SNS COLLEGE OF ENGINEERING

Kurumbapalayam (Po), Coimbatore – 641 107

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE NAME : 19OE120 AUTOMOTIVE ELECTRONICS I YEAR /I SEMESTER

MECHATRONICS ENGINEERING

Unit 2 – Sensors & Actuators

❖ Syllabus:

- Working principle of sensors, Types of sensors, Airflow rate sensor, Position sensor, Throttle angle sensor, Temperature sensor, MAP sensors, Knock/Detonation Sensor, Load cell, Lambda Sensor(Exhaust gas O2 Sensor), yaw rate sensor, sensor feedback control, Electronic Control Unit (ECU), Principle of actuator, Types of actuators, engine control actuators, Solenoid actuators, motorized actuators (Stepper motors).

❖Sensors:

- Sensors are the components of the system that provide the inputs that enable the computer **(ECM)** to carry out the operations that make the system function correctly.
- In the case of vehicle sensors

usually a voltage that is represented by a code at the computer’s processor. If this voltage is incorrect the processor will probably take it as an invalid input and record a fault.

VARIABLE TO BE MEASURED

1. Mass air flow (MAF) rate
2. Exhaust gas oxygen concentration (possibly heated)
3. Throttle plate angular position
4. Crankshaft angular position/RPM
5. Coolant temperature
6. Intake air temperature
7. Manifold absolute pressure (MAP)
8. Differential exhaust gas pressure
9. Vehicle speed
10. Transmission gear selector position

❖ Mass air flow (MAF) rate sensor

- Airflow sensors are used on engines with multiport electronic fuel injection. This is because the amount of fuel delivered by an EFI system is controlled by a computer (powertrain control module or PCM) which turns the fuel injectors on and off.
- The airflow sensor keeps the computer informed about how much air is being pulled into the engine past the throttle plates. This input along with information from other engine sensors allows the computer to calculate how much fuel is needed.
- The computer then increases or decreases injector duration (on time) to provide the correct air/fuel ratio.
- Types: 1. Vane type Air Flow Rate Sensor

2. Hot Wire type Air Flow Rate Sensor

❖ Vane type air flow (MAF) rate sensor

- An engine requires the correct air–fuel ratio to suit various conditions. With electronic fuel injection the ECM controls the air–fuel ratio and in order to do this it needs a constant flow of information about the amount of air flowing to the engine.
- With this information, and data stored in its memory, the ECM can then send out a signal to the injectors, so that they provide the correct amount of fuel.
- Air flow measurement is commonly performed by a 'flap'-type air flow sensor. The air flow sensor shown in Figure A. uses the principle of the potential divider (potentiometer).

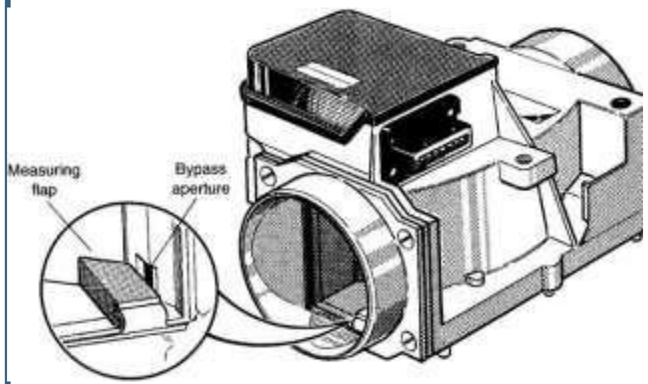


Fig. A

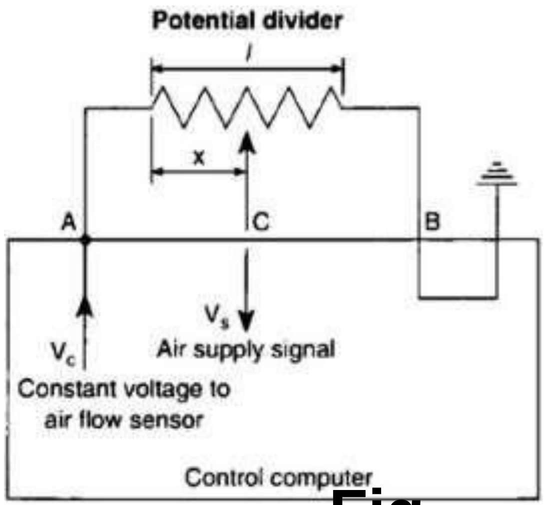
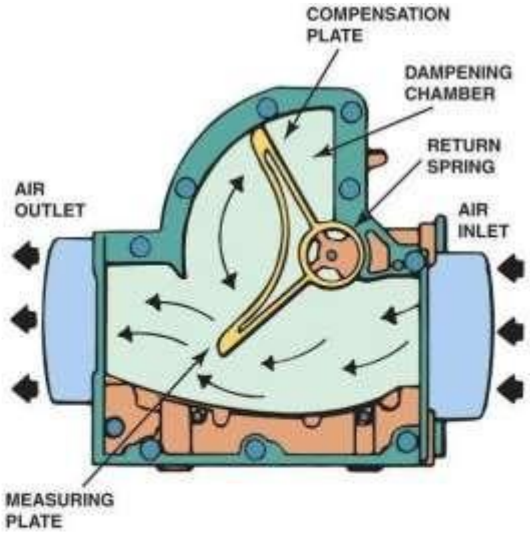
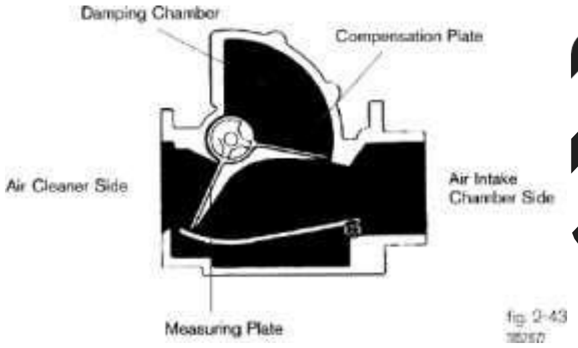


Fig. B

- Figure B. shows the theoretical form of a simple potential divider. A voltage, say 5 V, is applied across terminals *A* and *B*. *C* is a slider which is in contact with the resistor and a voltmeter is connected between *A* and *C*. The voltage V_{AC} is related to the position of the slider *C* in the form $V_{AC} = V_{AB} * x/l$.
- In the air flow sensor, the moving probe (wiper) of the potential divider is linked to the pivot of the measuring flap so that angular displacement of the measuring flap is registered as a known voltage at the potentiometer.

- Figure shows a simplified form of the air flow sensor. The closed position of the measuring flap will give a voltage of approximately zero, and when fully open the voltage will be 5 V.
- Intermediate positions will give voltages between these values. In practice, it is not quite as simple as this, because allowance must be made for other contingencies.
- A vane airflow sensor is located ahead of the throttle and monitors the volume of air entering the engine by means of a spring-loaded mechanical flap. The flap is pushed open by an **amount that is proportional to the volume of air entering the engine.**





- The flap has a wiper arm that rotates against a sealed potentiometer (variable resistor or rheostat), allowing the sensor's resistance and output voltage to change according to airflow.
- The greater the airflow, the further the flap is forced open. This lowers the potentiometer's resistance and increases the voltage return signal to the computer.
- A compensation plate acts as a shock absorber to prevent rapid movement or vibrations of the measuring plate.
- A sealed idle mixture screw is also located on the airflow sensor. This controls the amount of air that bypasses the flap, and consequently the richness or leanness of the fuel mixture.

❖VANE AIRFLOW SENSOR PROBLEMS

- Vane airflow sensors as well as all the other types of airflow sensors **can't tolerate air leaks.** Air leaks downstream of the sensor can allow "unmetered" or "false" air to enter the engine. The extra air can lean out the fuel mixture causing a variety of driveability problems, including lean misfire, hesitation and stumbling when accelerating, and a rough idle.
- **Dirt can also cause problems**. Unfiltered air passing through a torn or poor fitting air filter can allow dirt to build up on the flap shaft of a vane airflow sensor causing the flap to bind or stick. The operation of the flap can be tested by gently pushing it open with a finger. It should open and close smoothly with even resistance. If it binds or sticks, a shot of carburetor cleaner may loosen it up otherwise the sensor will have to be replaced.

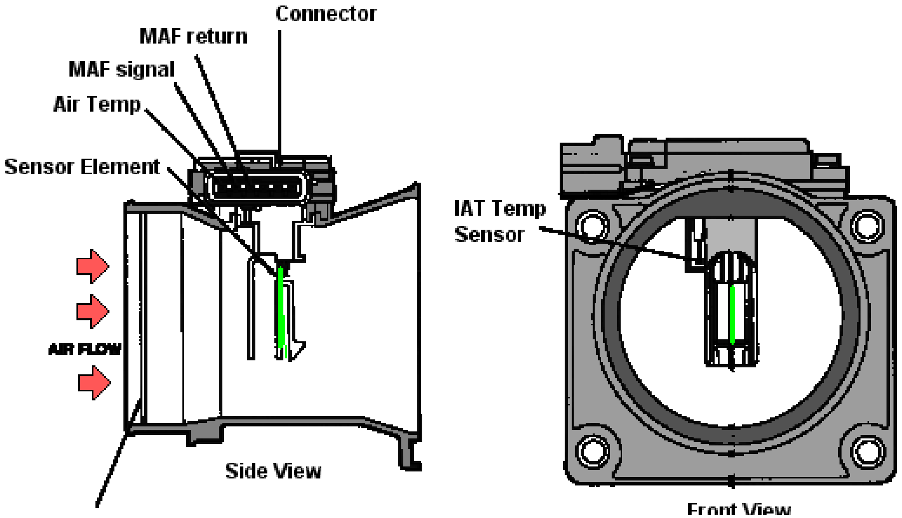
- **Backfiring in the intake manifold** can force the flap backwards violently, **often bending or breaking the flap.** Some sensors have a "backfire" valve built into the flap to protect the flap in case of a backfire by venting the explosion. But the anti-backfire valve itself can become a source of trouble if it leaks. A leaky backfire valve will cause the sensor to read low and the engine to run rich.

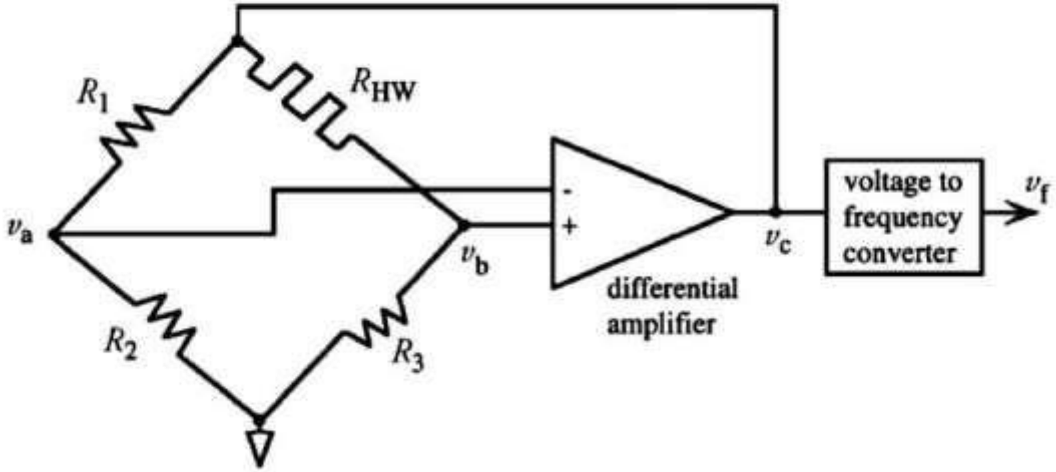
❖Hot Wire Type MAF:

- The hot wire MAF sens a variation classic air flow sensor that was know wire anemometer and was use for examp measure wind velocity for weather forecasti
- In this MAF, the hot-wire, or sensing, elem replaced by a hot-film structure mounted on a substrate.
- On the air inlet side is mounted a honeyc flow straightener that "smooths" the air f (causing nominally laminar air flow over the element). the lower portion of the

structure is the signal processing

- The film element is electrically heated to a constant temperature above that of the inlet air.
- The hot-film element is incorporated in a Wheatstone bridge circuit (Figure at top).
- The power supply

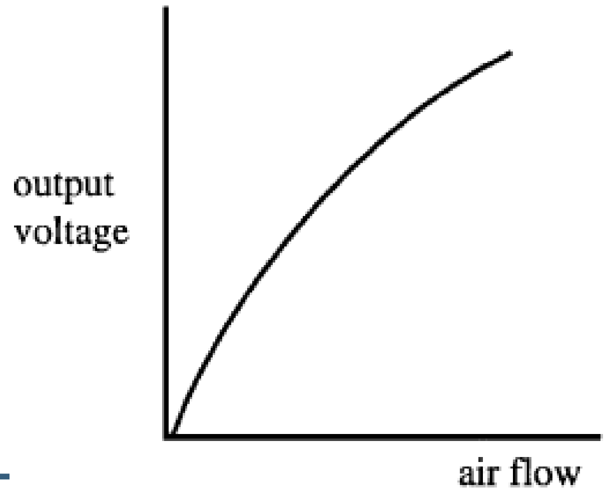




- The Wheatstone bridge consists of three fixed resistors R_1, R_2, and R_3 and a hot-film element having resistance R_{HW}. With no air flow the resistors R_1, R_2, and R_3 are chosen such that voltage v_a and v_b are equal (i.e., the bridge is said to be balanced).
- As air flows across the hot film, heat is carried away from the film by the moving air. The amount of heat carried away varies in **proportion to the mass flow rate of the air.**
- The heat lost by the film to the air tends to cause the resistance of the film to vary, which unbalances the bridge circuit, thereby producing an input voltage to the amplifier.
- The output of the amplifier is connected to the bridge circuit and provides the power for this circuit. The amplified voltage changes the resistance in such a way as to maintain a fixed hot-film temperature relative to the inlet temperature.

▪The amplifier output voltage v_c varies with MAF and serves as a measure of R_m. Typically the conversion of MAF to voltage is slightly nonlinear, as indicated by the calibration curve depicted in Figure.

▪Fortunately, a modern digital engine controller can convert the analog bridge output voltage directly to mass air flow by simple computation.



- Hot Wire MAF sensors have no moving parts. Unlike a vane airflow meter that uses a spring-loaded flap, mass airflow sensors use electrical current to measure airflow.
- The sensing element, which is either a **platinum wire (hot wire) or nickel foil grid** (hot film), is heated electrically to keep it a certain number of degrees hotter than the incoming air.
- In the case of **hot film MAFs, the grid is heated to 75^{o}C** above incoming ambient air temperature. With the **hot wire sensors, the wire is heated to 100 ^{o}C** above ambient temperature.
- As air flows past the sensing element, it cools the element and increases the current needed to keep the element hot. Because the cooling effect varies directly with the temperature, density and humidity of the incoming air, the amount of current needed to keep the element hot is **directly proportional to the air "mass" entering the engine**

❖ Positions Sensors:

- The positions sensors are generally speed sensors of different working principle used for detecting the position of different parameters.
- Parameters Measured,
  1. Crankshaft Position Sensor
  2. Camshaft Position Sensor
  3. ABS Wheel Sensors
  4. Vehicle Speed Sensor
- Working Principles used,
  1. Magnetic Reluctance (Variable Reluctance) type
  2. Hall Effect type
  3. Optical Type

❖ Crankshaft Position Sensor:

- A **crank position sensor** is a component used in an internal combustion engine to monitor the position or rotational speed of the crankshaft. This information is used by engine management systems to control ignition system timing and other engine parameters.

❖Magnetic Reluctance (or Variable Reluctance) type sensor

- This type of sensor is used in many vehicle applications, such as ignition systems, engine speed sensors for fuelling, and wheel speed sensors for anti-lock braking etc.
- Air has a greater reluctance (resista magn than iron and this fact is made in many s The basic principle of op of a variable relu type sensor (Fig. 5. be understood fro following descriptio
- The principal elements of the sensor are:

➢an iron rotor with lobes on it;

➢a permanent magnet;

➢a metallic path (the pole piece) for carrying the magnetic flux;

➢a coil, wound around the metallic path, in which a voltage is induced.

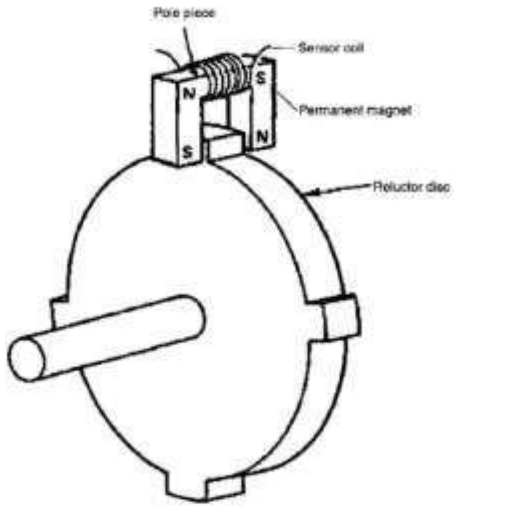


Fig. 5.1 The basic principle of the variable reluctance sensor

- The reluctor disc has a number of tabs on it and these tabs are made to move through the air gap in the magnetic circuit.
- The movement of the reluctor tabs, through the air gap is achieved by rotation of the reluctor shaft. The voltage induced in the sensor coil is related to the rate of change of magnetic flux in the magnetic circuit.
- The faster the rate of change of magnetic flux the larger will be the voltage that is generated in the sensor coil. When the metal tab on the reluctor rotor is outside the air gap, the sensor voltage is zero.
- As the tab moves into the air gap the flow of magnetism (flux) increases rapidly. This causes the sensor voltage to increase, quite quickly, to a maximum positive value. Figure 5.2 shows the approximate behavior of the voltage output as the reluctor is rotated.

- Figure 5.2(a) shows the reluctor tab moving into the air gap. As the metal tab moves further into the gap the voltage begins to fall and, when the metal tab is exactly aligned with the pole piece, the sensor voltage falls back to zero (Although the magnetic flux is strongest at this point, it is not changing and this means that the voltage is zero.)

- Figure 5.2(b) shows that there is zero voltage when the reluctor tab is in alignment with the pole piece.

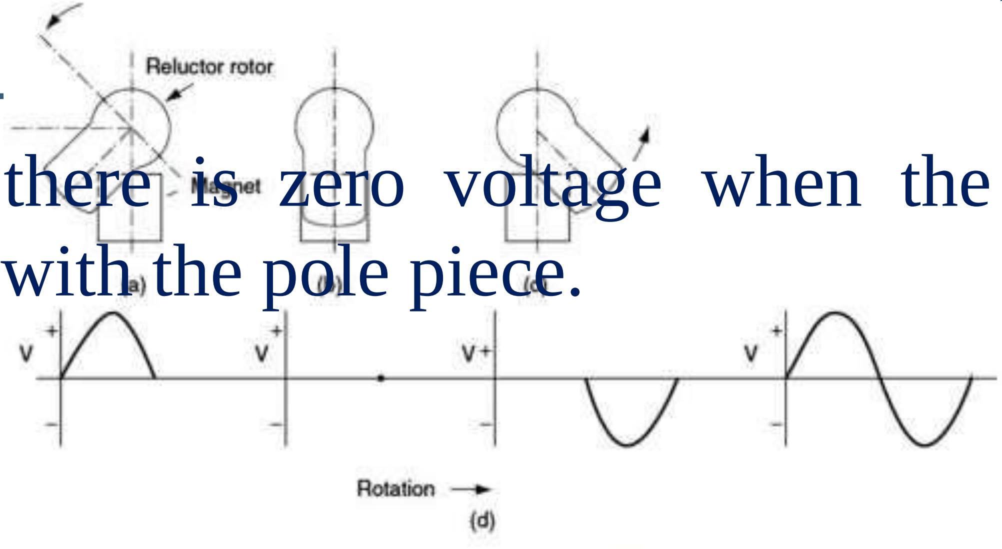


Fig. 5.2 The voltage pattern from a variable reluctance sensor

- As the metal tab continues to rotate out of the air gap and away from the pole piece, the rate of change of the magnetic flux is rapid, but opposite in direction to when the tab was moving into the air gap.
- This results in the negative half of the voltage waveform as shown in Fig. 5.2(c). When the tab has moved out of the air gap the sensor voltage returns to zero. While the rotor shaft continues to turn another tab will enter the air gap and the above process will be repeated.
- If the sensor coil is connected to an oscilloscope the pattern observed will be similar to that shown in Fig. 5.2(d).

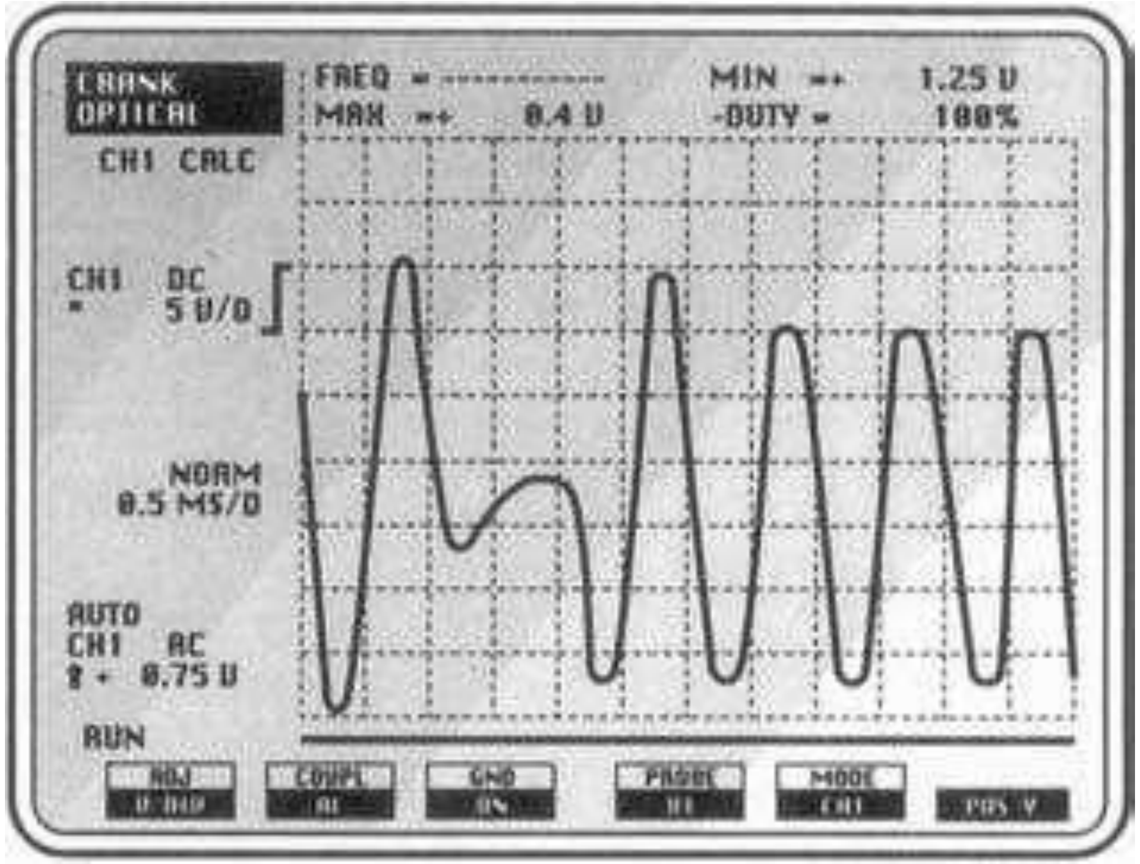
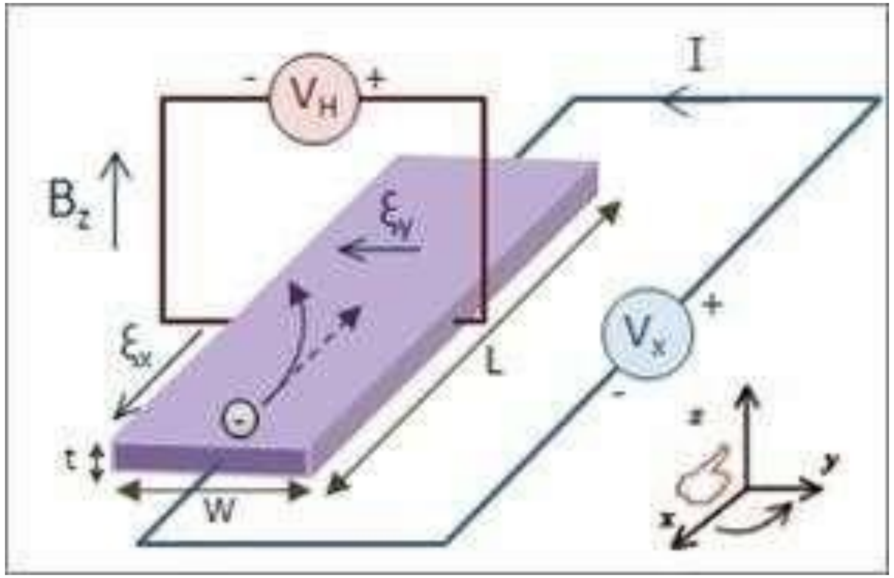


Fig. 5.4 A crank sensor voltage pattern

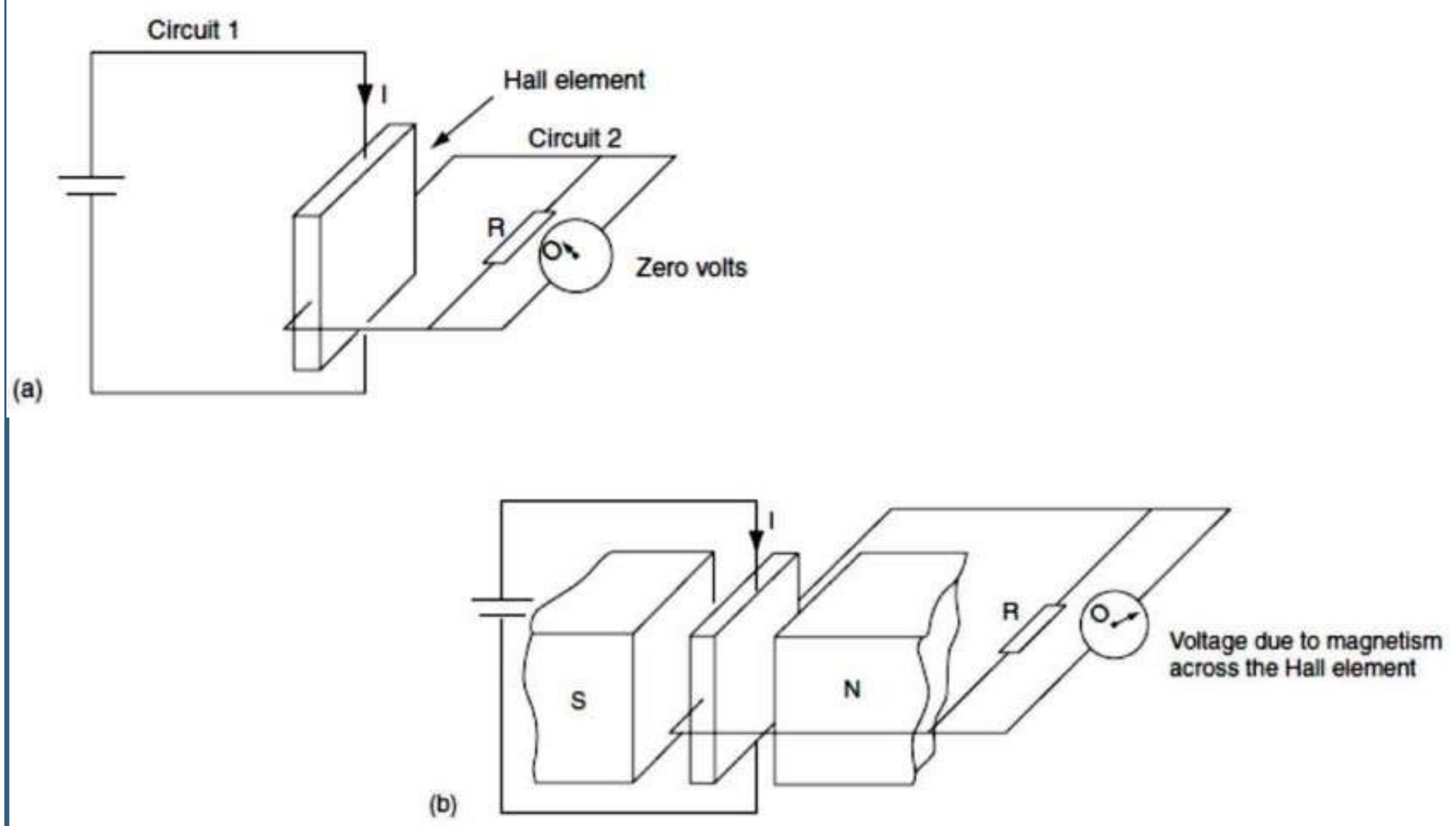
❖ Hall Effect:

- The **Hall effect** is the production of a **voltage difference** (the **Hall** voltage) across an electrical conductor, transverse to an electric current in the conductor and to an applied **magnetic field perpendicular** to the current. It was discovered by Edwin **Hall** in 1879.

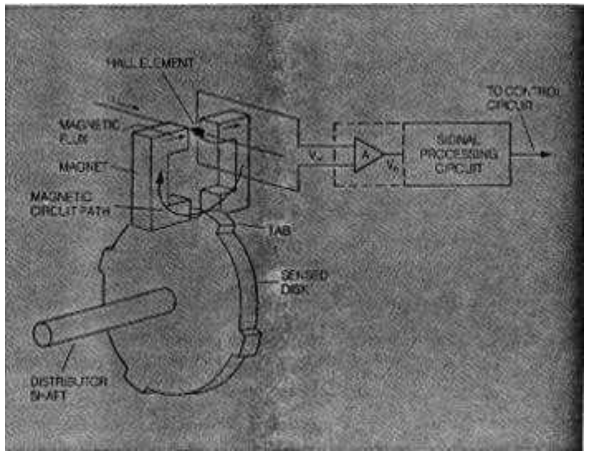


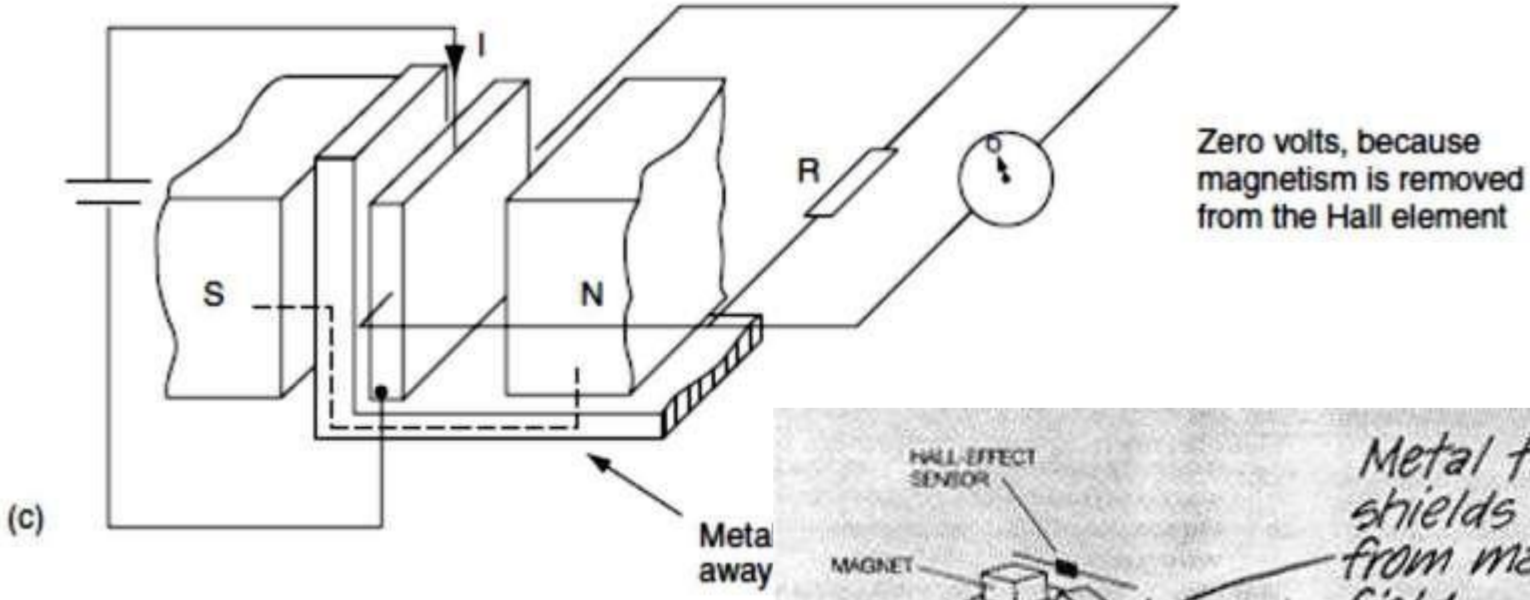
2. Hall Effect type sensor:

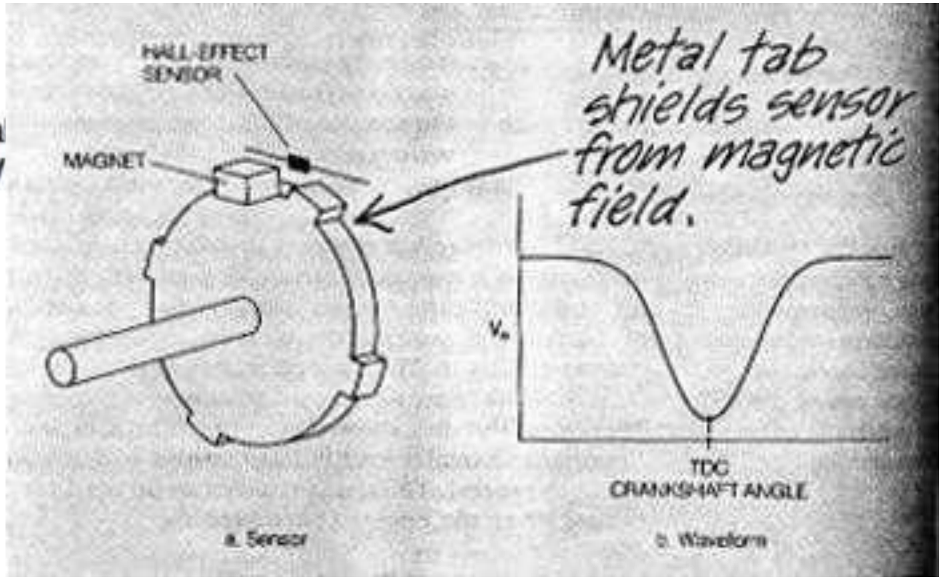
- Figure shows the principle of a Hall type sensor. The Hall element is a small section of semiconductor material such as silicon.
- When connected as shown in Fig.(a), the battery will cause current to flow through the semiconductor Hall element and battery circuit, but there will be no current in the circuit which is at right angles to the battery circuit, as shown by a zero reading on the voltmeter.


Circuit 1
Hall element
Circuit 2
I
R
Zero volts
(a)
I
R
S
N
Voltage due to magnetism across the Hall element
(b)

- When a magnetic field is imposed on the Hall element, as shown in Fig. (b), a current will flow in circuit 2.
- When the magnetic effect is prevented from reaching the Hall element, as in Fig.(c), the current will cease to flow in circuit 2.
- The result is that the current in circuit 2 can be switched on and off by shielding the Hall element from the magnetic field.

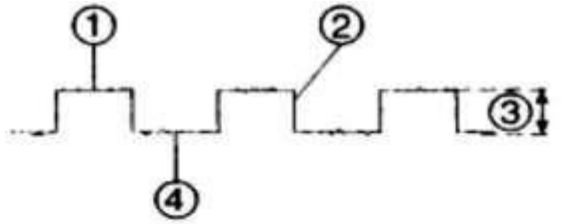



I
R
S
N
(c)
Zero volts, because magnetism is removed from the Hall element


HALL-EFFECT SENSOR
MAGNET
Metal tab shields sensor from magnetic field.
TDC
CRANKSHAFT ANGLE
a. Sensor
b. Waveform

- When the metal plate that is inserted between the magnet and the Hall element is mounted on a rotating shaft, the Hall current can be switched on and off at any desired frequency.
- The Hall type sensor produces an output power that is virtually constant at all speeds.
- Hall effect sensors are used wherever other electromagnetic sensors are used, e.g. engine speed and crank position, ABS wheel sensors, camshaft (cylinder) identification (for ignition and fuelling) etc.

- The voltage from a Hall element is quite small and it is common practice for Hall type sensors to incorporate an amplifying and pulse-shaping circuit. The result is that the sensor produces a digital signal, i.e. it is a rectangular waveform as shown in Fig. 5.7.



1	The upper horizontal lines should reach reference voltage.
2	Voltage transitions should be straight and vertical.
3	**Peak-Peak** voltages should equal reference voltage.
4	The lower horizontal lines should almost reach ground.

The duty cycle of the signal remains fixed, determined by the spacing between shutter blades.

Frequency of the signal increases as the speed of the engine increases.

Fig. 5.7 A Hall sensor output signal

❖Optical Sensor:

- In a sufficiently clean environment a shaft position can also be sensed using optical techniques. Figure below illustrates such a system. Again, as with the magnetic system, a disk is directly coupled to the crankshaft.
- This time, the disk has holes in it that correspond to the number of tabs on the disks of the magnetic systems.
- Mounted on each side of the disk are fiber-optic light pipes. The hole in the disk allows transmission of light through the light pipes from the light-emitting diode (LED) source to the phototransistor used as a light sensor.
- **Light would not be transmitted from source to sensor when there is no hole because the solid disk blocks the light.**

- As shown in Figure below, the pulse of **light is detected by the phototransistor** and coupled to an amplifier to obtain a satisfactory signal level. The output pulse level can very easily be standard transistor logic levels of +2.4 V for the high level and +0.8 V for the low level.
- One of the **problems with optical sensors is that they must be protected from dirt and oil; otherwise, they will not work properly.**
- They have the advantages that they can sense position without the engine running and that the pulse amplitude is constant with variation in speed.

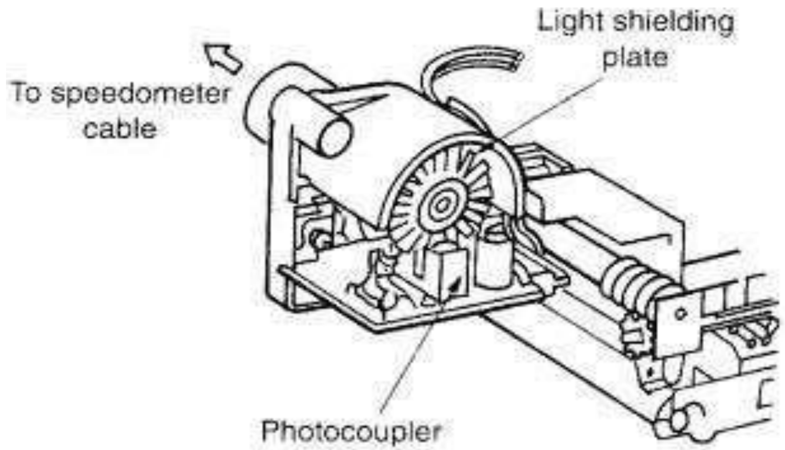
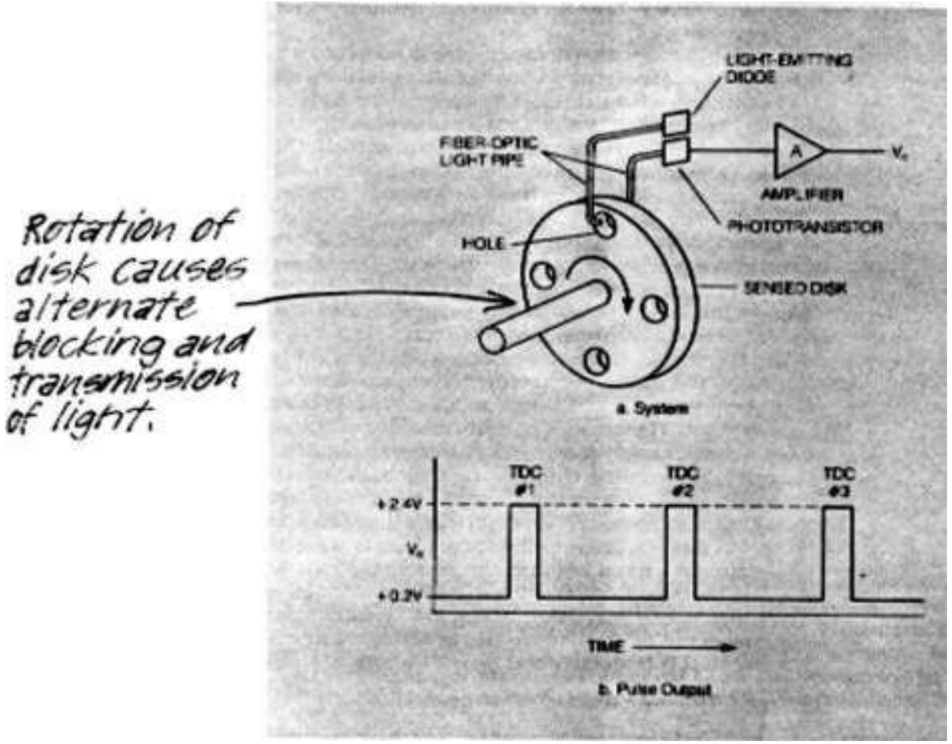


Fig. 5.8 An optoelectronic sensor



❖ Throttle Position Sensor:

▪ When an engine is s idling the exhau h scavenging of the cylinders is poor. This effect of diluting the incoming mixture. in the

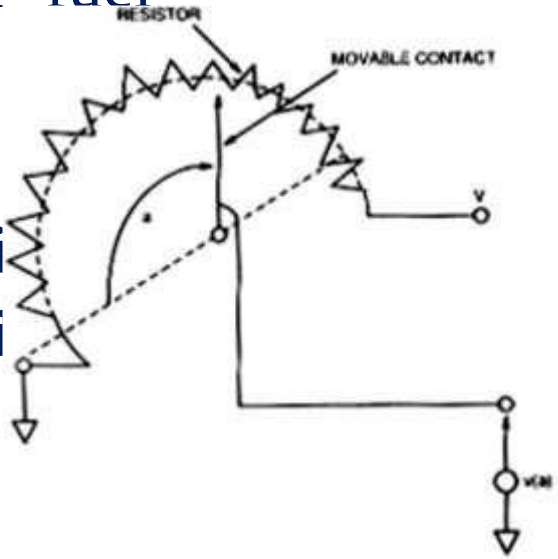
idling position, so that alteration of the air–fuel

ratio can occur to ensure that the engine cont

▪ The ECU must detect when the throttle is

to run smoothly.

▪ At full engine load and full throttle, the mi (air–fuel ratio) needs enrich so the EC needs a signal show that the throttle is open.



- These duties are performed by the throttle position switch. Figure 5.12 shows how the action of a throttle position sensor is based on the principle of the potential divider.
- The sensor produces a voltage which is related to throttle position. The voltage signal is conducted to the ECU where it is used, in conjunction with other inputs, to determine the correct fuelling for a given condition.

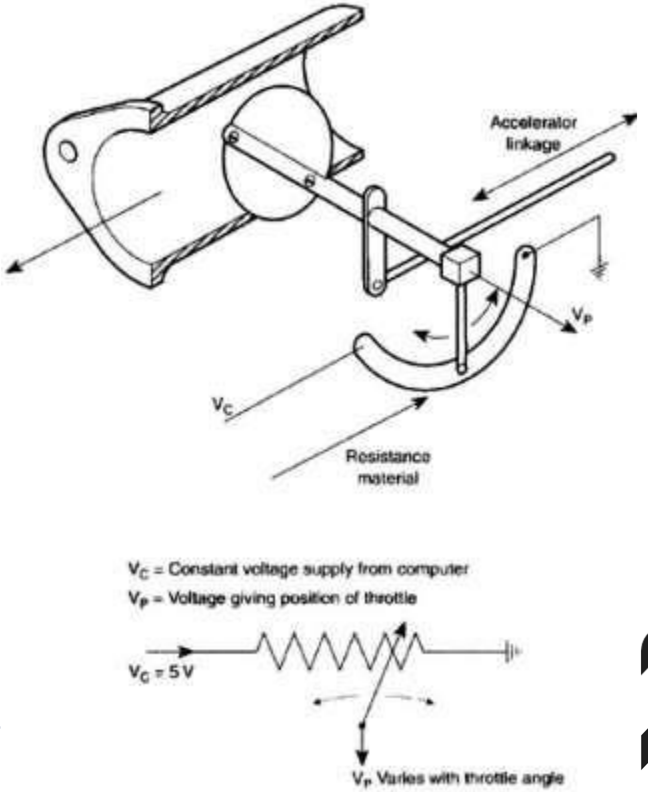


Fig. 5.12 The principle of the throttle position sensor