Areas

•**Power Density and Inertia per Torque Unit**: Our review emphasizes these aspects, highlighting the implications of compact size and low inertia in high-performance servomotors.

Omitted Characteristics

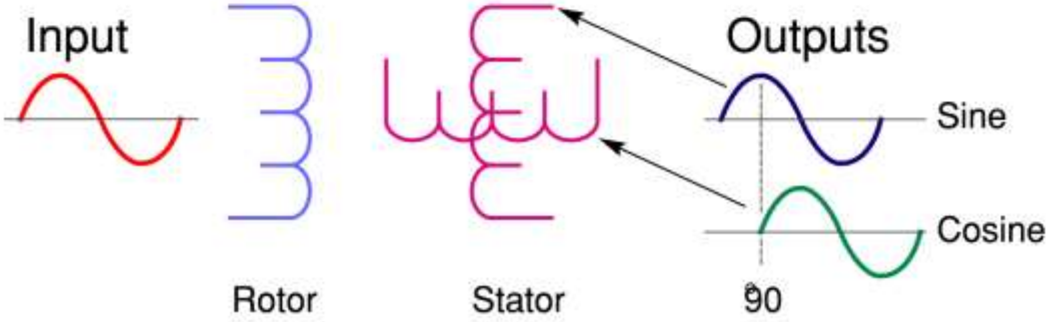
•**Cogging Torque and Thermal Efficiency**: These factors, though important, are not covered in this review due to their impact on motor power density and cost.

Simplified Resolver Output

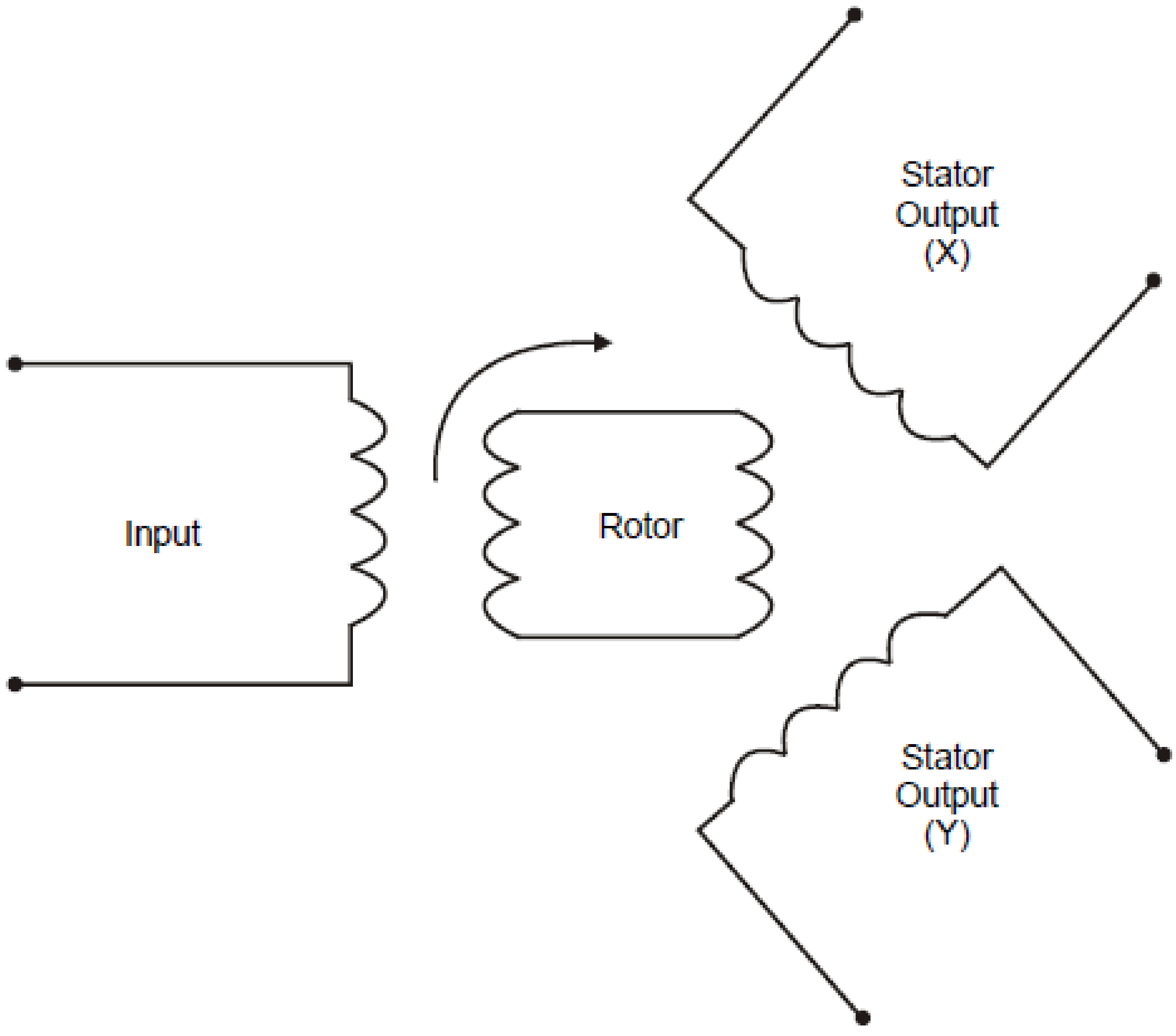


Baldor

Resolver Signals

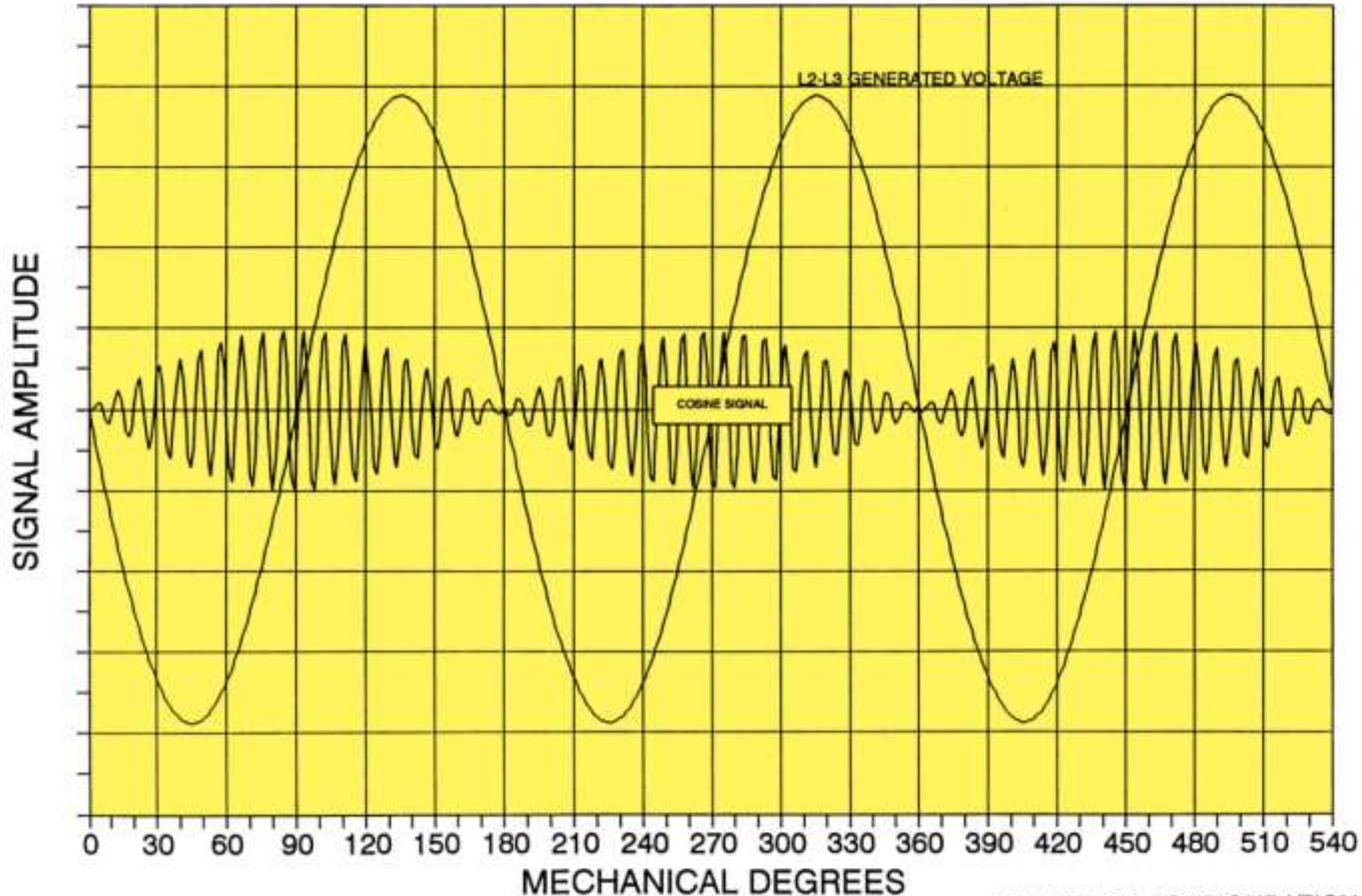


Baldor


Stator
Output
(X)
Input
Rotor
Stator
Output
(Y)

BALDOR

WAVEFORM 2
4 POLE MOTOR AND 1 SPEED RESOLVER



STANDARD CONFIGURATION
4 POLE MOTOR

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Motor Design Aspects

Torque Density

- **Materials and Technologies**: The differentiation among manufacturers arises from technologies that enhance slot fill ratio or reduce end turn length.

Permanent Magnet Material

- **Rare Earth Magnets**: Widely used across manufacturers, with some opting for more expensive magnets like SaCo for better thermal demagnetization resistance.

Insulation Class System

- **Class Variations**: Most manufacturers use Class F insulation, with some exceptions. Innovations like Lenze's reinforced insulation system offer greater thermal resilience.

Stator Core Design

- **Technological Advancements**: The evolution in stator core and winding technology significantly impacts motor compaction and power density.

Rotor Inertia and Dynamic Applications

Importance

- **Rotor Inertia**: A critical factor, especially for dynamic applications, where lower inertia is often more suitable.

Comparative Analysis

- **Cut-Core Motors**: A detailed comparison of various models with Cut-Core design is provided, showing nuanced differences in performance.

Thermal Performance

- **Insulation Class Impact**: The insulation class plays a significant role in the motor's continuous performance capabilities.

Prospective Technologies

Potential Developments

- **Advanced Technologies**: Innovations like "PCB End Turn" could further enhance motor power density.

Theoretical Best ServoMotor (BSM)

Conceptual Model

- **BSM Overview**: Incorporating the best of current servomotor technology, the BSM model showcases potential advancements in compactness and dynamic performance.

Thermal Management and Materials

Focus on Thermal Resistance

- **Innovations in Epoxy**: Developing epoxies with higher thermal conductivity could significantly improve motor power density.

Rotor Inertia's Impact on Dynamic Performance

Considerations

- **Rotor Design Variations**: Employing a hollow rotor design can reduce inertia by over 50%, enhancing dynamic performance.

Addressing Inertia Mismatch

- **Manufacturers' Approach**: Some, like Compumotor, have introduced motors with added inertia for high inertia mismatch scenarios, emphasizing that rotor inertia reduction caters to a specific market segment.

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

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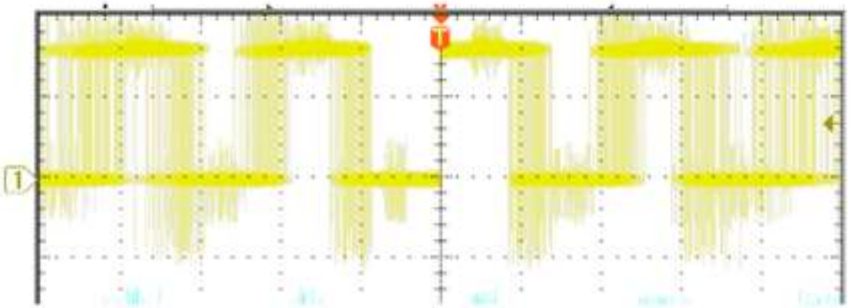
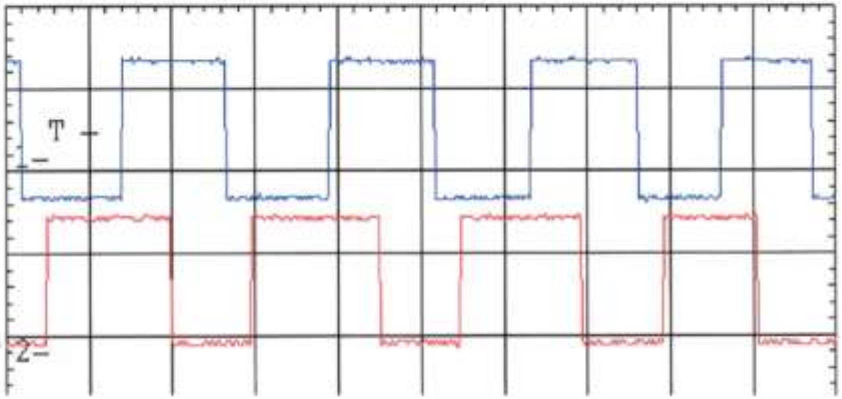
Encoder Waveforms



Encoder Jitter

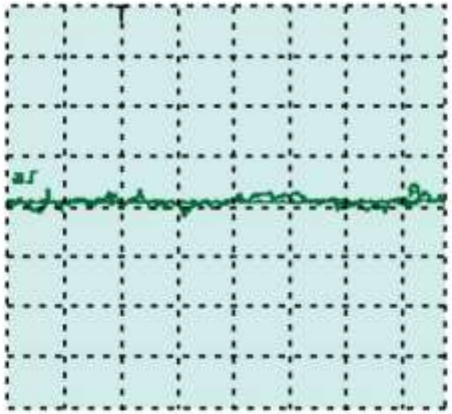


Symmetry Problems

Tachometer Waveforms

.5 volts/div.

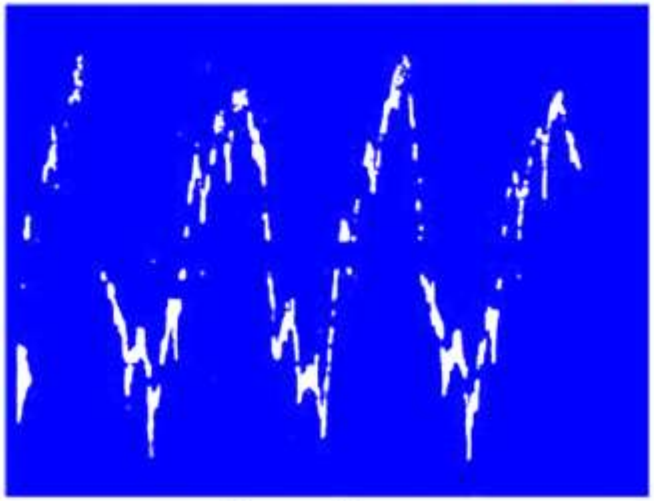
Tach output without filter



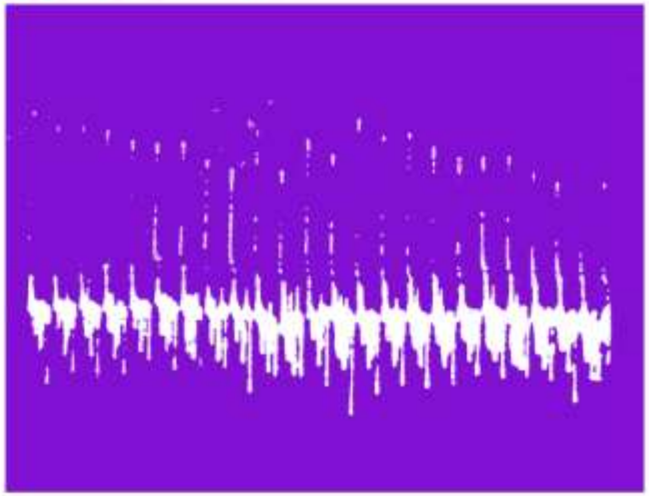
.5 volts/div.

Tach output with filter

Tachometer Waveforms



Open Bar



Poorly Fused Comm

Good Waveform

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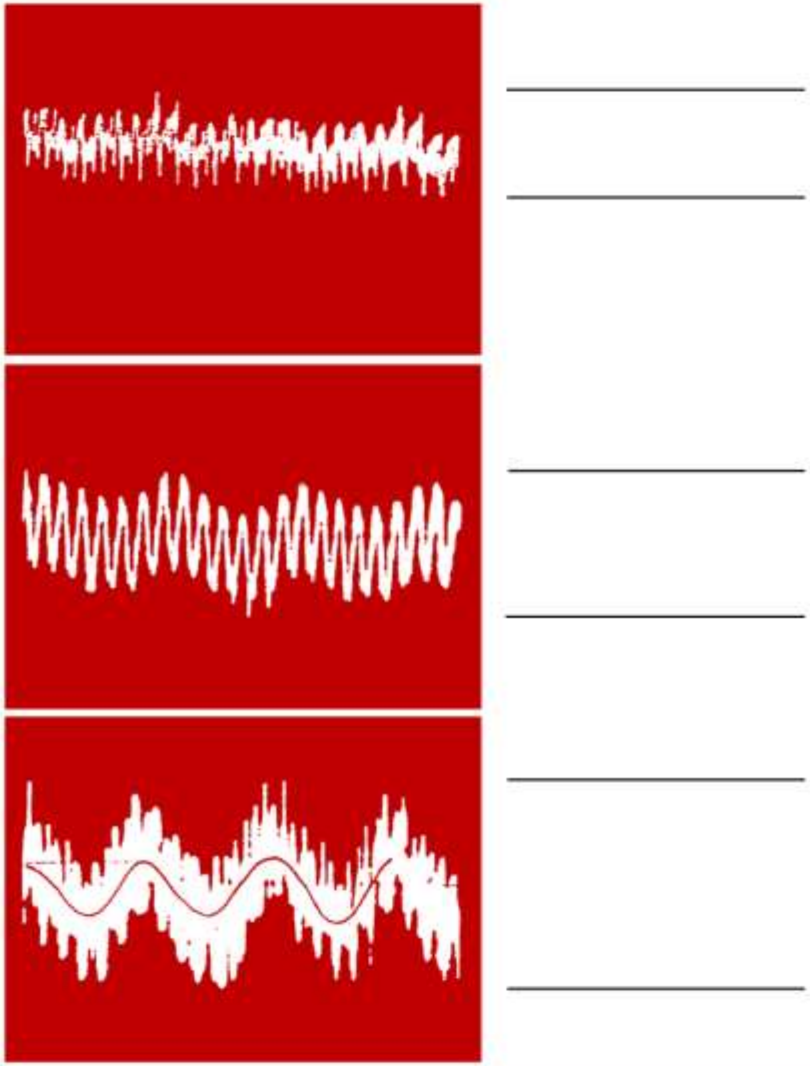
Tachometer Ripple

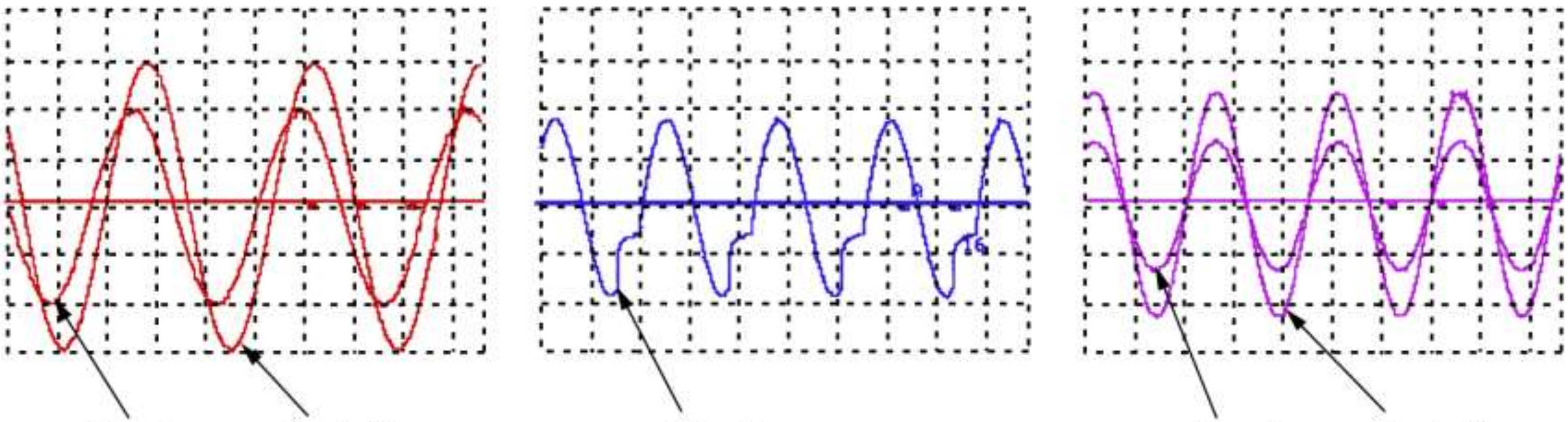


Peak-to-peak – 0.6

Peak-to-peak – 0.5

Peak-to-peak – 0.9

Resolver Waveforms



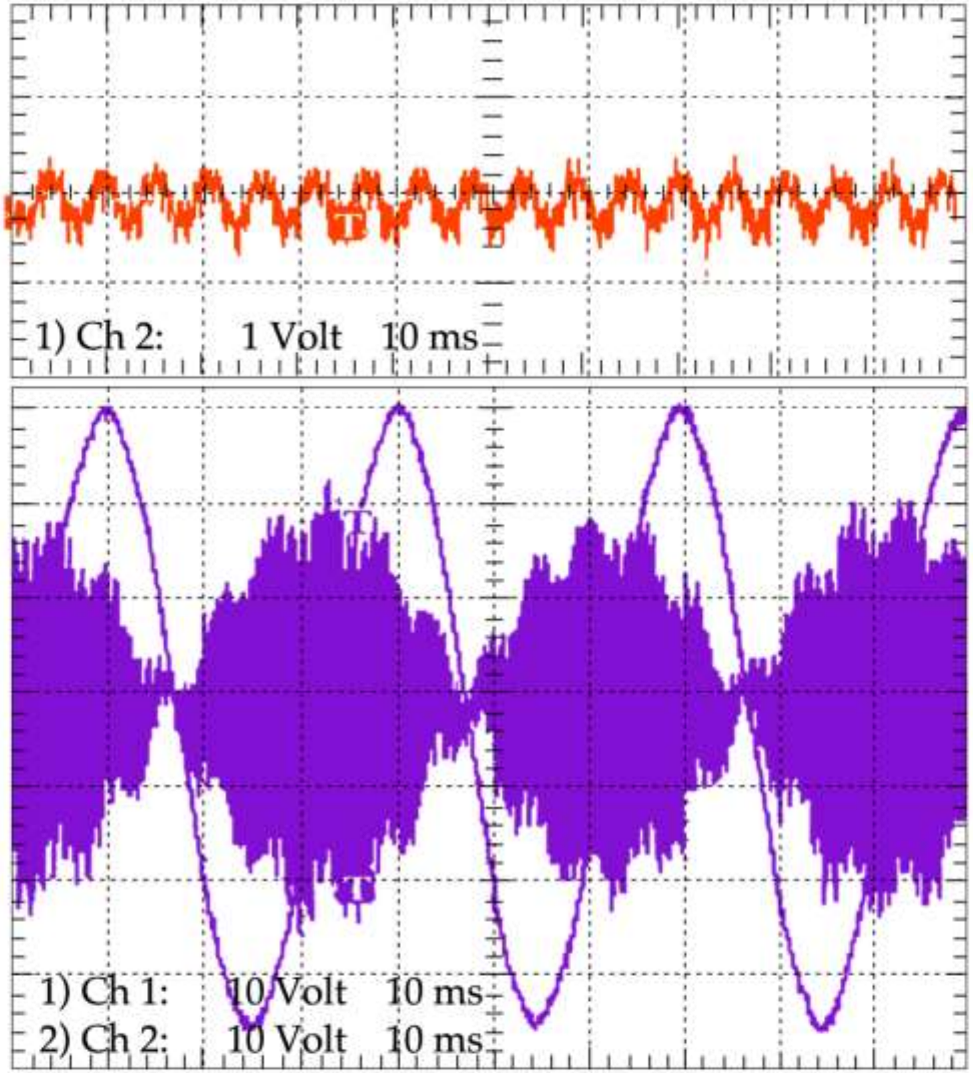
Signal Excitation Signal Signal Excitation

Excitation Frequency causing phase shift zero crossing to be out of phase

Excitation Voltage too high resulting in distortion of excitation waveform

Current Relationship

Resolver Waveforms



Bad Resolver

Good Resolver

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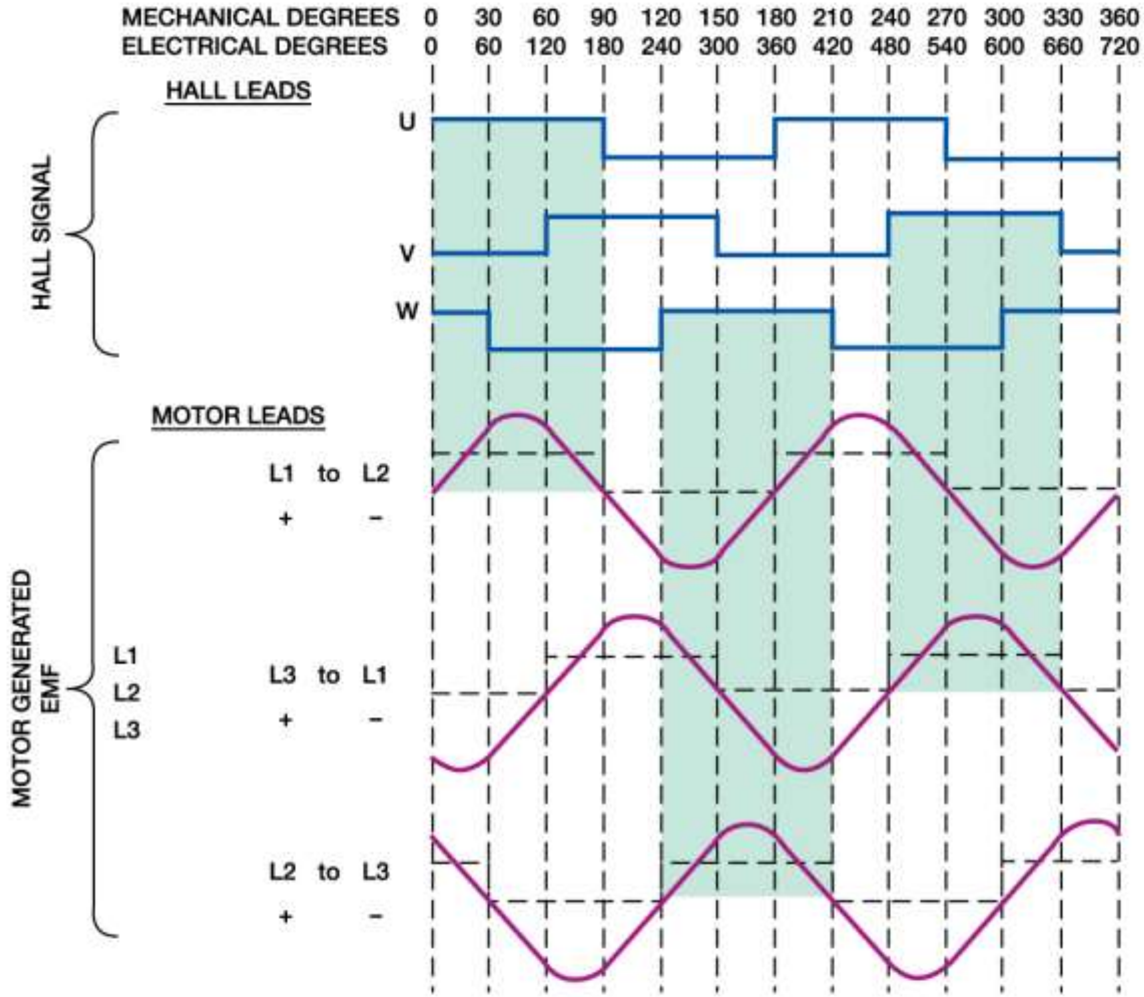
Hall Commutation



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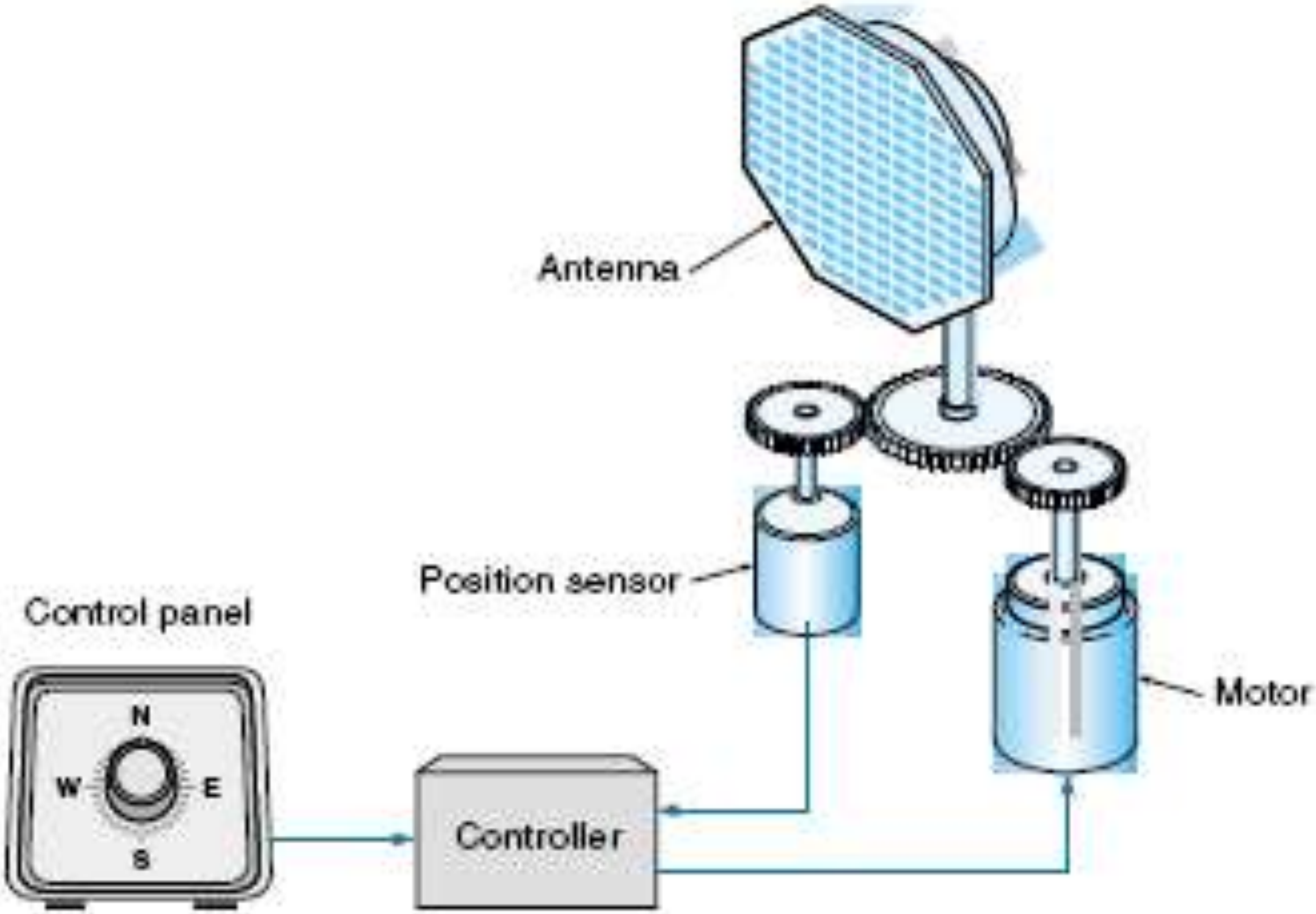

Antenna
Position sensor
Control panel
N
W
E
S
Motor
Controller

Motion Control

Definition and Components: Motion control encompasses the management of movement in open-loop or closed-loop electromechanical systems. Key components include:

Motors: The primary source of kinetic energy.

Mechanical Parts: These are the elements that physically move, translating electrical signals into motion.

Feedback Sensors (in closed-loop systems): These sensors provide real-time data to adjust and optimize performance.

Applications: You'll find motion control systems in automated assembly machines, industrial robots, and numerical control machines. Their versatility and precision are crucial in modern manufacturing and automation.

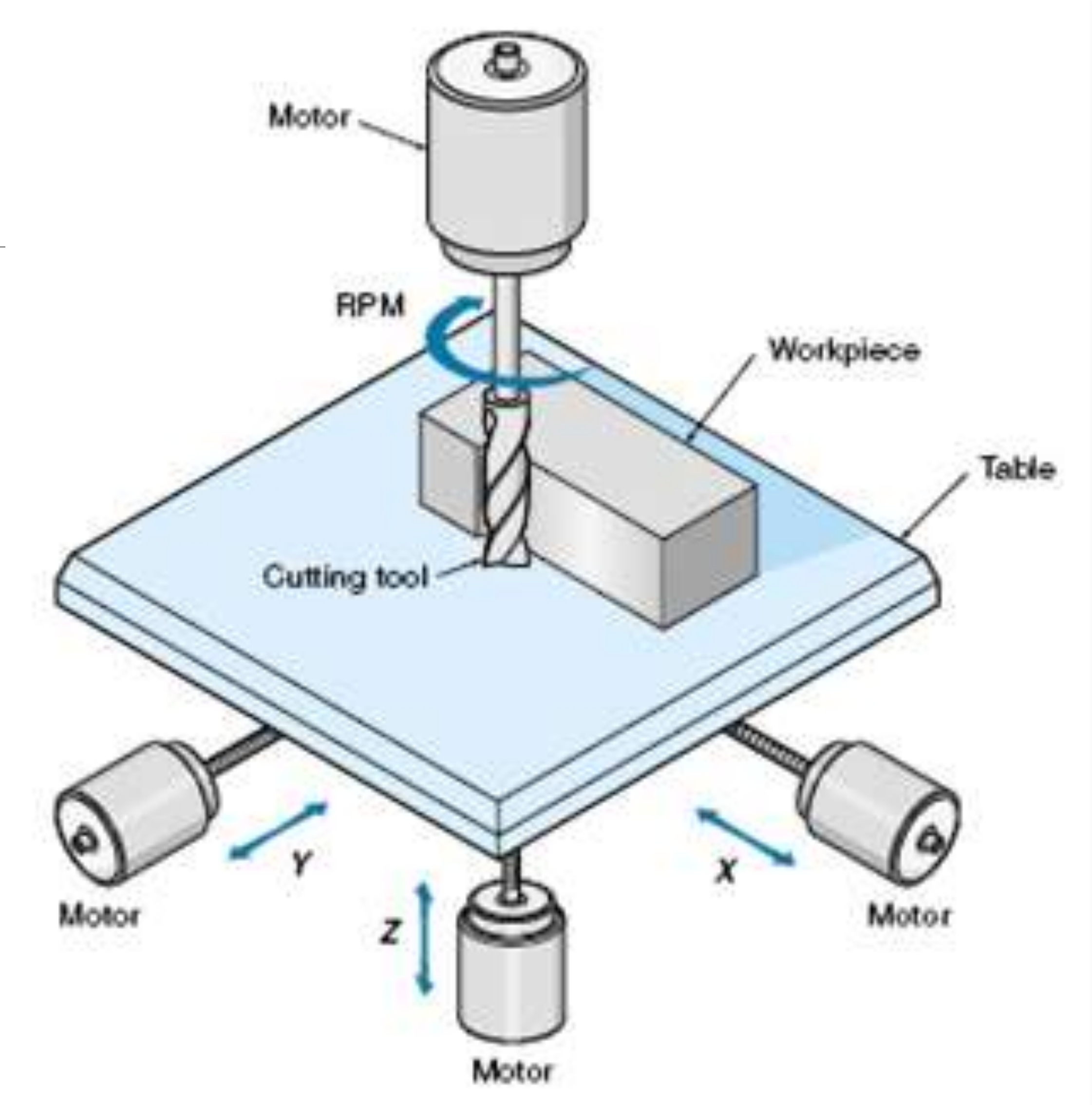
Servomechanisms

Fundamentals: Servomechanisms represent a specialized subset of motion control systems, defined by their closed-loop nature. They are essential for tasks requiring high precision and responsiveness.

Operation: A typical servomechanism controls either the output position, the output velocity, or both. The controlled variable, like the position of a radar antenna, is continuously monitored and adjusted.

Example: Consider a radar antenna positioning system. The user commands a position, and the servomechanism, through an electric motor and a controller, precisely aligns the antenna. This exemplifies the high precision and responsiveness integral to servomechanisms.

Numerical Control (NC)
Definition: NC refers to the digital control of machine tools like lathes and milling machines. It represents a significant evolution in manufacturing, enabling automation and precision.
Functionality:
Control Axes: Machines have specific axes (e.g., X, Y, Z) that are meticulously controlled.
Automated Movement: The workpiece is moved in three dimensions against a cutting tool, with parameters like velocity and cutting depth being meticulously managed.
Parameter Control: Parameters such as position (X, Y, Z) and rotation speed (RPM) are controlled in real-time to ensure precision manufacturing.
Evolution with CAD/CAM:
Traditional Approach: Initially, NC machines were programmed manually from part drawings.
Integration with CAD: Computer-Aided Design (CAD) has revolutionized this process. Now, a postprocessor can translate CAD drawings into manufacturing instructions.
Computer-Aided Manufacturing (CAM): This transition from CAD to a finished part exemplifies CAM, enhancing efficiency and precision in manufacturing.
Advantages:
Versatility: A single NC machine can produce a variety of parts.
Inventory Management: Reduced need for large parts inventories, as parts can be quickly manufactured on demand.
Computer-Integrated Manufacturing (CIM): This approach integrates computers at every stage, from customer orders to the final product delivery, representing a comprehensive shift in manufacturing paradigms.


Motor
RPM
Workpiece
Table
Cutting tool
Y
Z
X
Motor
Motor
Motor

Introduction to Industrial Robots

Industrial robots are quintessential examples of position control systems in mechatronics. These robots, often featuring an articulated arm with joints (shoulder, elbow, wrist) and an end effector, are central to a myriad of industrial applications. The end effector could be a gripper or a specialized tool, like a paint spray gun. Industrial robots streamline tasks such as material handling, assembly, machine loading/off-loading, spray painting, and welding.

Pick-and-Place Robots:

Functionality: These robots are tasked with simple movements - picking up objects and placing them elsewhere.

Control Mechanism: Often operating in an open-loop system without sophisticated feedback control, they rely on mechanical stops or limit switches for movement regulation, referred to as a “bang-bang” system.

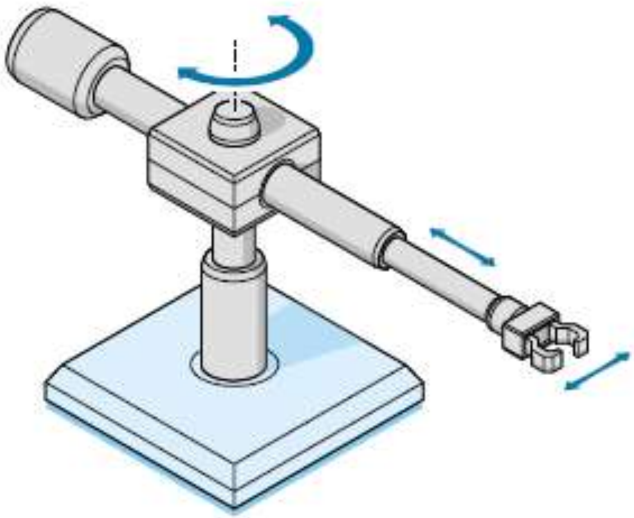
Example: A basic pick-and-place robot might use pneumatic cylinders for lifting, rotating, and extending its arm, programmed to repeat a set sequence.

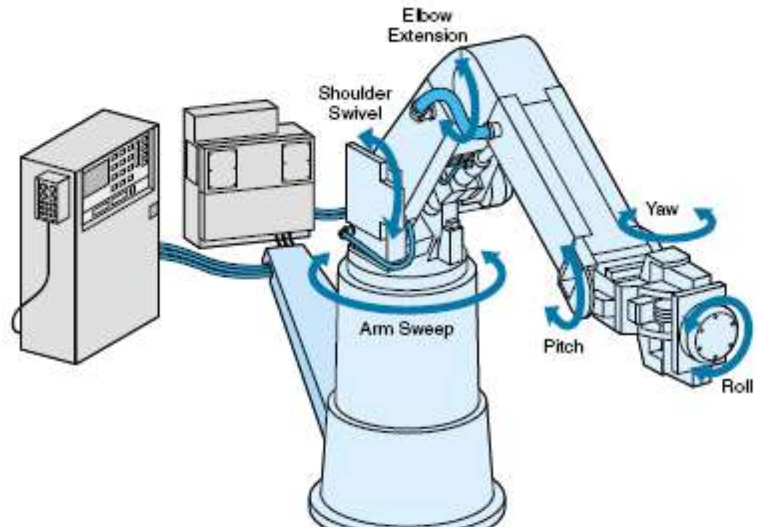
Advanced Industrial Robots:

Complexity: These robots utilize closed-loop position systems for precise control over each joint.

Degrees of Freedom: Typically, such a robot would have six degrees of freedom, enabling it to reach challenging locations.

Control and Programming: Accompanied by a dedicated computer-based controller, these robots can be programmed during a "teaching" phase to execute complex tasks, moving with specified velocity and reaching positions with high precision.




Elbow
Extension
Shoulder
Swivel
Yaw
Arm Sweep
Pitch
Roll

Sensors in Robotics

Sensors are critical components in robotic systems, providing vital data for control and feedback.

Position Sensors: These include potentiometers, optical rotary encoders, and linear variable differential transformers. They provide precise positional feedback for the control system.

Velocity Sensors: Examples are optical and direct current tachometers. They measure the speed of moving parts, crucial for dynamic control.

Proximity Sensors: These include limit switches, optical proximity switches, and Hall-effect switches. They are used to detect the presence or absence of objects or determine their relative position.

Load Sensors: Such as bonded-wire strain gauges and semiconductor force strain gauges, these sensors measure forces like tension and compression.

Pressure Sensors: Including Bourdon tubes, bellows, and semiconductor pressure sensors, these devices measure fluid or gas pressure.

Temperature Sensors: Types include bimetallic sensors, thermocouples, resistance temperature detectors, thermistors, and IC temperature sensors. They are essential for monitoring and controlling temperatures in robotic operations.

Flow Sensors: These include orifice plates, venturis, pitot tubes, turbines, and magnetic flowmeters, used for measuring fluid flow rates.

Liquid-Level Sensors: These sensors, both discrete and continuous types, are used for monitoring the level of liquids in a system.