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).

❖ Thermistor:

- Thermistors are of two opposite fundamental types:
- With **NTC** thermistors, resistance ***decreases*** as temperature rises. An NTC is commonly used as a temperature sensor, or in series with a circuit as an inrush current limiter.
- With **PTC** thermistors, resistance ***increases*** as temperature rises. PTC thermistors are commonly installed in series with a circuit, and used to protect against *overcurrent* conditions, as resettable fuses
- Thermistors differ from resistance temperature detectors (RTDs) in that the material used in a thermistor is generally **a ceramic or polymer**, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a greater precision within a limited temperature range, **typically −90 °C to 130 °C**

❖ Temperature sensor

- A commonly used device used for s temperature is **the thermistor.** A thermistor u the concept of **negative temperature coeffici**

▪Most electrical conductors have a **po temperature coefficient**. This means that **hotter the conductor gets the higher elec resistance.**

▪This thermistor operates differently; its **resistance gets lower as its temperature increases and this is a characteristic of semiconductor materials**.

Fig. 5.17 An engine coolant temperature sensor

- There is a well-defined relationship between temperature and resistance.
- This means that current flow through the thermistor can be used to give an accurate representation of temperature.
- Figure shows the approximate relationship between temperature and resistance.
- The coolant temperature sensor provides the ECU with information about engine temperature and thus allows the ECU to make alterations to fuelling for cold starts and warm-up enrichment.

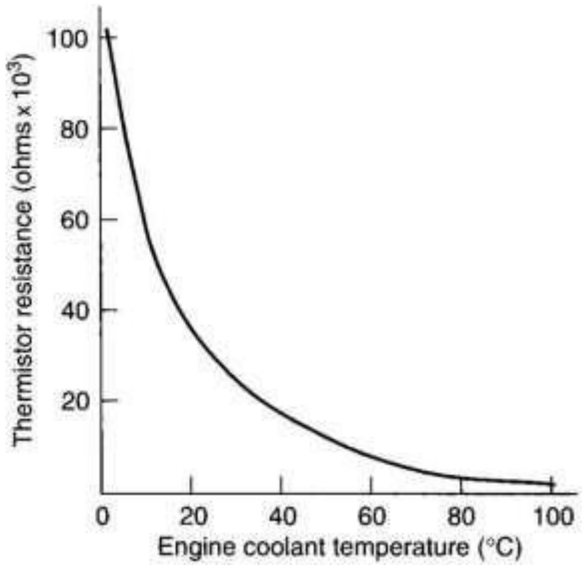


Table 5.1 Temperature and corresponding resistance for a coolant sensor

Temperature (°C)	Resistance (ohms)	Voltage
0	6000	4.5
20	2500	3.2
30	1400	3.1
60	800	2.4
80	280	1.2

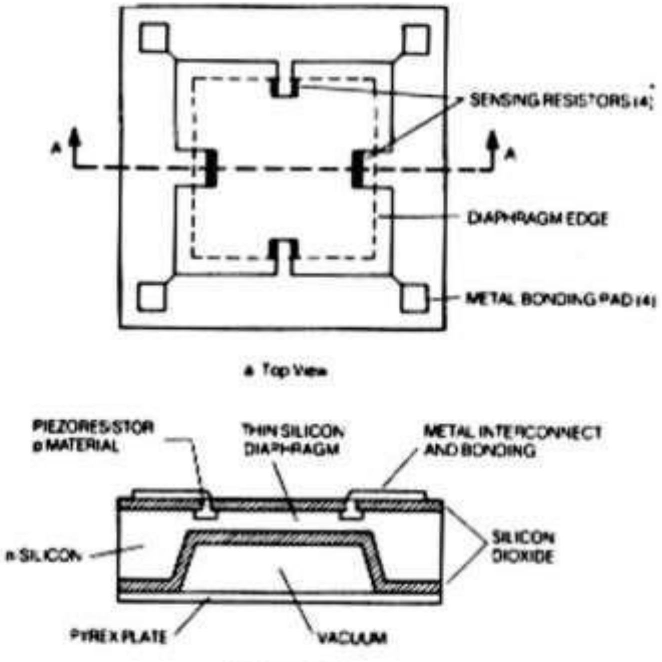
❖ Manifold Absolute Pressure (MAP) Sensor:

- Several MAP sensor configurations have used in been automotive applications.
  - The earliest sensors were derived from aerospace instrumentation concepts, but these proved more expensive than desirable for automotive applications and have been replaced with more cost-effective designs.
  - It is interesting to note that none of the MAP sensors in use measure manifold pressure directly, but instead measure the displacement of a diaphragm that is deflected by manifold pressure.
- The details of the diaphragm displacement and the measurement of this displacement vary from one configuration to another.

❖ Strain Gauge MAP Sensor

- One relatively inexpensive MAP sensor configuration is the silicon diaphragm diffused strain gauge sensor shown in Figure.
- This sensor uses a silicon chip that is approx millimeters square. A outer edges, t approximately 250 m micrometers (1 micro millionth a meter) thick, but the center ar 25 micrometers thick and forms a l diaphragm.
- The edge of the chip is sealed to a pyrex p thereby forming a vacuum chamber the pl

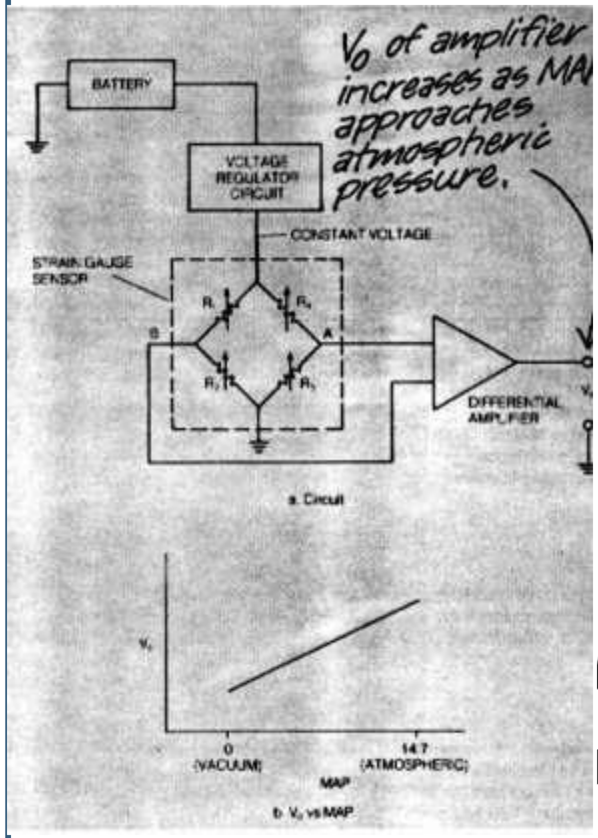
the center area of the silicon chip.



a Top View
b Section A-A

- A set of sensing resistors is formed around the edge of this chamber, as indicated in Figure. The resistors are formed by diffusing a doping impurity into the silicon.
- External connections to these resistors are made through wires connected to the metal bonding pads. This entire assembly is placed in a sealed housing that is connected to the intake manifold by a small-diameter tube.
- Manifold pressure applied to the diaphragm causes it to deflect.
- The resistance of the sensing resistors changes in proportion to the applied manifold pressure by a phenomenon that is known as **piezoresistivity**.
- Piezoresistivity occurs in certain semiconductors so that the actual resistivity (a property of the material) changes in proportion to the strain (fractional change in length).

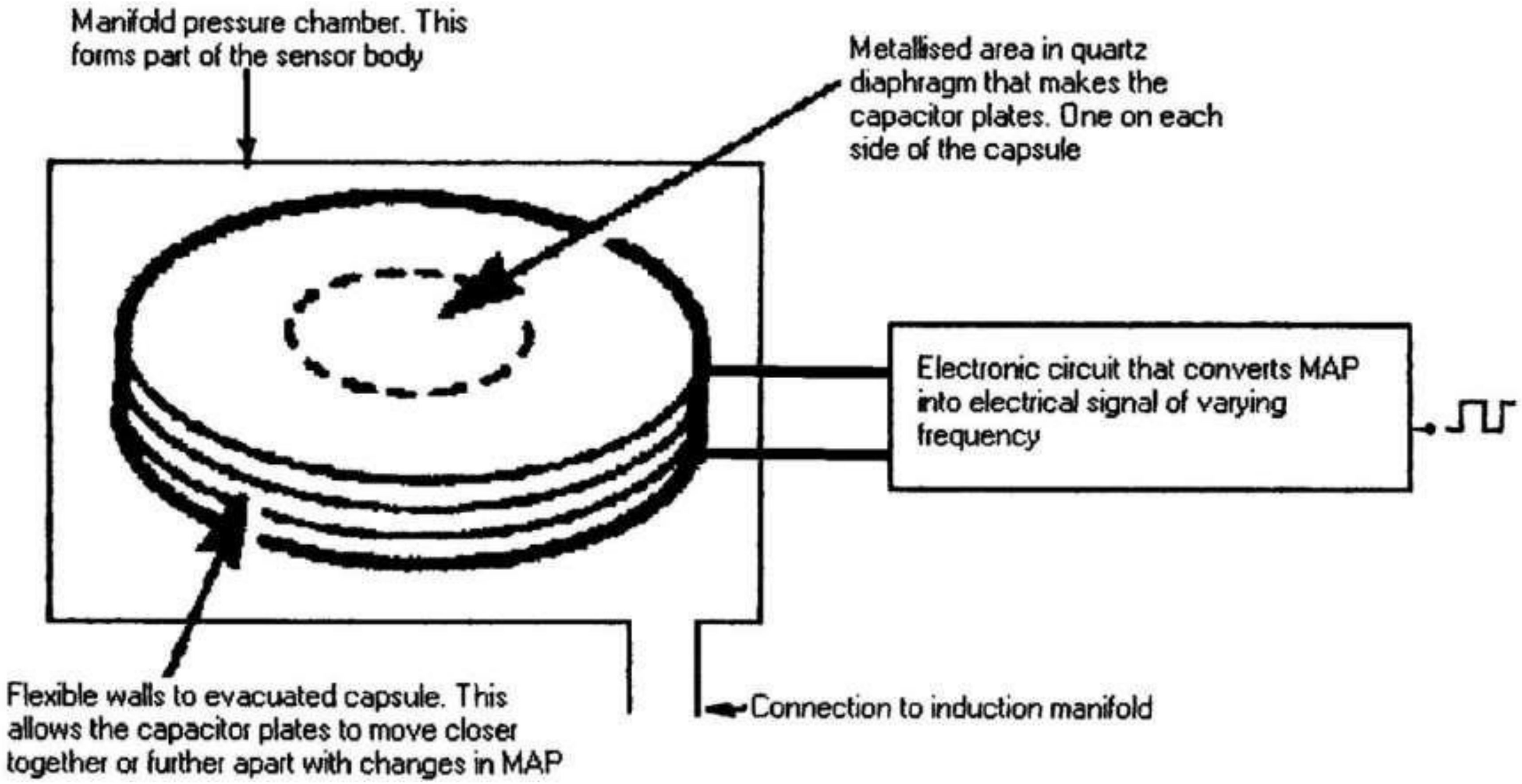
- The strain induced in each resistor is proportional to the diaphragm deflection, which, in turn, is proportional to the pressure on the outside surface of the diaphragm. This pressure is the manifold pressure.
- An electrical signal that is proportional to the manifold pressure is obtained by connecting the resistors in a circuit called a Wheatstone bridge, as shown in the schematic of Figure a.
- The voltage regulator holds a constant dc voltage across the bridge.



- The resistors diffused into the diaphragm are denoted R_1, R_2, R_3, and R_4 in Figure a.
- When there is no strain on the diaphragm, all four resistances are equal, the bridge is balanced, and the voltage between points A and B is zero. When manifold pressure changes, it causes these resistances to change in such a way that **R_1 and R_3 increase by an amount that is proportional to pressure; at the same time, R_2 and R_4 decrease by an identical amount**.
- This unbalances the bridge and a net difference voltage is present between points A and B. The differential amplifier generates an output voltage proportional to the difference between the two input voltages (which is, in turn, proportional to the pressure), as shown in Figure b.

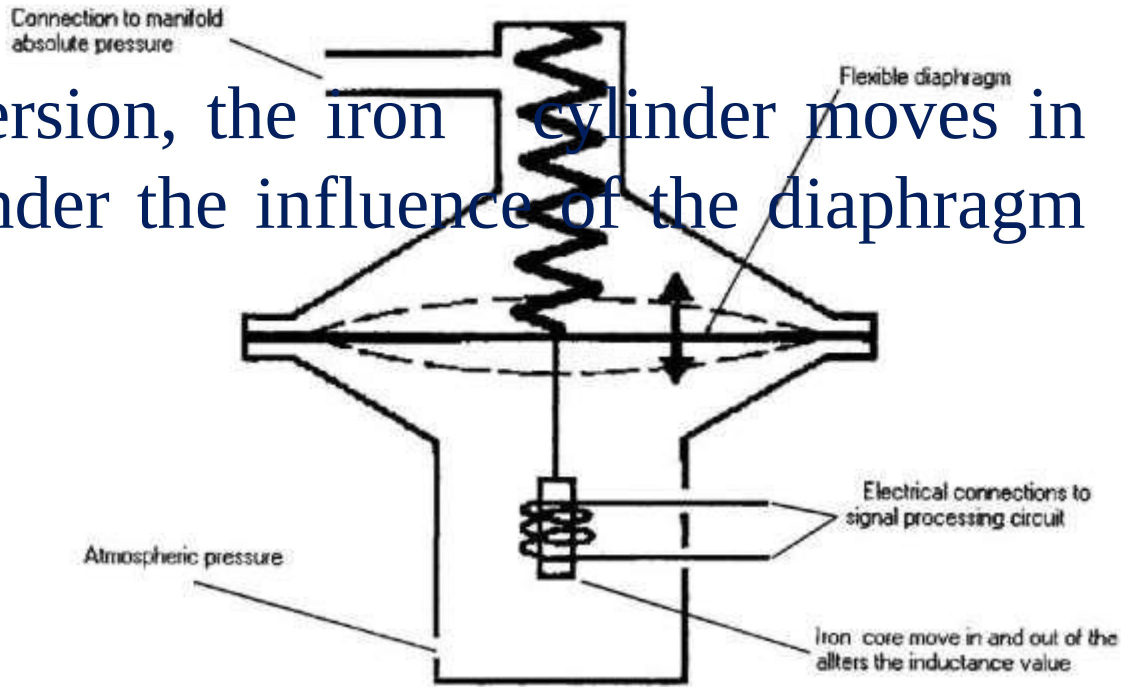
❖ Variable-Capacitance type MAP Sensor

- Figure below gives an indication of the principle of operation of the variable capacitance type of MAP sensor.
- Capacitance $C = e_o A/d$, where e_o = permittivity in a vacuum, A = area of the metallized plates and d = the distance between the plates.
- The metallized plates of the capacitor are placed on each side of an evacuated capsule.
- This capsule is placed in a chamber which is connected to manifold pressure and, as the manifold pressure changes, the distance d between the capacitor plates changes.
- This change in distance between the capacitor plates causes the value of the capacitance C to change. The capacitor is connected into an electronic circuit that converts changes in capacitance into an electrical signal.

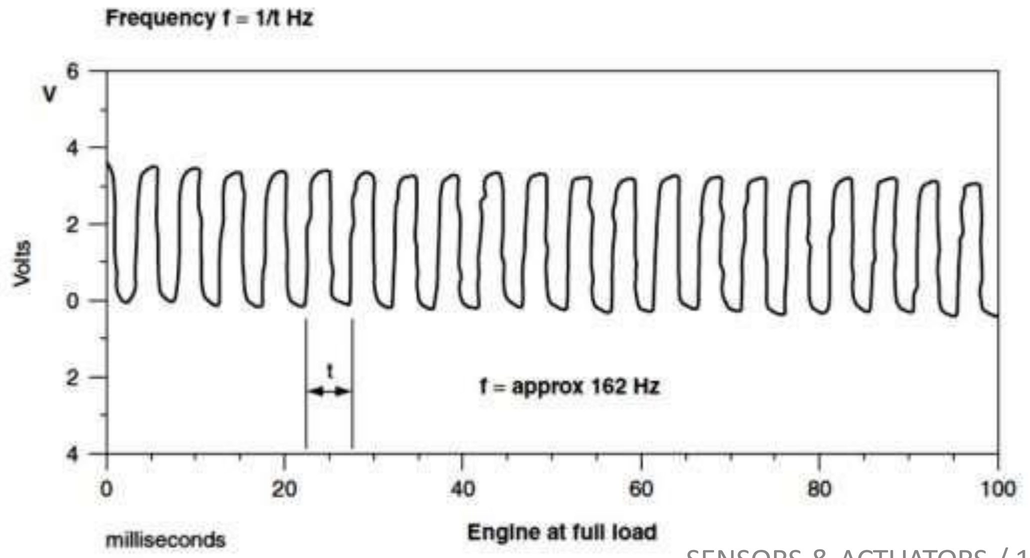

Manifold pressure chamber. This forms part of the sensor body
Metallised area in quartz diaphragm that makes the capacitor plates. One on each side of the capsule
Electronic circuit that converts MAP into electrical signal of varying frequency
Flexible walls to evacuated capsule. This allows the capacitor plates to move closer together or further apart with changes in MAP
Connection to induction manifold

❖ Variable-Inductance type MAP Sensor:

- The variable-inductance type of MAP sensor relies on the principle that the inductance of a coil is altered by varying the position of an iron cylinder placed in the center of the coil. Figure illustrates the principle involved.
- In this simplified version, the iron cylinder moves in or out of the coil under the influence of the diaphragm and spring.



- Variations in manifold absolute pressure increase or decrease the ‘suction’ force acting on the diaphragm and the resultant changes in inductance are related to the manifold absolute pressure.
- The coil (inductance) forms part of an electronic circuit and this circuit is designed so that the changes in frequency of the square-wave output are accurate representations of manifold absolute pressure. Figure shows the approximate form of the variable frequency output of sensors of this type.



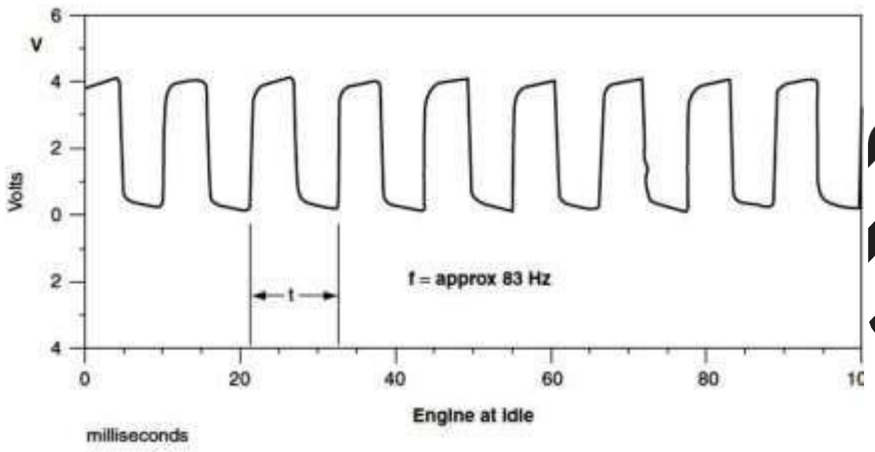


Fig. 5.25 Frequency patterns for a MAP sensor at full load and idle

❖ Knock Sensor:

- A knock sensor that is commonly used in engine control systems utilizes the piezoelectric generator effect, i.e. the sensing element produces a small electric charge when it is compressed and then relaxed.
- Materials such as quartz and some ceramics like PZT (a mixture of platinum, zirconium and titanium) are effective in piezoelectric applications.
- In the application shown, the knock sensor is located on the engine block adjacent to cylinder number 3 (Fig. 5.10). This is the best position to detect vibrations arising from combustion knock in any of the four cylinders.
- Because combustion knock is most likely to occur close to TDC in any cylinder, the control program held in the ECM memory enables the processor to use any knock signal generated to alter the ignition timing by an amount that is sufficient to eliminate the knock.

- When knock has ceased the ECM will advance the ignition, in steps, back to its normal setting. The mechanism by which vibrations arising from knock are converted to electricity is illustrated in Fig. 5.11.

- The sensor is accurately designed pre- tensions the piezoelec ac torqued. The steel wash seismic mass has dimens

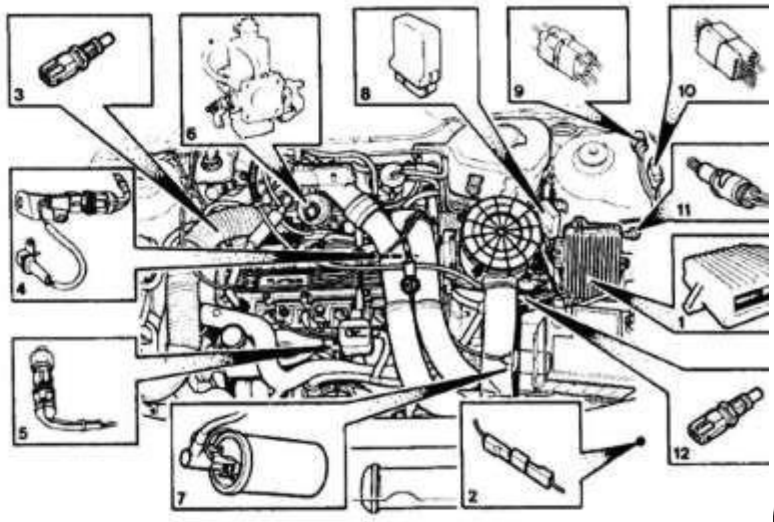


Fig. 5.10 The knock sensor on the engine

- When combustion knock occurs, the resulting mechanical vibrations are transmitted by the seismic mass, to the piezoelectric crystal. The ‘squeezing up’ and relaxing of the crystal in response to this action, produces a small electrical signal that oscillates at the same frequency as the knock sensor element.

- The electrical signal is conducted away from the crystal by wires that are secured to suitable points on the crystal.

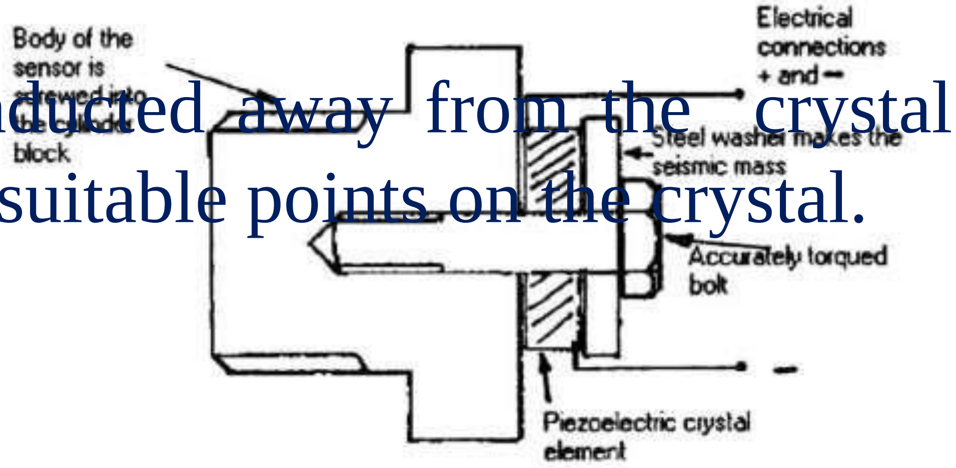


Fig. 5.11 The principle of the piezoelectric combustion knock sensor

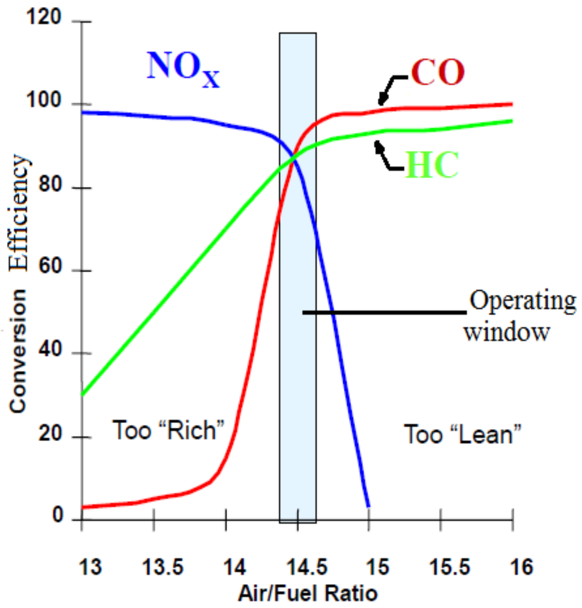
- The tuning of the sensor is critical because it must be able to distinguish between knock from combustion and other knocks that may arise from the engine mechanism. This is achieved because combustion knock produces vibrations that fall within a known range of frequencies.

❖ Lambda Sensor (Exhaust Gas Oxygen Sensor)

- In order for the exhaust emissions catalyst to operate correctly, the air–fuel ratio must be kept close to 15:1 (by mass), and it is the exhaust gas oxygen (EGO) sensor that assists the ECM to keep the air–fuel ratio within the required limits.
- The EGO sensor constantly monitors the oxygen content of the exhaust gas, and hence the air–fuel ratio at the engine intake, since the percentage of oxygen in the exhaust gas is an accurate measure of the air–fuel ratio of the mixture entering the engine cylinders.
- Figure 5.26 shows the relation between the oxygen content of the exhaust gas and the air–fuel ratio of the mixture entering the combustion chambers of the engine.

- The information (voltage) from the sensor is fed back to the ECM so t h amount of fuel injected into the e may be changed to ensure that th fuel ratio is kept within the rec limits.
- It is common practice to refer to t h fuel ratio that gives chemicallyc combustion as lambda = 1. e
- If the mixture is rich, lambda is l 1 (probably lambda = 0.97), ar mixture is weak, lambda is greater to 1 (probably lambda = 1.03). e reason, the exhaust gas oxygen often referred to as a lambda sensor.

$$\text{Lambda} = \frac{\text{actual air-fuel ratio}}{\text{chemically correct air-fuel ratio}}$$



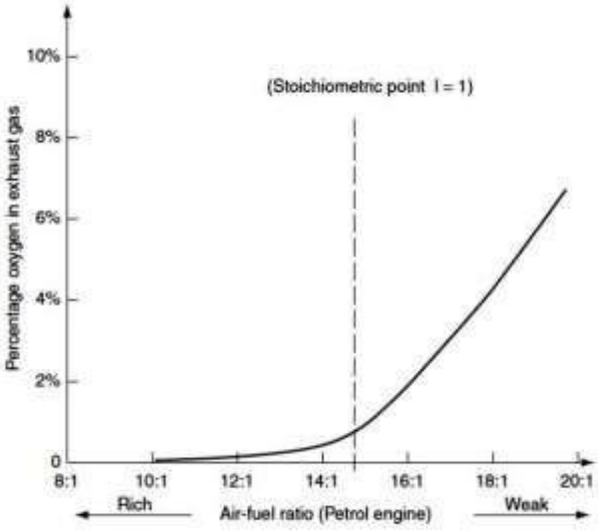


Fig. 5.26 Oxygen in exhaust versus air-fuel ratio

❖ THE VOLTAIC-TYPE EGO SENSOR

- The voltaic, or zirconia (ZrO_2), type oxygen sensor operates on the basis of a difference between the oxygen partial pressure of atmospheric air and the partial pressure of oxygen in the exhaust gas.
- At sea level, atmospheric air contains approximately 21% oxygen by weight, and this gives the oxygen a partial pressure of approximately 0.2 bar.
- The oxygen content of exhaust gas varies from zero in a rich mixture, to about 10% in a weak mixture, as shown in Fig.5.26.
- The partial pressure of the oxygen in the exhaust gas therefore ranges from near zero to approximately 0.01 bar.

- Figure 5.27 shows that the sensor element is essentially a cell (battery). The plates are made from platinum and they have a layer of ceramic zirconia between them which acts as an electrolyte.
- The platinum plates act as catalysts for the oxygen which makes contact with them, and they are also used to conduct electricity away from the sensor.

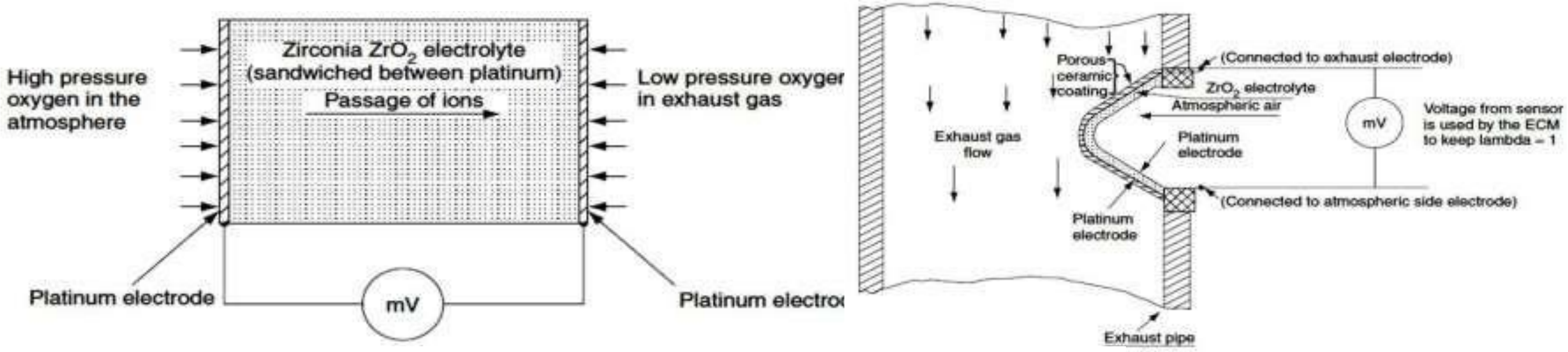
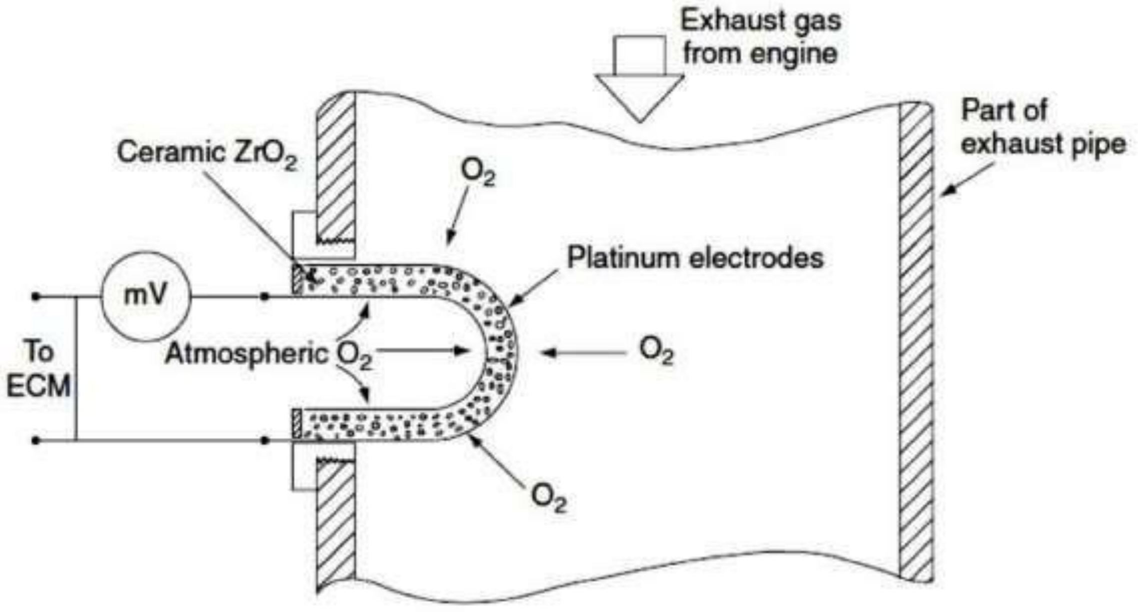
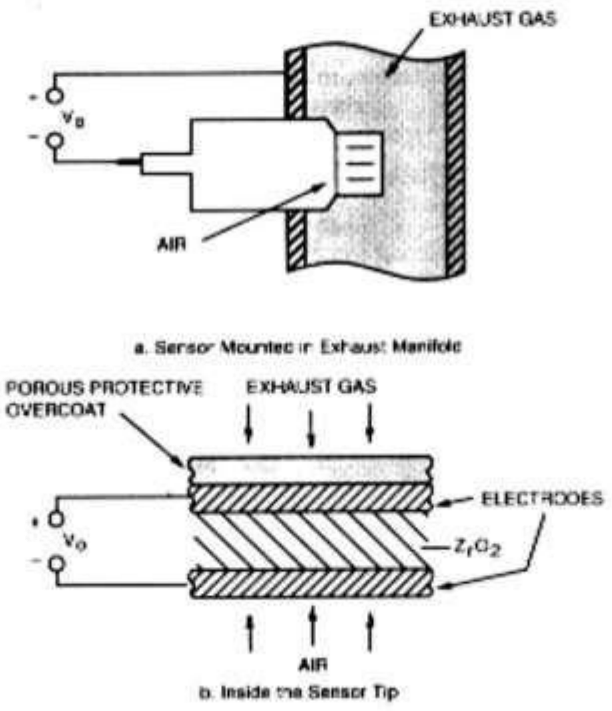


Fig. 5.27 The EGO sensor as a voltaic cell

- The catalyzing action that takes place when oxygen contacts the platinum plates causes the transport of oxygen ions through the electrolyte and this creates the electric current that gives rise to the e.m.f. (voltage) of the sensor.
- This sensor voltage is an accurate representation of the oxygen content of the exhaust gas.
- In practice the sensing element is formed into a thimble shape as shown in Fig. 5.28.
- This type of construction exposes the maximum area of platinum to the exhaust gas on one side and to the atmospheric air on the other side. The platinum that is exposed to the exhaust gas is covered with a porous ceramic material.
- This allows the oxygen through to the platinum but protects the platinum against harmful contaminants in the exhaust products.



ɡ. 5.28 Diagrammatic representation of the oxygen sensor in the exhaust pipe



- The greater the difference in oxygen levels between the atmospheric air and the exhaust gas, the greater is the voltage produced by the EGO sensor.
- When the air–fuel ratio changes from slightly rich, say 14:1 lambda = 0.93 to slightly weak, 16:1 lambda = 1.06, there is a marked change in the oxygen partial pressure of the exhaust gas and this leads to a step change in the EGO sensor voltage because the ceramic electrolyte (zirconia) is very sensitive to oxygen levels, as shown in Fig. 5.29.
- This sudden change in sensor voltage is used to trigger an action by the ECM, that will alter the fuelling, to maintain lambda=1 (chemically correct air–fuel ratio).

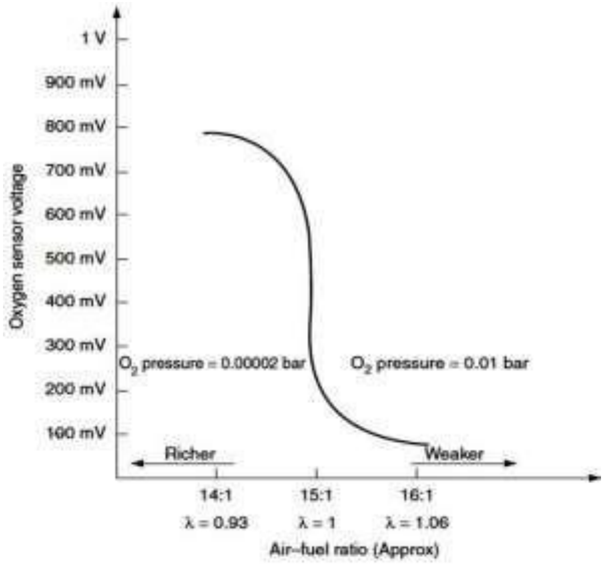


Fig. 5.29 Change in sensor voltage as air–fuel ratio changes

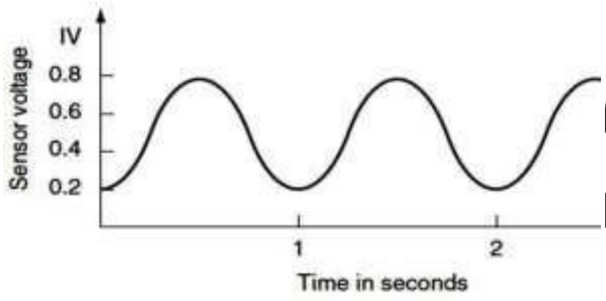


Fig. 5.30 The voltage waveform of an EGO se

- The result of this action is that the EGO sensor output cycles up and down, at a frequency that ensures that the engine runs smoothly and the exhaust catalyst is kept functioning correctly.
- The actual frequency is determined by the program that the designer places in the ROM of the ECM. All of this means that a voltaic-type EGO produces a standard type of output that can be measured by means of equipment that is readily available to vehicle repairers
- The approximate shape of the voltage waveform from the EGO sensor when in operation is shown in Fig. 5.30. This waveform arises from the way that the ECM alters the amount of fuel injected, i.e. lowering and raising the amount of fuel injected, in an ordered way, so as to keep the air–fuel ratio within the required limits.

- The action of the oxygen sensor is dependent on its temperature. The sensor needs to reach a **temperature of around 250^{o}C** before it starts to function at its best.
- In order to assist the sensor to reach this te quickly as possible, from a cold start, it is co pra equip the sensor with a resistive-type h element as in Fig. 5.31.
- This means that most oxygen sensors will be e four wires: a signal wire and an earth f sensor e and a feed wire and an earth f heating element.
- This type of sensor is known as a **heated exhau oxygen sensor (HEGO)**

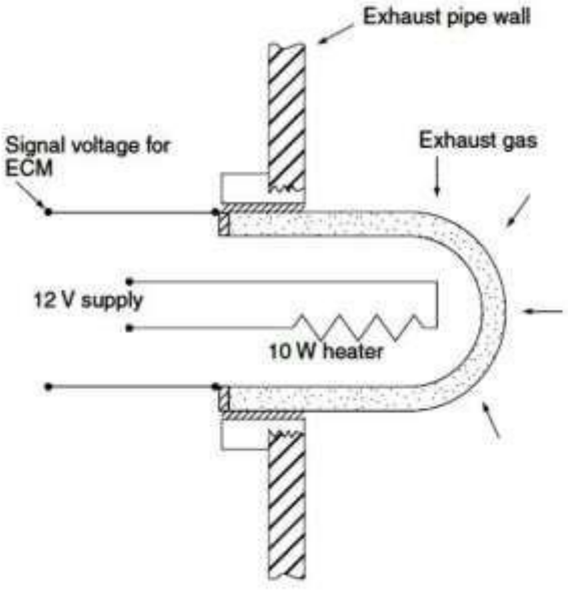


Fig. 5.31 A resistive-type heating element

❖*ON-BOARD MONITORING OF THE CATALYTIC CONVERTER*

▪The USA OBDII and impending European legislation requires that vehicle emissions systems are equipped with the facilities to illuminate a warning lamp (malfunction indicator lamp or MIL) should the catalytic converter cease to function correctly. In order to meet this requirement it is current practice to fit a second oxygen sensor downstream of the catalyst, as shown in Fig. 5.34.

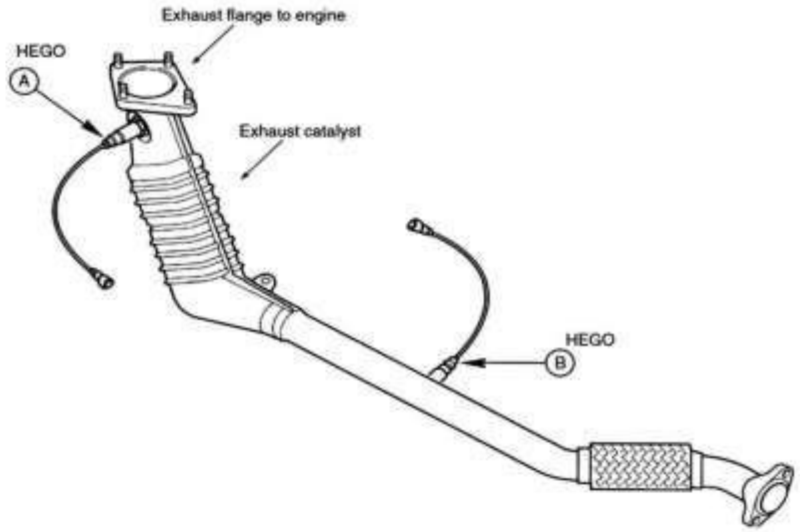
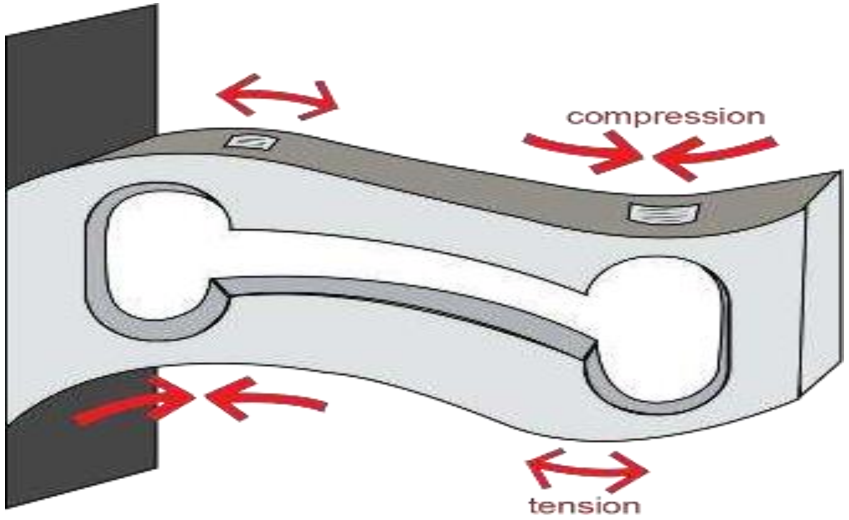


Fig. 5.34 The downstream oxygen sensor that monitors the catalyst

- In Fig. 5.34, A represents the upstream oxygen which is on the engine side of the catalyst.
- It is this sensor that provides the feedback signal that the ECM uses to control the air–fuel ratio within the required limits.
- The second sensor at B sends a signal to the ECM that is used to determine the efficiency of the catalyst. The voltage amplitude of this second sensor signal is the key to assessing the catalyst efficiency.
- As the catalyst ages, or is damaged by incorrect fuel etc., the voltage amplitude of this second sensor increases.

❖ Load Cell

- A **load cell** is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured.
- The various types of load cells include hydraulic load cells, pneumatic load cells and **strain gauge load cells**.



- The strain gauge measures the deformation (strain) as a change in electrical resistance, which is a measure of the strain and hence the applied forces.

$$\frac{\Delta R}{R} = K \times \varepsilon$$

Where,

R : Initial resistance of the strain gauge

ΔR : Resistance change caused by elongation or contraction

K : Proportional constant (called the "gauge factor") (ΔR/R/ΔL/L)

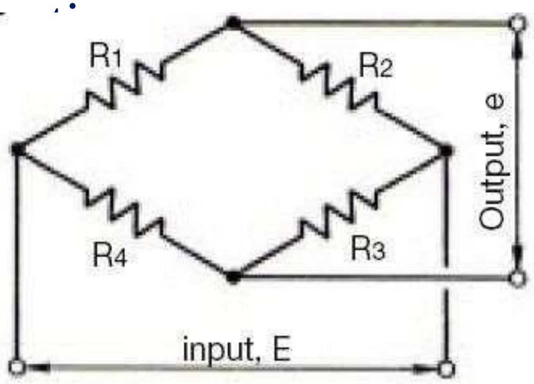
ε : Strain

Single Point Load Cells	Button Load Cells	S-Beam Load Cells	Miniature Load Cells	Through Hole Load Cells	Pancake Load Cells
					
Generally used to build scales and in applications where space is not limited. They offer excellent off-center loading compensation.	Ideal for measuring compression forces that are applied axially. They are compact and easy to use.	Ideal for tension (pull) or Universal (push and pull) force measurement applications	Smallest miniature load cells we offer for compression force measurements only. Ideal for cramped locations.	Rugged, industrial load cells for compression and/or tension force measurements. Has a through hole with threads to attach accessories	High Capacity load cells with capacities up to 100K lbs for compression and/or tension load cell measurements.

- The working principle is based on the strain/resistance relationship of electrical conductors.
- Any electrical conductor changes its resistance with mechanical stress, e.g. through tension or compression forces. The resistance change is partially due to the conductor's deformation and partially due to the change in the resistivity of the conductor material as a result of microstructural changes.
- **Operating Principle:**

Welded Sensor utilizes bonded strain gages connected in Wheatstone bridge circuit. The output is derived from imbalance in the bridge circuit as load is sensed by sensor.

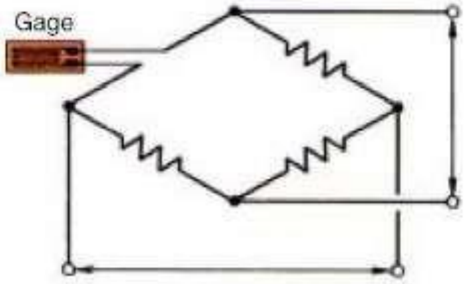
❖ Wheatstone Bridge:



- Wheatstone bridge is an electric circuit suitable for det of minute resistance changes, therefore used to m resistance changes of a strain gage
- The bridge is configured by combining four resistors

as shown in Fig.

- Initially $R_1=R_2=R_3=R_4$, in this condition no output volt there, **e=0**
- When one of the Resistances is replaced by strain Gauge attached to the object whose strain is to be measured and lo applied, then there is small change in the resistance of g a hence some output voltage is there which can be related to st as



$$e = \frac{1}{4} \cdot \frac{\Delta R}{R} \cdot E$$

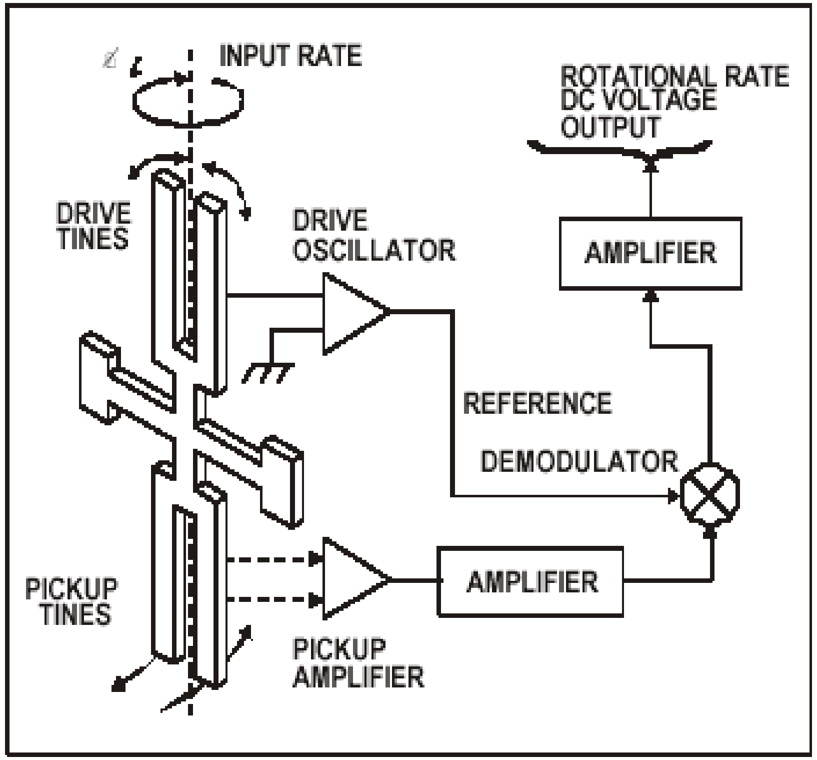
- From this, strain can be easily determined using the relation

$$e = \frac{1}{4} \cdot K \cdot \varepsilon \cdot E$$

❖ Yaw Rate Sensor:

- The drive portion looks and acts exactly like a simple tuning fork. Because the drive tines are constructed of crystalline quartz, it is possible to electronically “ring” this tuning fork.
- Each fork tine has a mass and an instantaneous radial velocity which changes sinusoidally as the tine moves back and forth.
- As long as the fork’s base is stationary the momenta of the two tines exactly cancel one another and there is no energy transfer from the tines to the base. In fact, it takes only ~6μW of power to keep the fork ringing.

- As soon as the tuning fork is rotated around its axis of symmetry, however, the Coriolis principle exerts a profound influence on the behavior of this mechanism.
- By convention, (the “right
the rotational vector, ω_i, is d
arrow that is aligned wit
rotation.
- The instantaneous radial e
of the tines will, throug
effect, generate a vector wit
this rotation vector.



- The net effect is that each tine will generate a force perpendicular to the instantaneous radial velocity of each of the tines:

$F = 2m\omega_i * V_r$ where:

– m = tine mass

– ω_i = rotation rate

– V_r = radial velocity

- Note that this force is directly proportional to the rotation rate, and since the radial velocity of the tines is sinusoidal, the force on each tine is also sinusoidal.
- Because the radial velocities of the two tines are equal and opposite, the Coriolis forces are equal and opposite, producing an oscillating torque at the base of the drive tine

fork which is proportional to the input angular rate.