Dr. Norbert Cheung's Lecture Series

Level 5 Topic no: 4

Motion Sensing

Contents

Email: norbert.cheung@polyu.edu.hk
Web Site: www.ncheung.com

1. Sensors Classification and Specification

Sensors Classification

Analogue Sensors - Output an analogue voltage or current. Possess infinite resolution. Performance can be affected by noise

- Synchros and Resolvers
- Variable Reluctance type sensors
- Resistance and Capacitance Variation

Digital Sensor - Output a discrete signal for each step change; possesses finite resolution. Noise free.

- Pulse generator
- Incremental encoder
- Absolute encoder

Hybrid Sensor - Use electronics to increase the resolution or enhance the performance of the sensor

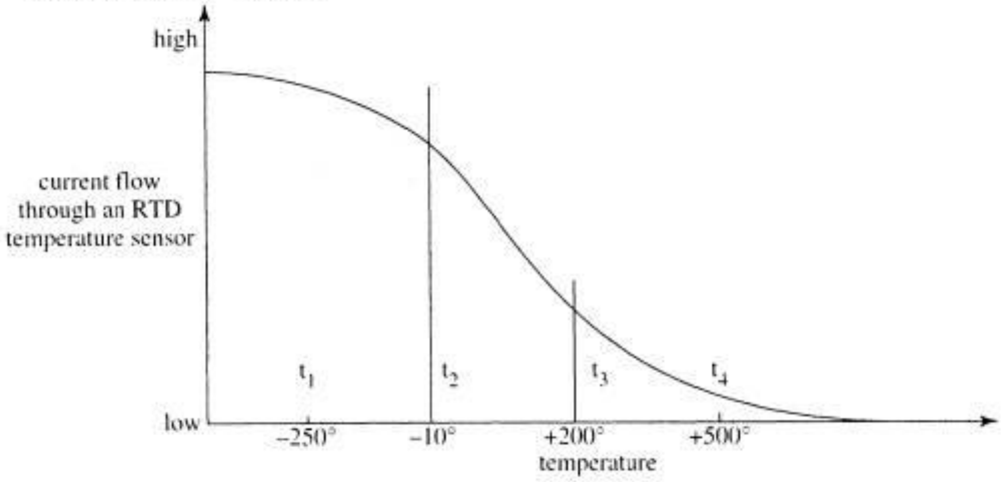
- Frequency generator
- A/D type Interpolator
- Multi-pole resolver

Sensors Specification

Range: limits of the measured variable that a sensor is capable of sensing

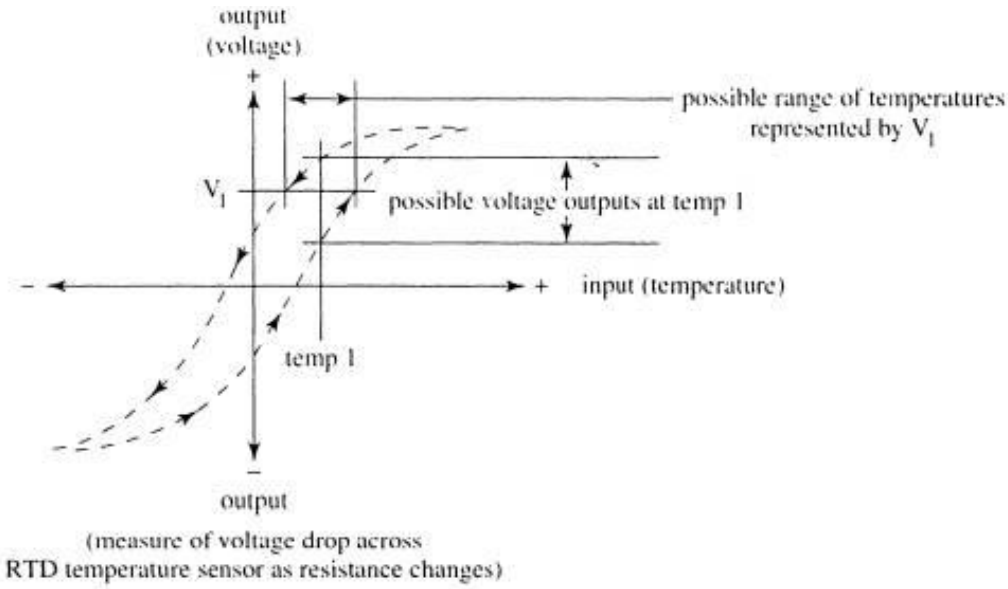
Span: Usefulness of the measuring range.

SPECIFICATIONS:
Span (or range): −10 to +200 degrees Celsius
Linearity error: +/− 2 degrees

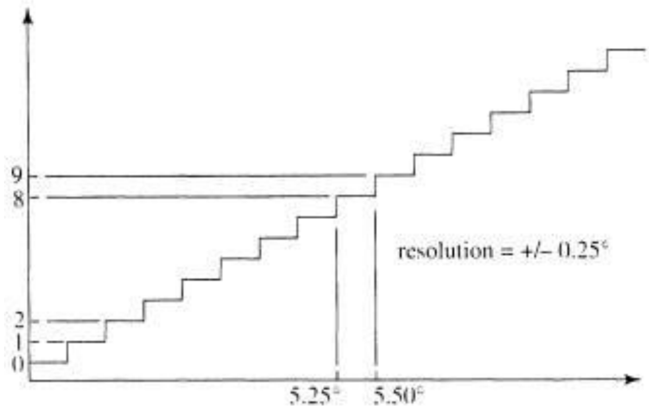


Error: The error between the ideal and the actual output of a sensor can be due to many sources. The types of error can be described as resolution error, linearity error, and repeatability error.

Resolution: The resolution value quoted for a sensor is the largest change in measured value that will not result in a change in the sensor's output. Resolution error may due to hysteresis or digital quantization.



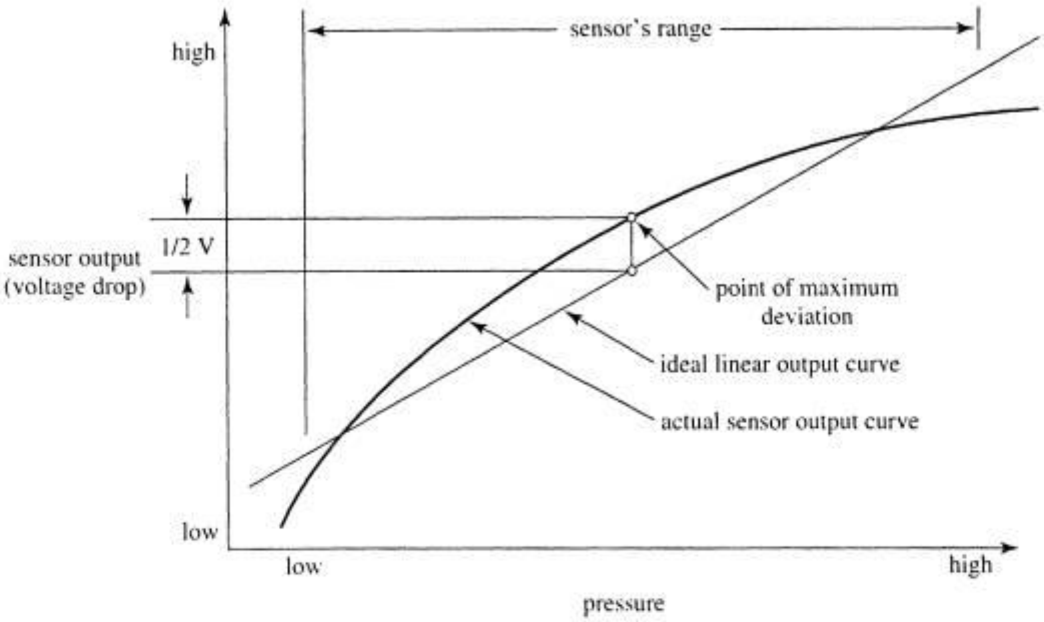
Hysteresis and resolution in a temperature sensor



Resolution in a digital temperature sensor

<u>Repeatability</u>: the range of output values that the user can expect when the sensor measures the same input values several times. Repeatability does not necessarily mean that the output value accurately represents the sensed condition! Looseness in mechanical linkages is one source of repeatability error.

Linearity: The ideal transducer is one that has an output exactly proportional to the variable it measures (within the sensor's quoted range). No transducer's output is perfectly proportional to its input, however, so the sensor user must be aware of the extent of the failure to be linear.



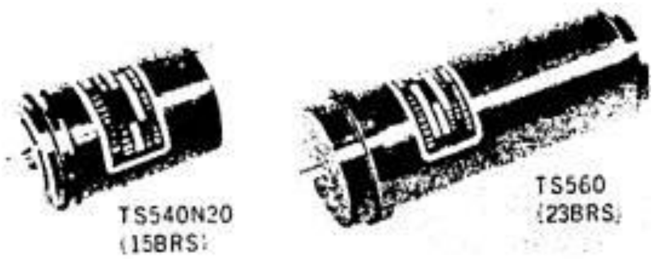
Non-linearity in a pressure sensor

2. Magnetic Type Rotary Position Sensors

Comparison of different type of magnetic rotary position sensors

Names of Rotary Sensors	Function	Characteristics	Perspective
Synchro	Torque, Angle Transfer, Remote Control, Induction Type	Strong Signal Level Absolute Type	Decreasing Special Needs
Resolver	Rotary, Angle Detector, Computation of Trigonometric Functions, for Military, for Aircraft	Strong Signal Level Absolute Type Expensive, Especially for Transducers	Promising for Industrial Purpose
Tachometer Generator	Speed Detection, Brushless DC or AC	Pulsation Component Brush, Ripple in the low speed regime.	Promising For Coreless Type
Electrostatic Type	Super-Small Type Rotary Angle Detector	Weak Signal Level	Uncertain
VR Type Resolver	Portable and Less-Expensive Rotary Angle Detector	Rigid Structure Inexpensive, Medium Precision	Large Expectations (Absolute Type)
VR Type Multi-Pole Resolver	Portable, Less-Expensive, High-Resolution Rotary Angle Detector	Rigid Structure High Precision	Medium Expectations
Microsyn	Small Displacement Angle Detector	Locally High Precision for Military Use	Uncertain

Synchro/Resolvers



A Resolver (left) and a Synchro (right)

- The resolver is slightly less complex, and it looks very similar to a DC motor.
- It has field windings (two of them, at 90 degrees to each other) and a winding in the rotor.
- The rotor winding is electrically connected to the outside world through slip rings.
- In operation, the resolver has more in common with a transformer than it does with a motor.

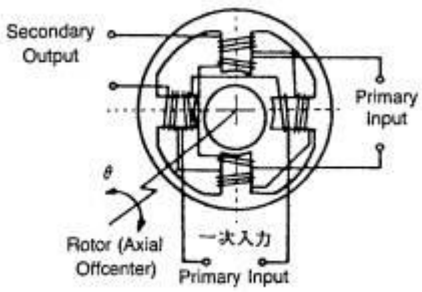
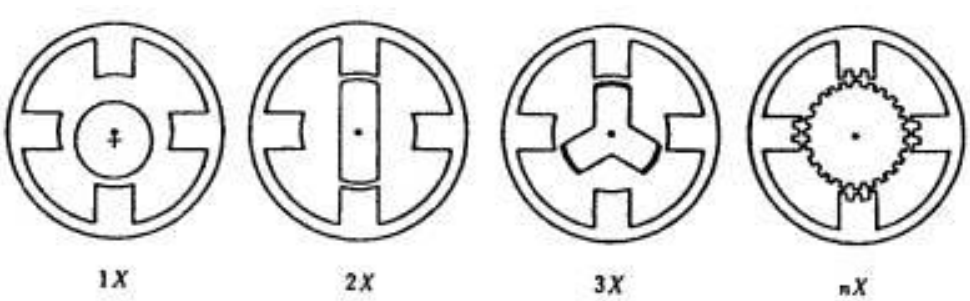
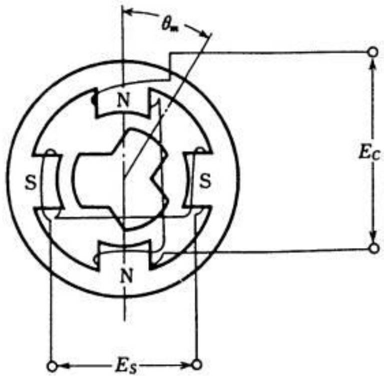


Figure 2.3. Example of a VR type resolver (NSD, Ltd.).

An Off-Centre Variable Reluctance (VR) Resolver



Different Pole-Pitch to increase the Resolution



The Vernier Resolver (3x, 6 pole-pair)

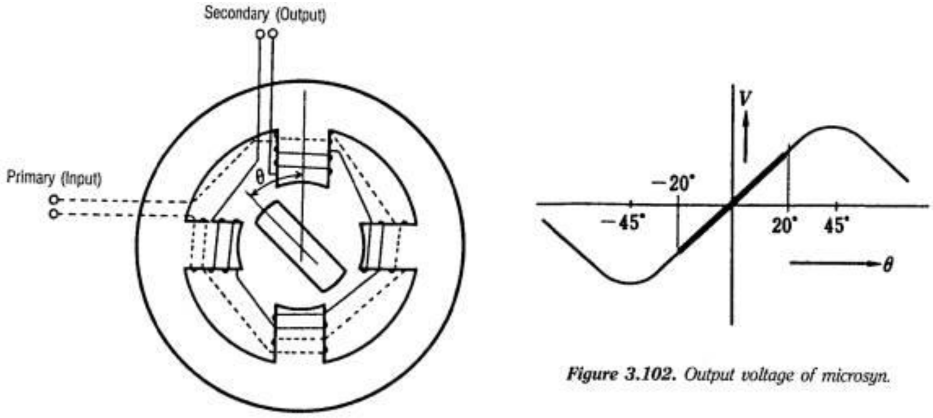
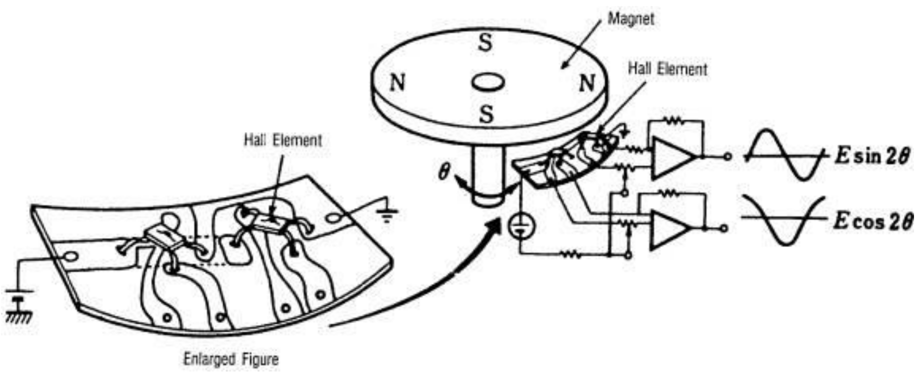


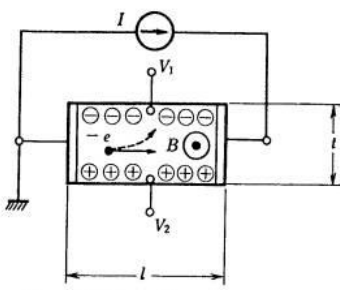
Figure 3.102. Output voltage of microsyn.

The Microsyn resolver



The Hall Effect element resolver

$$V_H = R_H \frac{BI}{t}$$



Principle of Hall Effect

Synchros are different from resolvers in that they include a third "field" winding. The three "field" windings are at 120 degrees from each other. This extra winding allows synchros to be used where added precision is required.

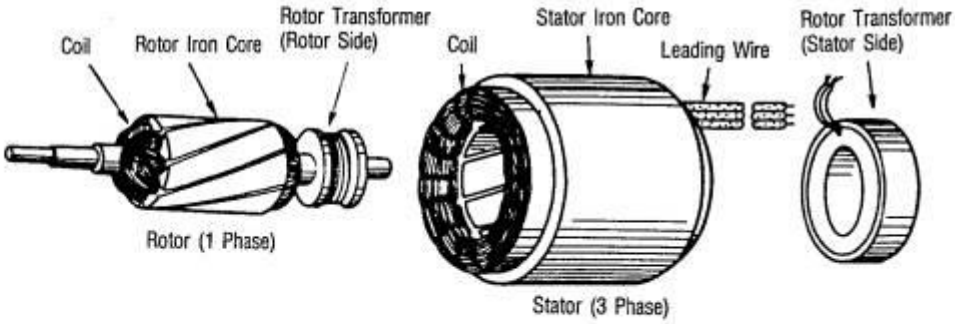
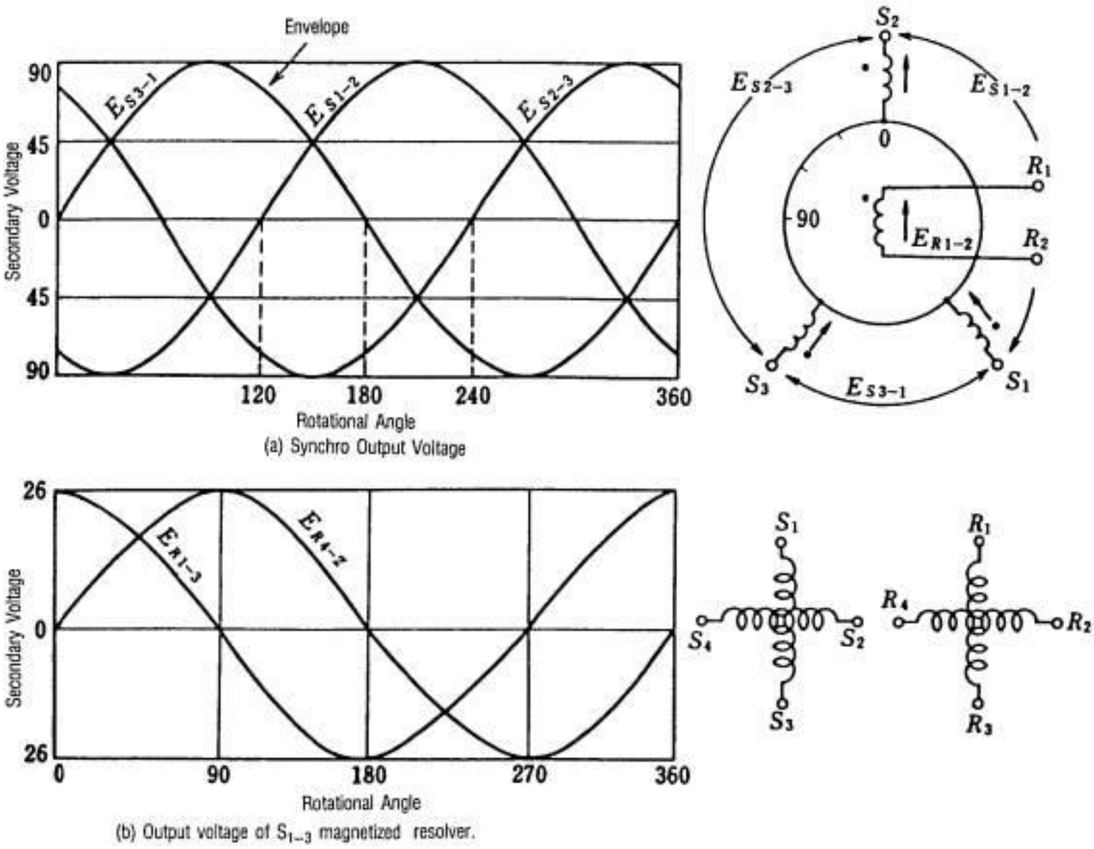


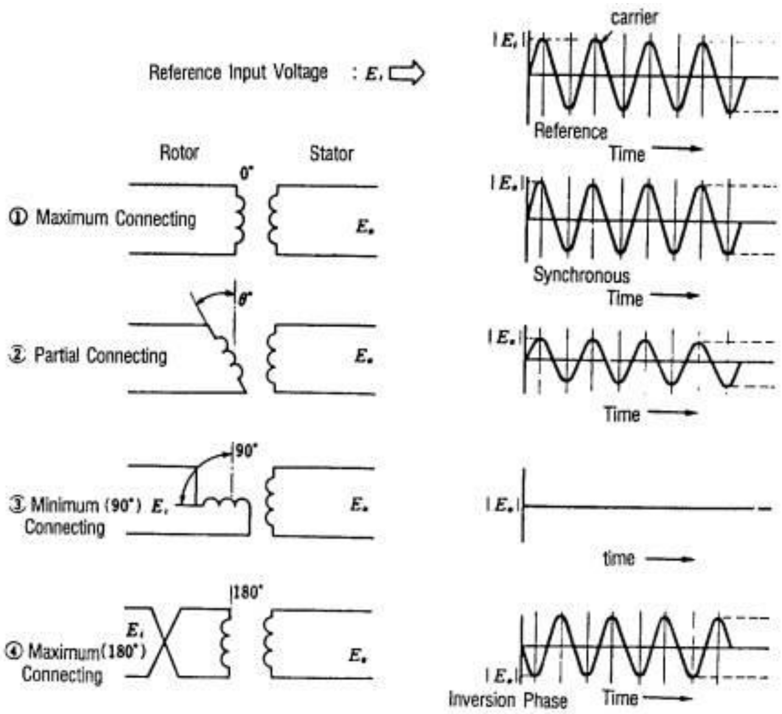
Figure 3.62. Assembly of brushless synchro/resolver.

A Brushless Synchro

$$\left.\begin{aligned} E_{S3-1} &= KE_{R1-2}\sin\theta \\ E_{S1-2} &= KE_{R1-2}\sin(\theta-120^\circ) \\ E_{S2-3} &= KE_{R1-2}\sin(\theta-240^\circ) \end{aligned}\right\} \qquad (3\cdot10)$$

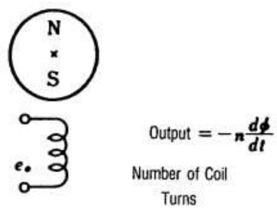
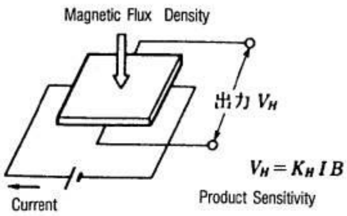
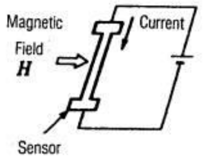
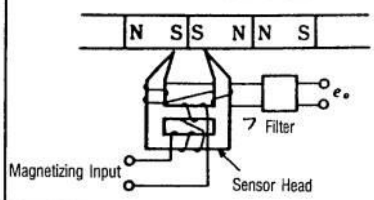


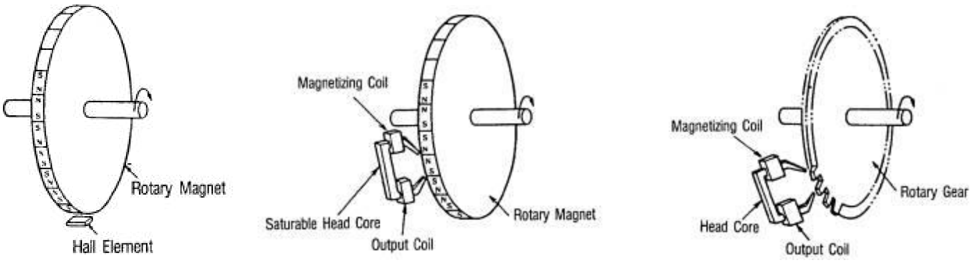
Interconnection and Output Voltages of the Synchro



The Output Waveforms

The Magnetic Pulse Generators (Classification)

No.	Sensor	Principle	Characteristics
1	Coil (Induction)		① Strong Environmental Immunity ② No Output at Stop
2	Hall Element		① Large Output Voltage ② Poor Temperature Characteristics
3	Magnetic Resistance Element Effect	 Variable Resistivity Depending On Magnetic Field	① Simple Structure ② Good Frequency Characteristics
4	Magnetic Modulation Type Head		① Output Available at Stop ② Poor Frequency Characteristics ③ Complicated Structure of Sensor



Hall Effect Type, Magnetic Modulation Type,
and Geared Magnetic Modulation Type.

3. Optical Type Rotary Position Sensors

Types of optical encoders

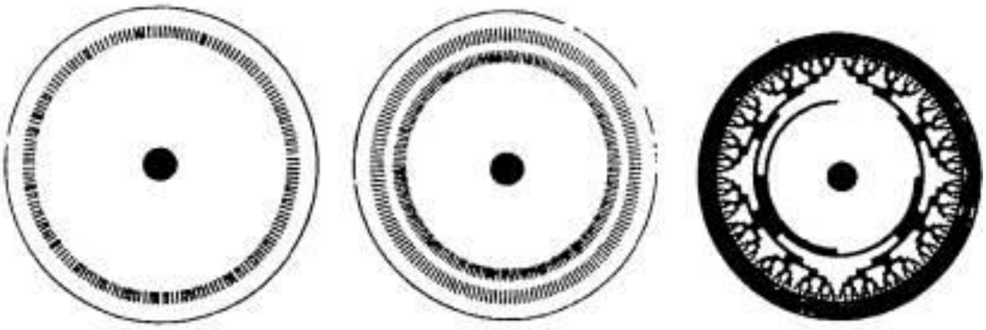
- Pulse generators (PG) - single channel output
- Incremental encoders (IE) - two & three output channels
- Absolute Encoders (AE) - chan dependent on resolution

Signal	Clockwise	Counter-clockwise

Outputs of incremental encoders and their decoded pulse trains

Table 2.2. Comparison of function in digital sensors.

Function \ Kinds of Sensors	PG	IE	AE
Pulse Signal (Speed)	Yes	Yes	Yes
Reference Point Signal	Yes	Yes	Yes
Rotary Direction Indication	No	Yes	Yes
Absolute Position Detection	No	No	Yes

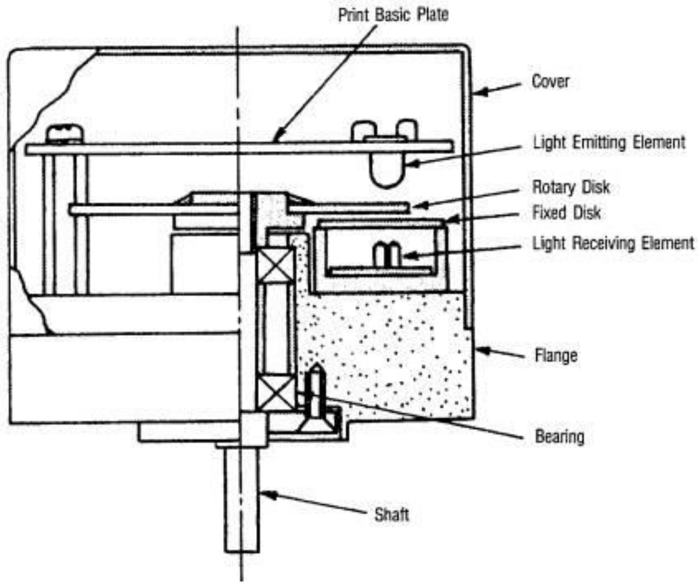


(a) PG (b) IE (c) AE

Table 2.4. Comparison of functions and characteristics of digital sensors.

Rotary Sensor	Function	Characteristics	Perspective
Pulse Generator (Optical, Magnetic)	Only Pulse Count Unclear Rotary Direction	Hard to Handle Inexpensive	Less Expectation, Due to Impossible Direction Indication
Incremental Encoder (Optical, Magnetic)	Possible Indication of Rotary Direction by A & B Phases Same Principles as Pulse Generator With Original Point Signal	Inexpensive With Minimum Function	High Expectation Promising Price
Absolute Encoder (Optical, Magnetic)	2^n Pulse Separation With Bit Sensor Possible Detection of Absolute Position	Expensive Weak Shock Resistance High Performance	Medium Expectation Problems With Structure
Moire Sensor Optical	High Resolution (Optical)	Hard to Handle	Uncertain

Pulse Generators, Incremental Encoders and Absolute Encoders



Structure of Rotary Optical Encoders

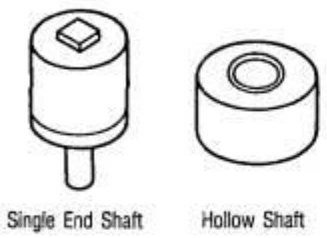
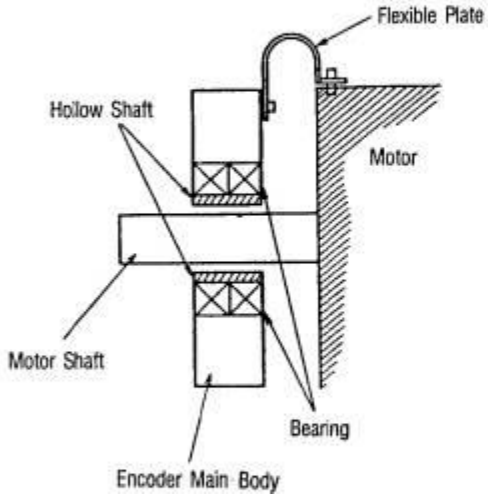
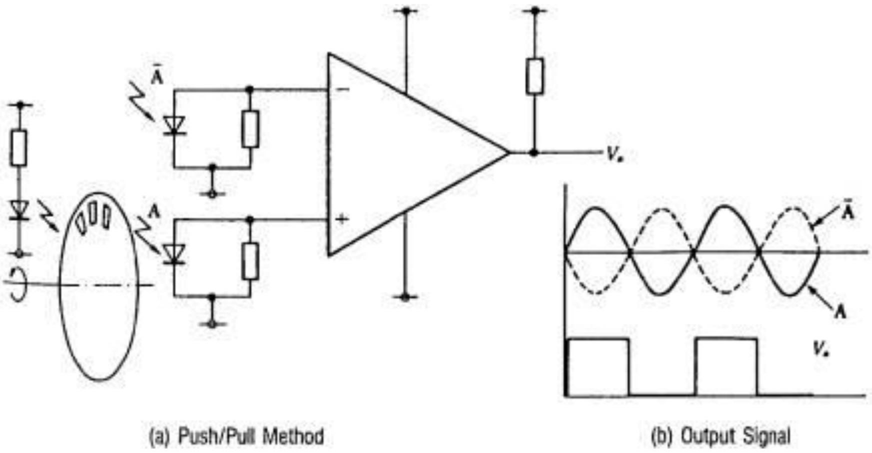


Figure 3.11. *Shaft configuration.*



The Shaft Configurations



The Push-Pull Method to obtain Symmetrical Sine Wave Output

4. Linear Position Sensors

Optical Type

- Most widely used, can be glass type or reflective type.
- High resolution, very low temperature coefficient.
- Can be used very near the motors.
- The signal output comes from the averaging of light from the gratings, individual defects on a single grid line will not affect the readings.

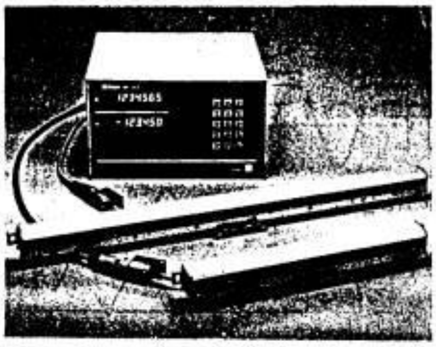
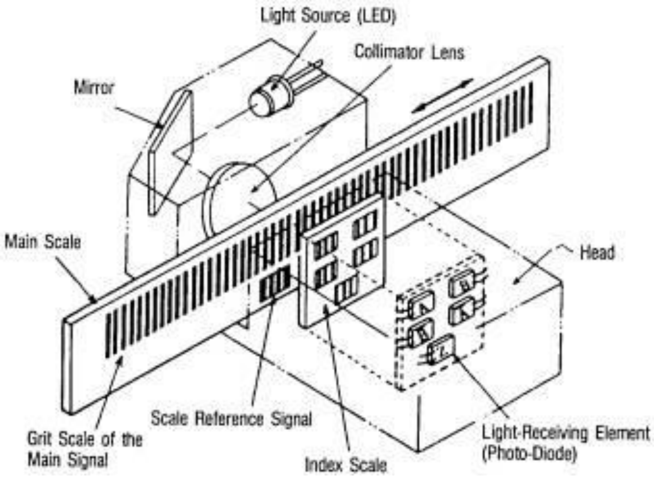
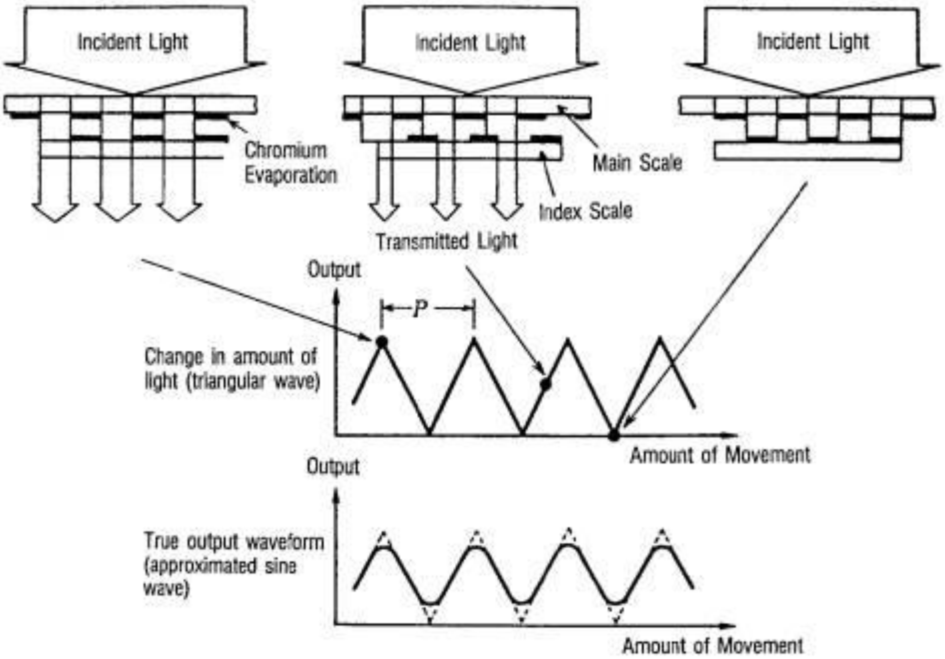
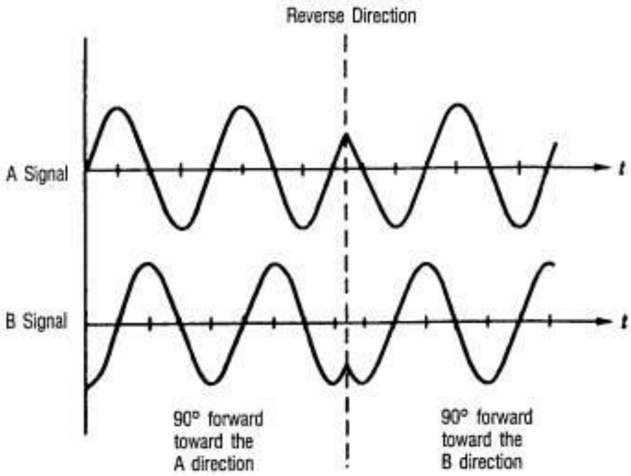


Figure 4.2. Position scale (Nihon Kogaku Kogyo.



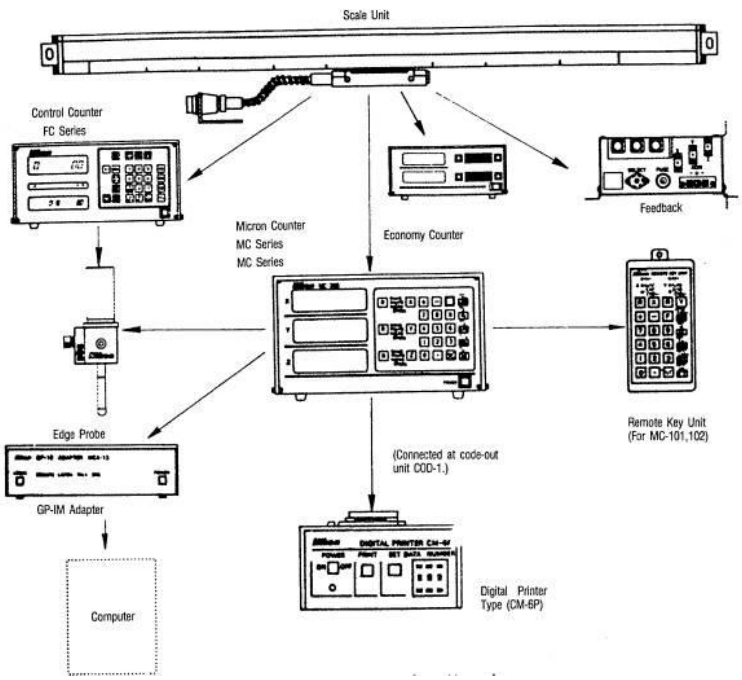


The Operating Principle



The Output Signals

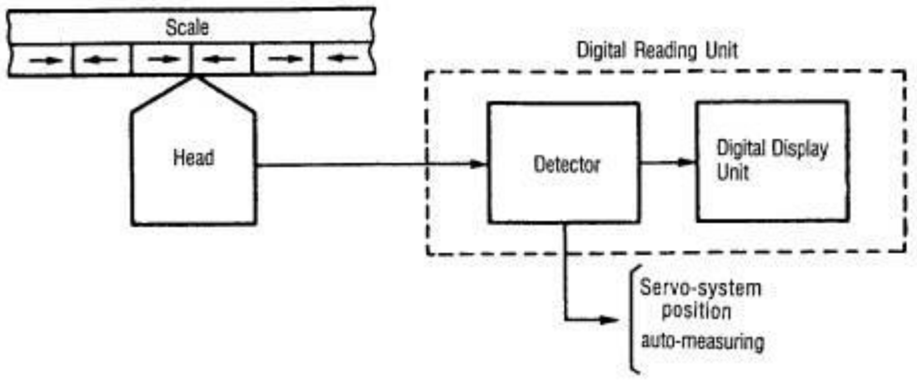
Analogue versus Digital Outputs



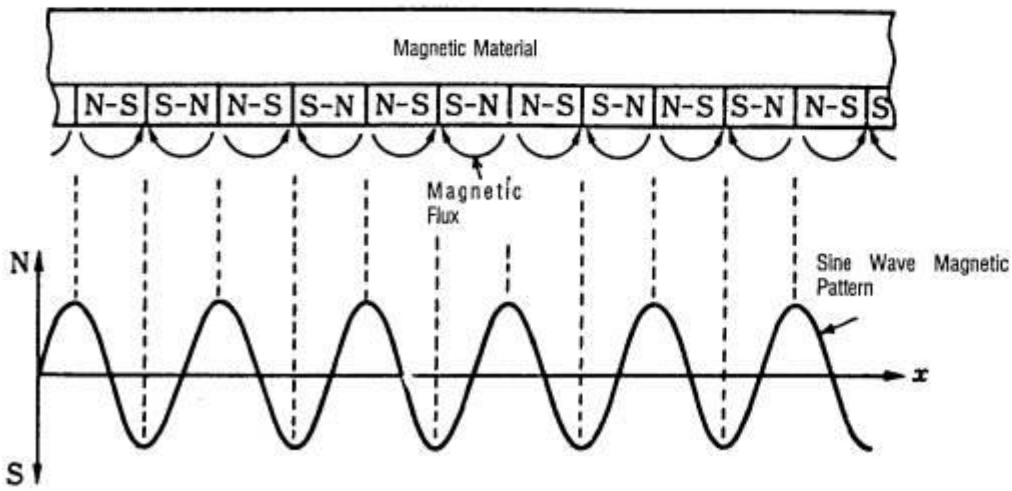
The Overall Setup

Magnetic Type

- The scale is a magnetic track recorded with a predefined magnetic pattern.
- A magnetic read-head is used to detect the pattern.
- A multi-gap head is used, so that it can detect the signal even at zero velocity
- The output has a fixed voltage output, but its phase will vary with position



The Overall Setup



Magnetic Pattern on the Scale

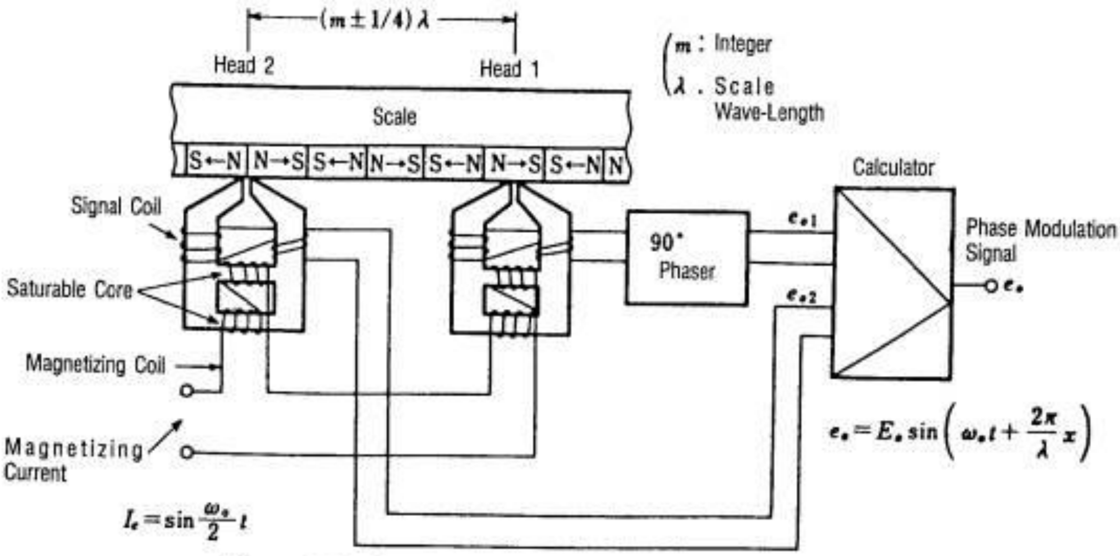
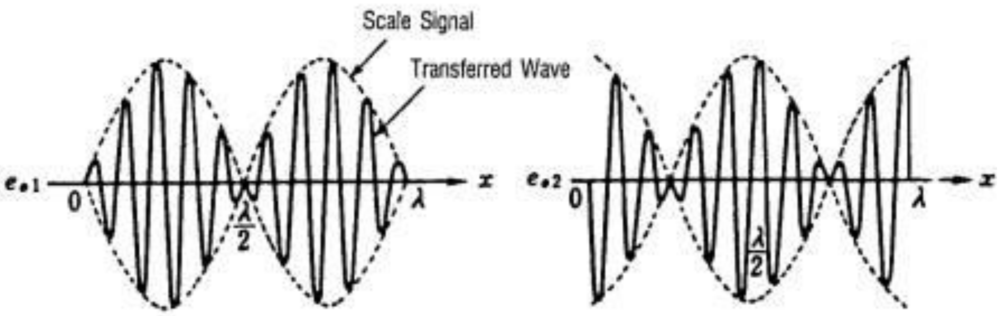


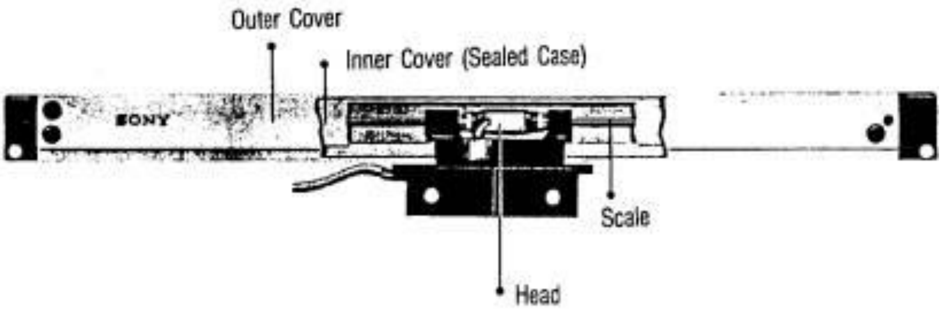
Figure 4.11. Structure, Positioning, and detecting circuit block diagram.

The Detection Circuit

$$e_{o1} = E_o \sin \frac{2\pi}{\lambda} x \cdot \cos \omega_o t \qquad (4 \cdot 7)$$



The Detected Waveform



The Outside Appearance

5. Velocity Sensors

1. AC tachometer - induction type, voltage variation
2. PM type AC tachometer - variation in frequency and voltage
3. DC tachometer - variation in DC voltage
4. Frequency generator - variation in pulse frequency

Induction Type Tachometer

- Only the drag cup rotates.
- The drag cup, when it rotates, creates an eddie current which distorts the magnetic flux.
- In this case the excitation coil is coupled to the output coil.

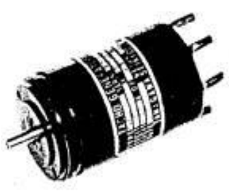


Figure 5.1. AC tachometer.

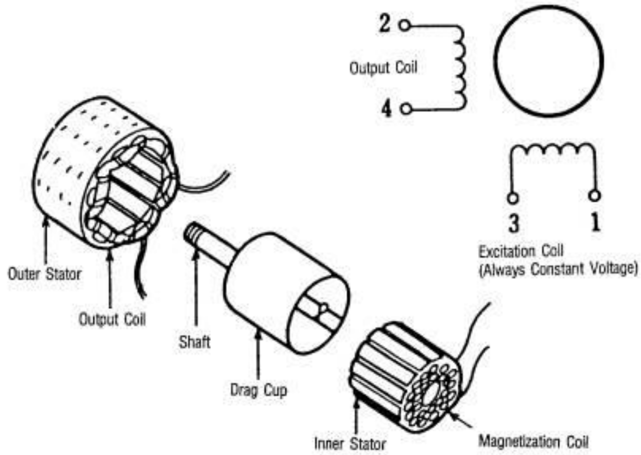
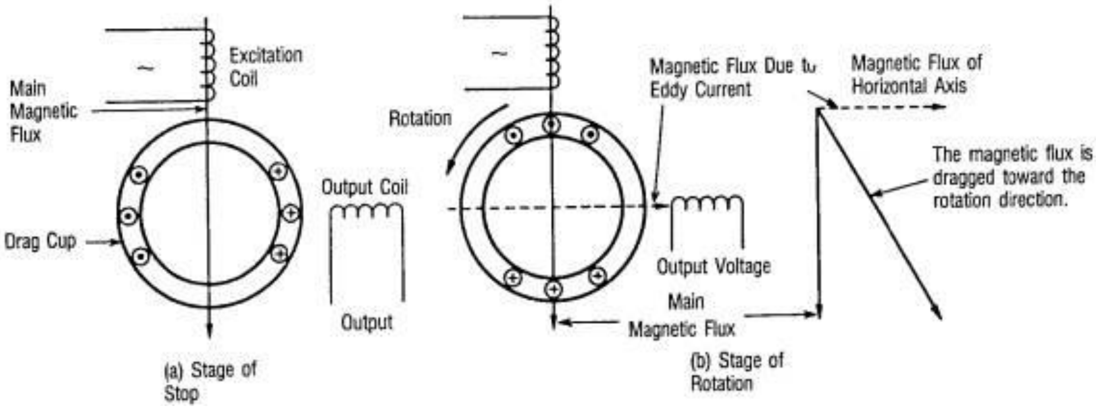


Figure 5.2. Structure of induction type AC tachometer.



The Induction Type Tachometer and its Operating Principle

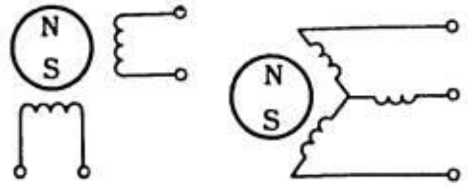


Figure 5.5. Principle diagram of permanent magnet type AC tachometer.

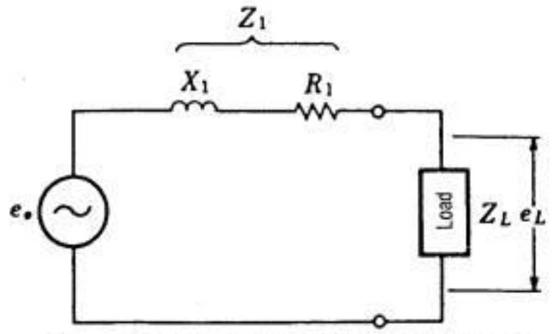
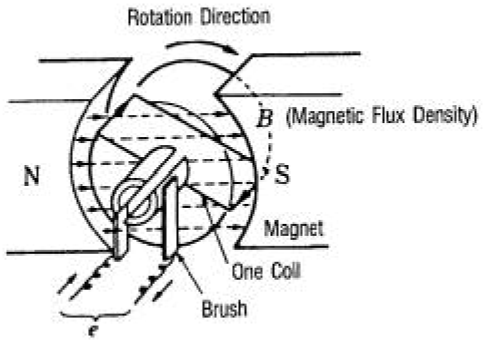


Figure 5.6. Equivalent circuit of permanent magnet type AC tachometer.

Permanent Magnet Type AC Tachometer



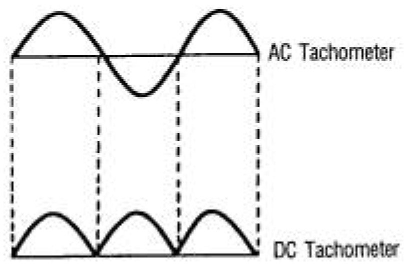
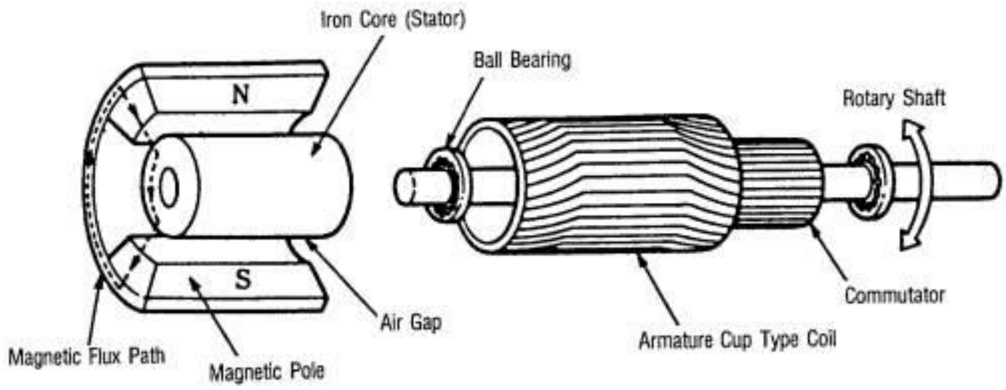
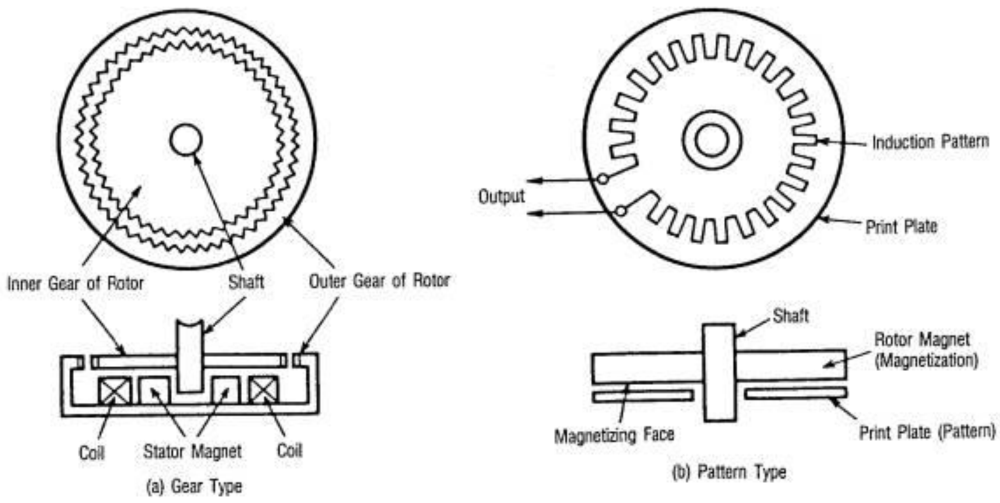


Figure 5.10. Output waveform.



Permanent Magnet Type DC Tachometer

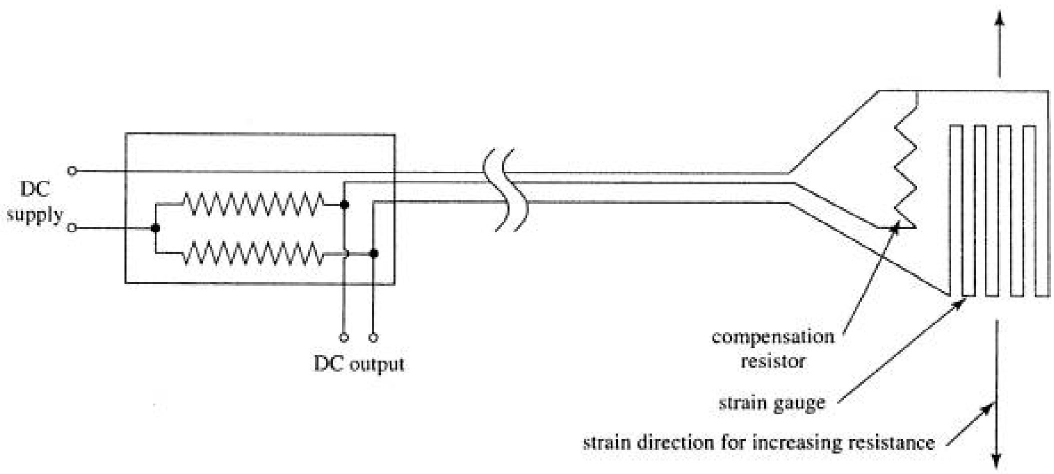


Frequency Generator Tachometer (Gear Type and Pattern Type)

6. Force and Acceleration Sensors

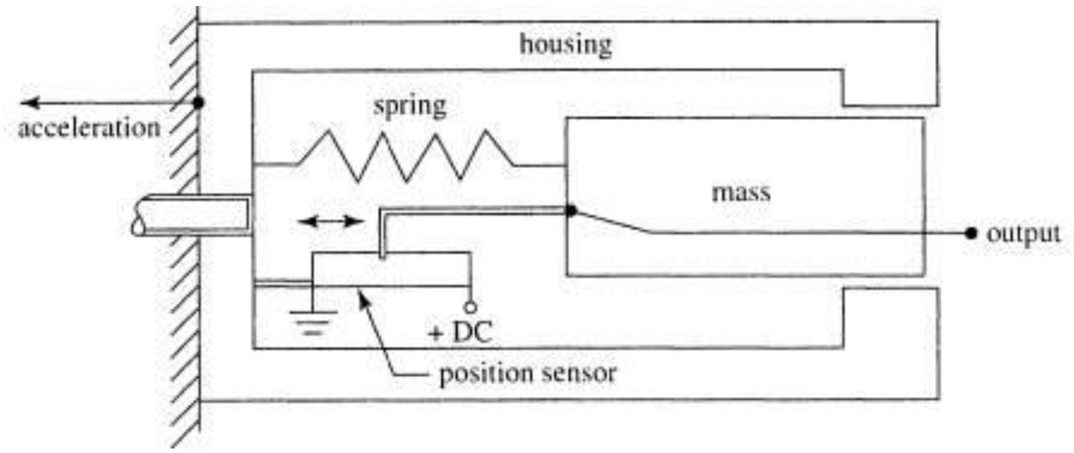
Strain Gauges

Strain gauges are used extensively in accelerometers and force sensors, due to its (i) large signal-displacement ratio, (ii) low cost, and (iii) ease of application. Strain gauges are sensors that measure deformation due to pressure. A strain gauge is essentially a long thin conductor, often printed onto a plastic backing in such a way that it occupies very little space. The change in resistance is small and so requires a reference resistance and compensating circuitry to compensate for other sources of resistance changes (such as temperature). Strain gauges are often glued to critical machine components to measure the deformation of those components under loaded conditions.

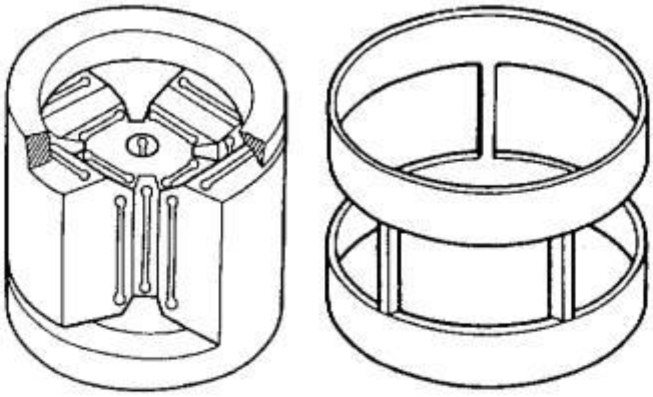


Acceleration Sensors

- Piezo-electric type accelerometer - When an external force is applied to a piezo-electric element, a voltage will be generated which is proportional to the applied external force. The force is then measured by this voltage. A measurement of acceleration will be performed by Newton's kinetic law F=ma.
- Oscillator type accelerometer - For an operational function, the acceleration of speed will be measured by detecting the rotational displacement by a Microsyn, since the acceleration of speed is applied to an oscillator, it becomes a small amount of rotational displacement.
- Accelerometers can also be used as vibration sensors. In this case, a piezo electric element must be used.

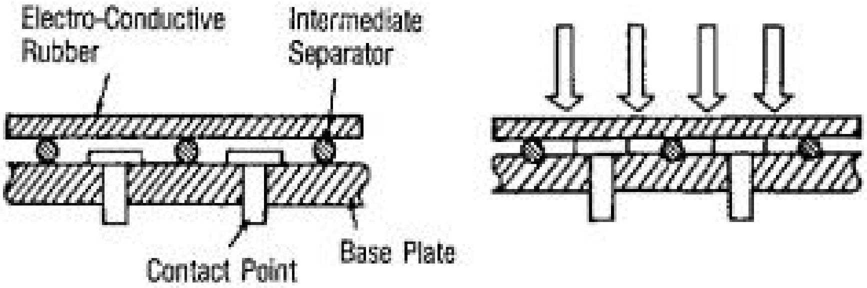


Force Sensors – can be single or multi-axis



A 6 axis sensor and a power sensor using circular column

Tactile Sensors

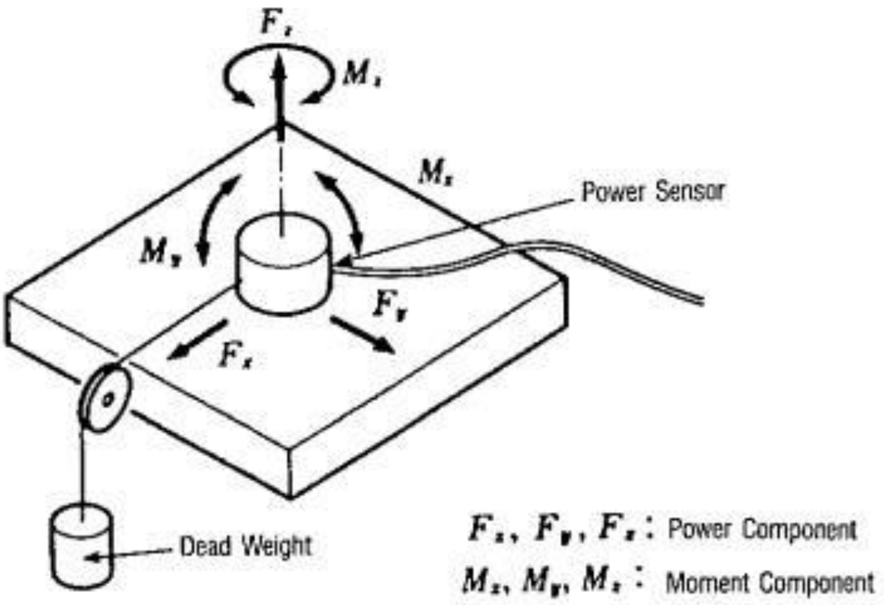


A One Dimension Tactile Sensor

Tactile sensors are mainly used in robotic applications. It is based on the variation of resistance on the electro-conductive rubber when a force is applied to it. The sensor can be a single point sensor, linear 1D sensor, or a 2D matrix sensor. For 2D tactile sensors, a matrix sensor interface has to be employed.

Calibration of sensors

The strain acting on the force sensor will vary greatly, even at the same force levels. Therefore it is essential to calibrate the sensor before using it. Figure below shows one method of sensor calibration. By applying a dead weight, an accurate force level is produced.



--- END ---