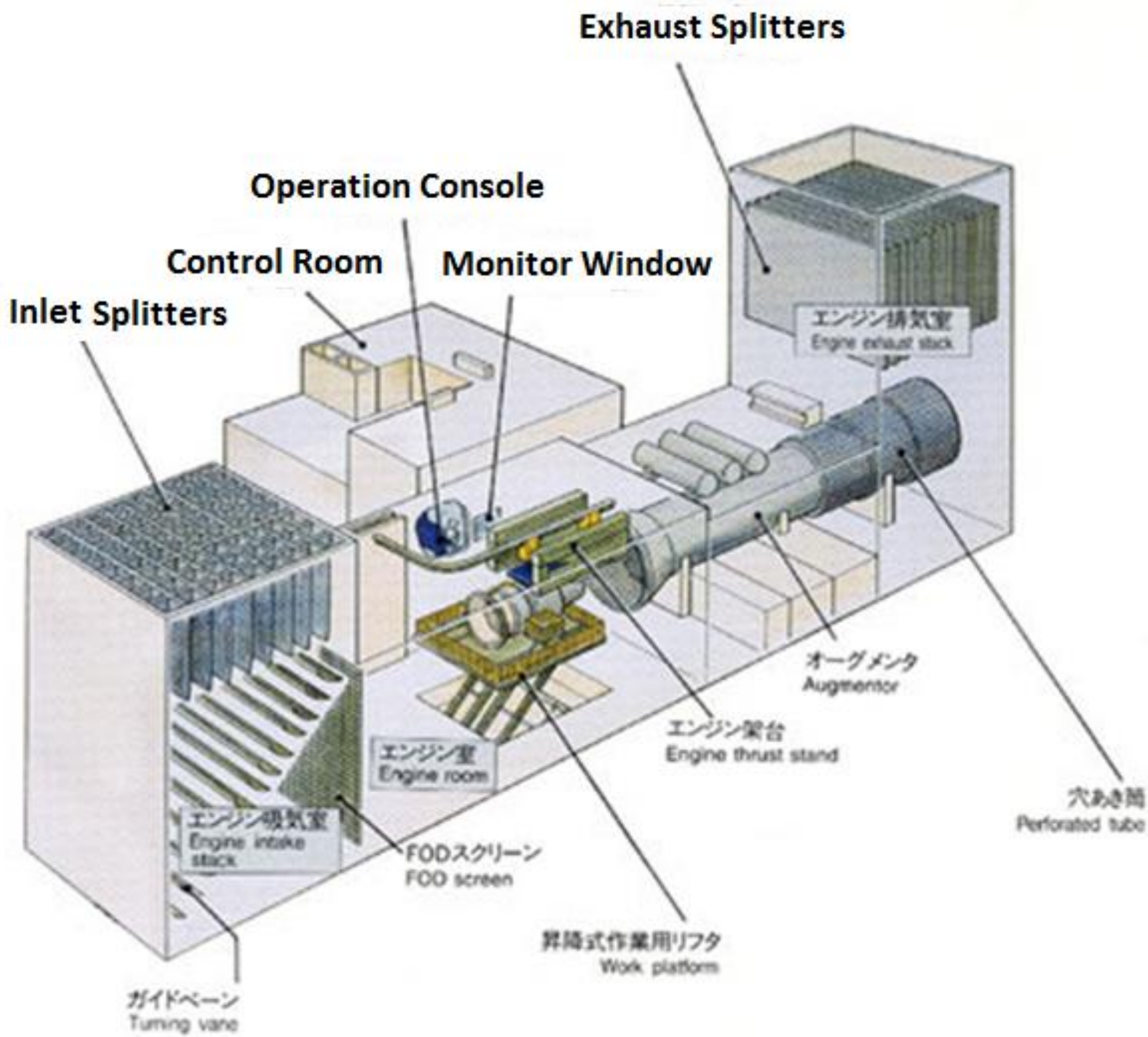
Module 5

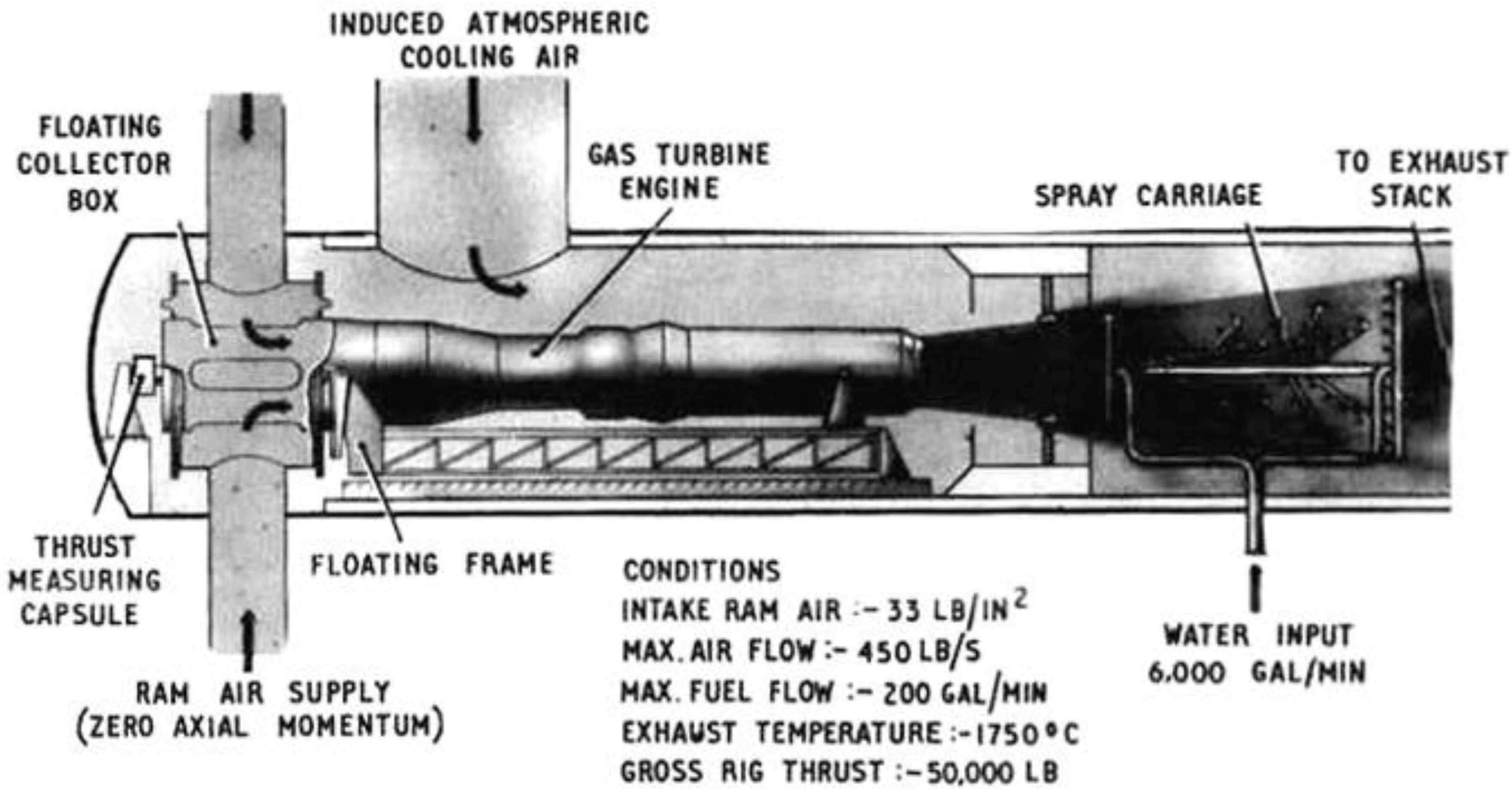
Engine Testing

The test cell for aircraft jet engine is the equipment in which performance checks are conducted after maintenance of an engine, and checks the operating condition of each section, adjustment of each part before loading to the aircraft.


Exhaust Splitters
Operation Console
Control Room
Monitor Window
Inlet Splitters
エンジン排気室
Engine exhaust stack
オーグメンタ
Augmentor
エンジン架台
Engine thrust stand
穴あき筒
Perforated tube
エンジン室
Engine room
エンジン吸気室
Engine intake stack
FODスクリーン
FOD screen
昇降式作業用リフタ
Work platform
ガイドベーン
Turning vane

Jet engine test cell


Atec
Atec


INDUCED ATMOSPHERIC
COOLING AIR
FLOATING
COLLECTOR
BOX
GAS TURBINE
ENGINE
SPRAY CARRIAGE
TO EXHAUST
STACK
THRUST
MEASURING
CAPSULE
FLOATING FRAME
CONDITIONS
INTAKE RAM AIR :- 33 LB/IN^2
MAX. AIR FLOW :- 450 LB/S
MAX. FUEL FLOW :- 200 GAL/MIN
EXHAUST TEMPERATURE :- 1750 °C
GROSS RIG THRUST :- 50,000 LB
WATER INPUT
6,000 GAL/MIN
RAM AIR SUPPLY
(ZERO AXIAL MOMENTUM)


symtx
symtx
symtx
PELCO

Test cells

- Test cells are fully equipped to measure all of the desired operating parameters.
- Contains control and engine rooms.
- Silencers for noise suppression.
- Water spray rig for cooling.

Measurements and instruments

- Pressure, temperature, power or thrust, shaft speed, fuel, vibrations and airflow are measured.

Temperature gages

- Fuel and oil inlet temperature.
- Starter air temperature.
- Scavenge air temperature.
- Compressor inlet temperature.
- Exhaust gas or turbine inlet temperature.
- Wet and dry bulb temperature.
- Ambient air temperature.

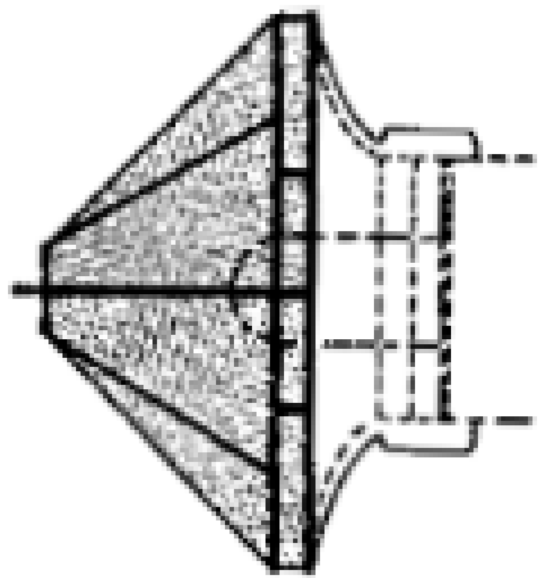
Pressure gages or manometer

- Fuel inlet pressure.
- Lubrication system pressure.
- Main and after burner fuel pump pressure.
- Starter air pressure.
- Ambient air pressure.
- Sump or breather pressure.
- Engine pressure ratio (EPR).
- Water pressure.
- Turbine cooling air pressure.

Additional instruments

- Power lever control .
- Vibration gage(at compressor and turbine).
- Clock and stopwatch.
- Tachometer and readout device.
- Fuel flow transmitter and meter.
- Load cell(to measure thrust)

Bellmouth inlet



Bellmouth Compressor Inlet

Bellmouth inlet

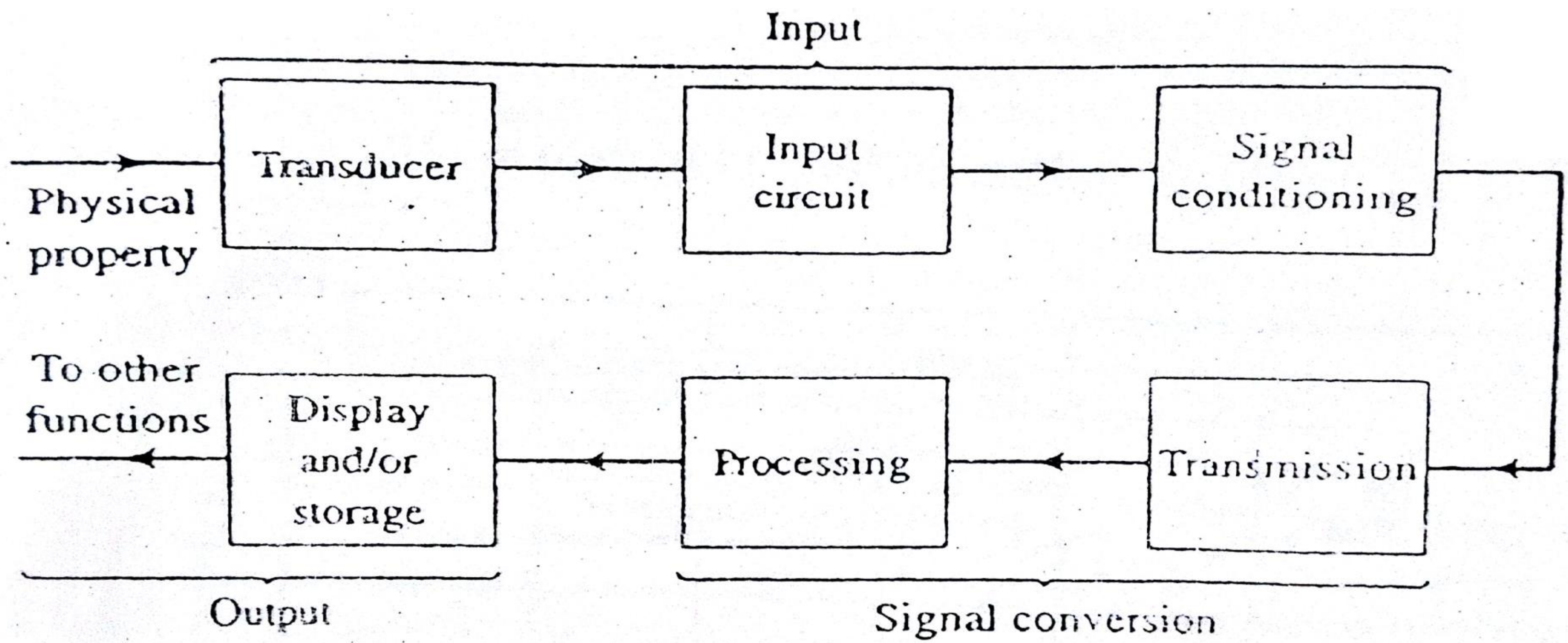
- It is a funnel shaped tube with rounded shoulders.
- Offers very small air resistance.
- Duct loss can be considered zero.

Uncertainties in measurement

- Causes and types of experimental errors
- Types of errors
  - Gross blunders: causes invalidation of the data
  - Fixed errors or systematic errors or bias errors: repeated error in reading.
  - Random errors: due to personal fluctuations, electronic fluctuation, influence of friction etc.

It is very difficult to distinguish between fixed errors and random errors.

Data Acquisition System



Data Acquisition System

1. Input stage: consists of transducers, input circuit and signal conditioning circuits. Eg: amplifiers, filters.
2. Signal Conversion stage: information readied for transmission.
3. Output stage: Data display and storage.

Data Acquisition System

- Transducer: it furnishes an electrical signal that is indicative of the physical variable being measured.

Eg: Thermocouple, strain gage, load cell, pressure transducer.

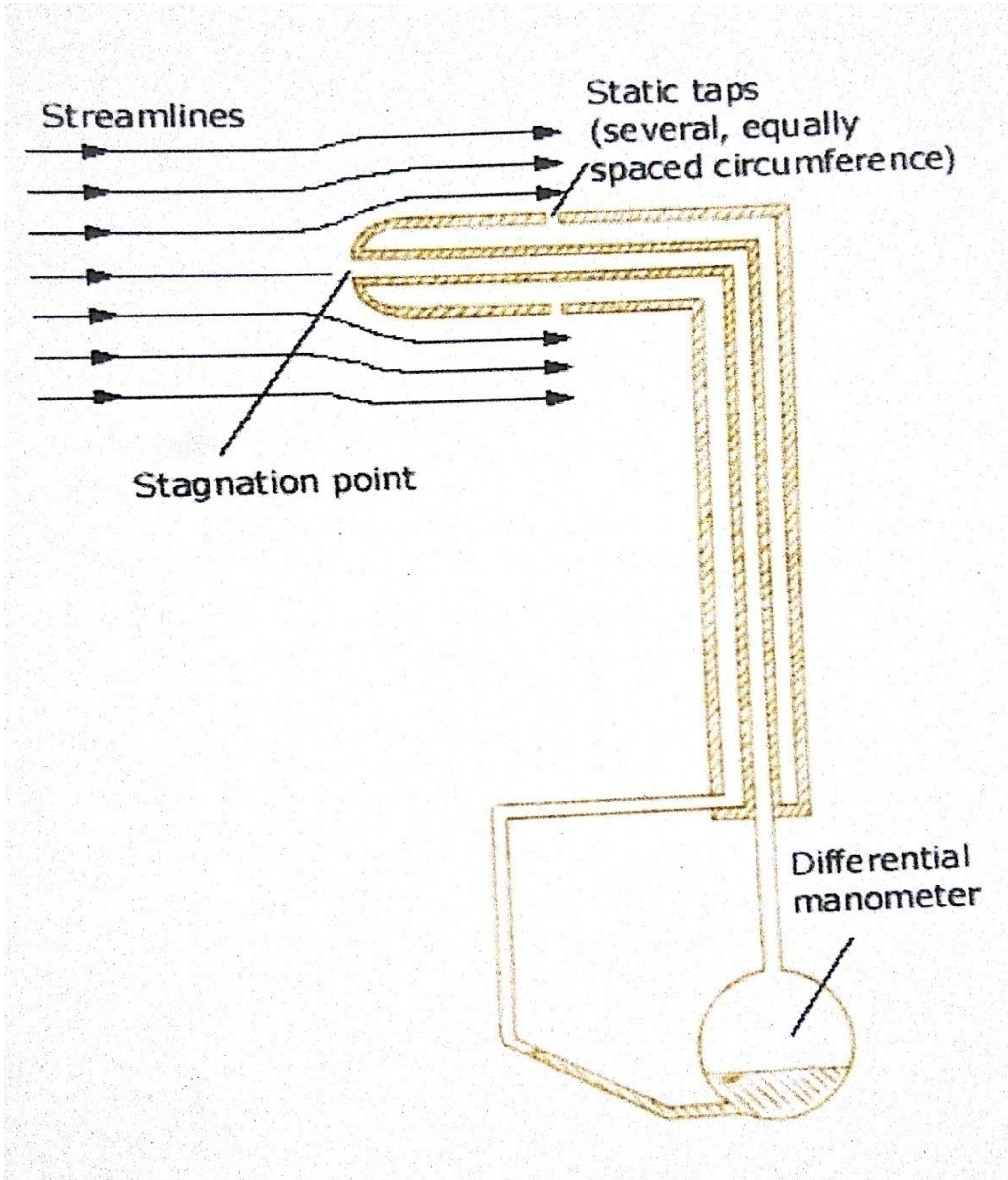
Data Acquisition System

Two principles to be observed in the Analog/ Digital sampling process,

1. Sampling must take place at a rate at least twice the highest frequency component in the signal.
2. If the frequency of the signal is unknown, the frequencies above the largest frequencies of interest should be filtered out and the highest frequency of interest must be less than half the sampling rate.

Pressure measurement

Pitot static tube



Pitot static tube

- An open-ended right-angled tube pointing in opposition to the flow of a fluid and used to measure pressure.

Pitot static tube

- Pitot static tube is used to measure both static and stagnation pressure.
- The opening in the front senses the stagnation pressure.
- The small holes around the outer periphery of the tube sense static pressure.
- The static pressure holes are normally placed at least eight diameters downstream the from the front of the probe.

Pitot static tube

- Stagnation pressure = dynamic pressure + Static pressure
- Transducers use resistive strain gauge on the diaphragm.
- Piezo electric material can be used as an alternative.
- Calibration using dead weight.
- Calibration curves relates the electrical signal to pressure levels.
- Transducer temperature should be controlled as it affects the strain gauge resistance.

Test cell static pressure

- Intake is inside the test bed and the pressure is measured in at least 2 places of low cell velocity.

Engine static pressure

- Static pressure can be measured by having the axis of the tapping, perpendicular to the flow direction. No dynamic head will be recovered.
- These give more accurate reading.

Engine total pressure

- For measuring total pressure, the pressure tapping is mounted in a probe which points its axis towards the direction of gas flow.

Types of transducers

- Piezo electric crystal
- Electromagnetic type
- Capacitance type
- Strain gauge type

Piezo electric crystal

- A Piezo electric crystal is placed between two plate electrodes.
- When a force is applied to plates, a stress will be produced in the crystal and a corresponding displacement.
- This deformation produces a potential difference at the surface of the crystal, called Piezo electric effect.
- The induced charge on the crystal is proportional to the impressed force.

Response depends on

- Response of transducer element that senses the pressure.
- Response of the pressure transmittinng fluid and connecting tubing.

Natural frequency of the transducer must be greater than the signal frequency to be measured.

Temperature measurement

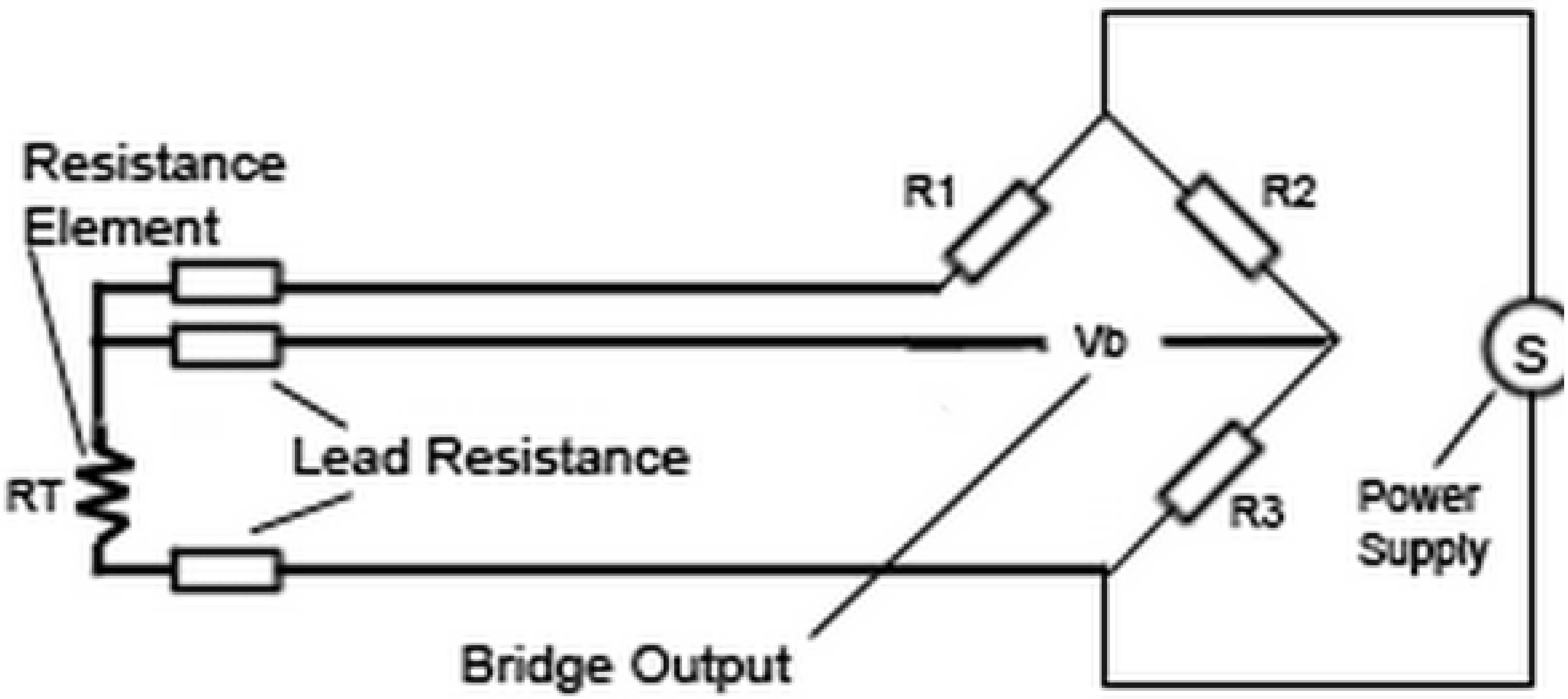
Need for Temperature measurement

- Determination of engine performance.
- To determine efficiency and flow capacity.
- To ensure that the engine is not operated beyond the stipulated limits for mechanical integrity.
- Mass flow measurement.

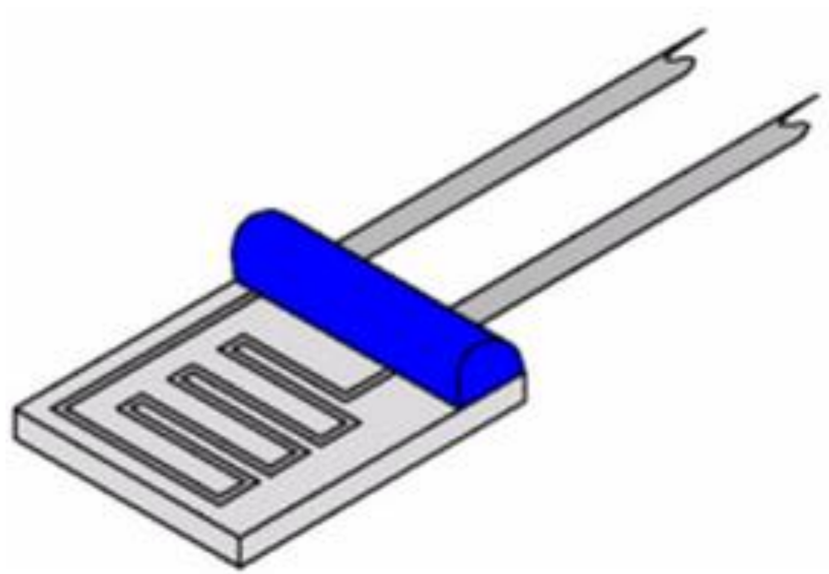
Resistance bulb thermometer(RBT)

- Resistance thermometers, also called resistance temperature detectors (RTDs), are sensors used to measure temperature by correlating the resistance of the RTD element with temperature.
- Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core.
- The RTD element is made from a pure material, typically platinum, nickel or copper.
- The material has a predictable change in resistance as the temperature changes and this change is used to determine temperature.

Resistance bulb thermometer(RBT)



Resistance bulb thermometer(RBT)



Resistance bulb thermometer(RBT)

The temperature is measured via changes in resistance in a heated material.

- Platinum resistance thermometer (PRT)
- Range 1000K
- Accuracy 0.1K
- Delicate
- Uses: air inlet temperature, reference temperature in thermocouple systems.

Temperature

- ***Wet bulb temperature:*** temperature measurement with the thermometer having its bulb covered with wet cloth and exposed to air stream whose temperature is being measured.
- ***Dry bulb temperature***: Dry bulb temperature refers to the temperature of air measured with ordinary thermometer having its bulb open.
- Difference between dry bulb temperature and wet bulb temperature is called wet bulb depression.
- Wet bulb depression is zero in case of saturated air as the dry bulb temperature and wet bulb temperatures are equal.

Thermocouple

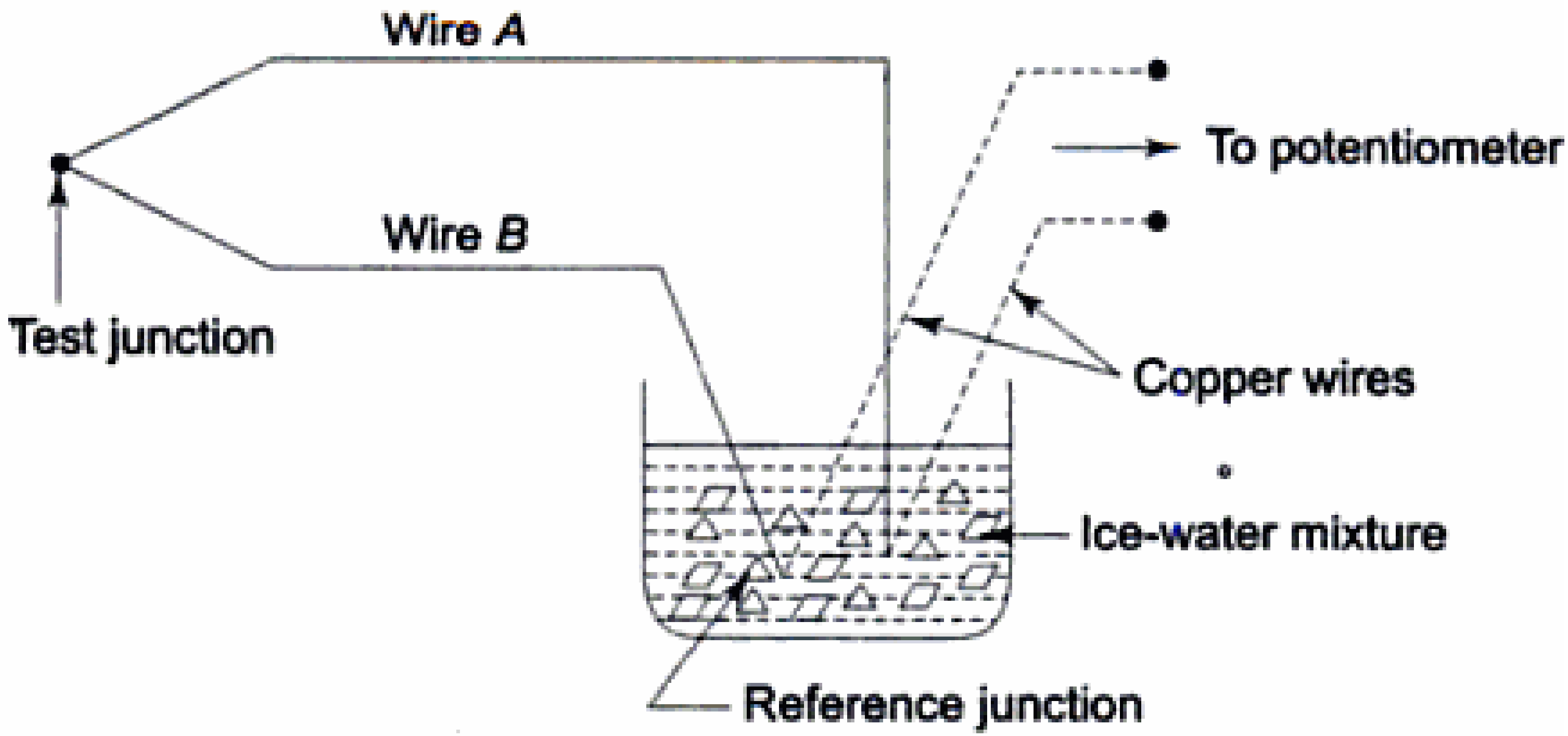


Fig. 2.4 *Thermocouple*

- A thermocouple circuit is made from joining two wires A & B made of dissimilar metals.
- Due to the ‘seebeck’ effect a net e.m.f. (electro motive force) is generated in the circuit which depends on the difference in temperature between the hot and cold junctions.
- Hence the e.m.f. is a thermometric property of the circuit.
- This e.m.f. can be measured by a micro-voltmeter to a high degree of accuracy.
- The choice of metals depends on the temperature range to be measured.
- The combination of metals in use are chromel – alumel, copper – constantan, platinum – rhodium etc.

Thermocouples

- Less accurate than RBT, but robust.
- K type – chromel alumel (Ni-Cr/Ni-Al).
- Used to measure compressor and turbine temperatures.

Measurement of temperature of turbine blading

Measurement of temperature of turbine blading

- Sheathed Chromel alumel thermocouples installed in drilled turbine blades.
- Cooling air to the slip rings.

Blade modification

welding technique

electric discharge machining

conventional drilling

Disc modification

Mercury sliprings

Fuel flow

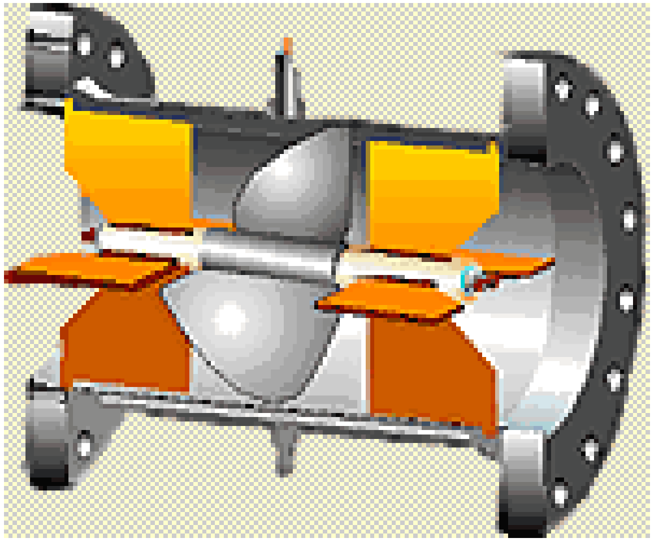
- Bulk meter
- Turbine flow meter

Fuel flow

- Bulk meter
  - Measures volumetric flow
  - Pistons connected to a rotating crank shaft.
  - No upstream flow conditioning is required since they are unaffected by inlet flow profile and swirl.

Fuel flow

- Turbine flow meter
  - Instantaneous volumetric fuel flow rate.
  - Flow straightener – colander plate.

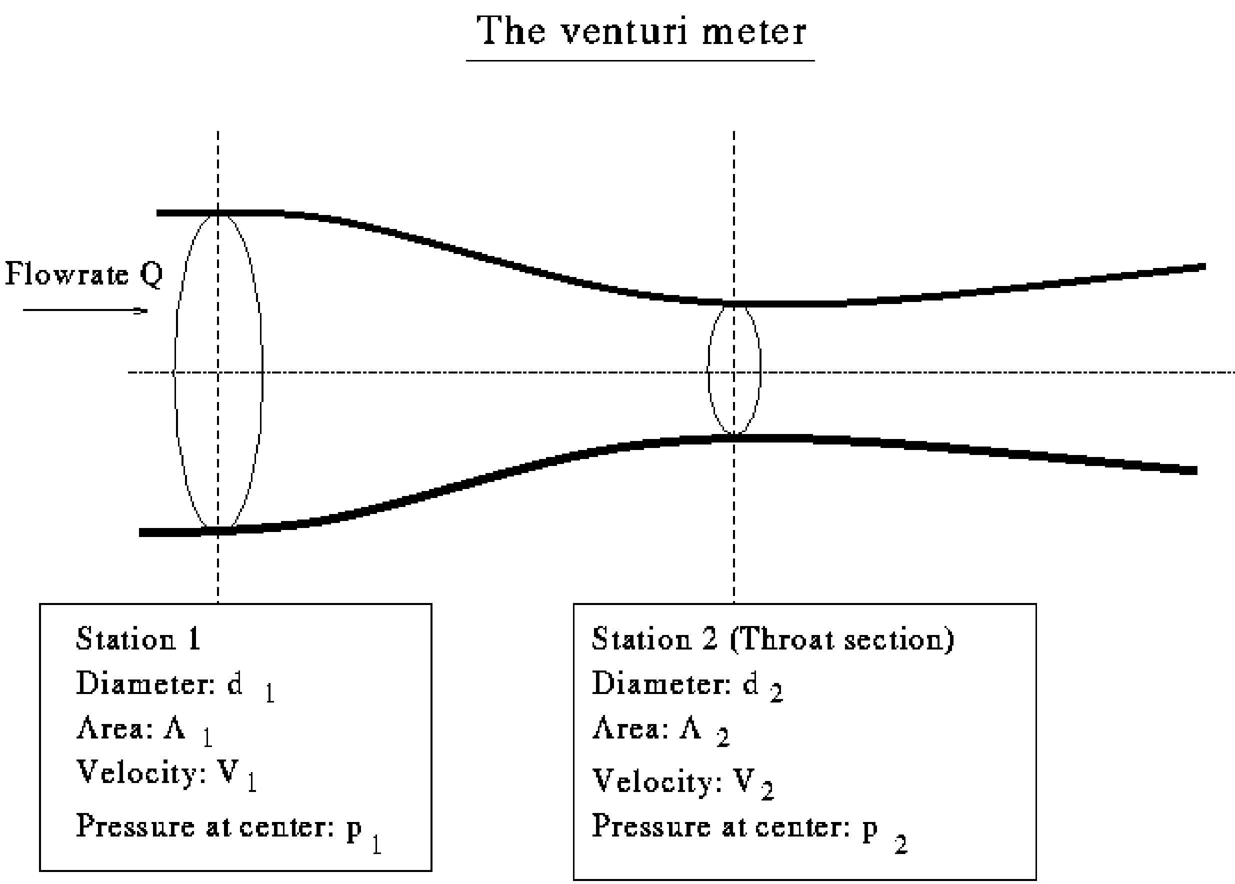


Air mass flow

- Air meter
  - Venturi meter

$$Cd = \frac{\text{Actual discharge}}{\text{Theoritical discharge}}$$

Air mass flow



Discharge, $Q = A_1V_1 = A_2V_2$

Venturi meter

Thrust

- Load cell
  - 4 strain gauges.
    - 2 opposite gauges in axial direction
    - 2 opposite gauges in transverse direction

Axial strain $\varepsilon_a = P/AE$

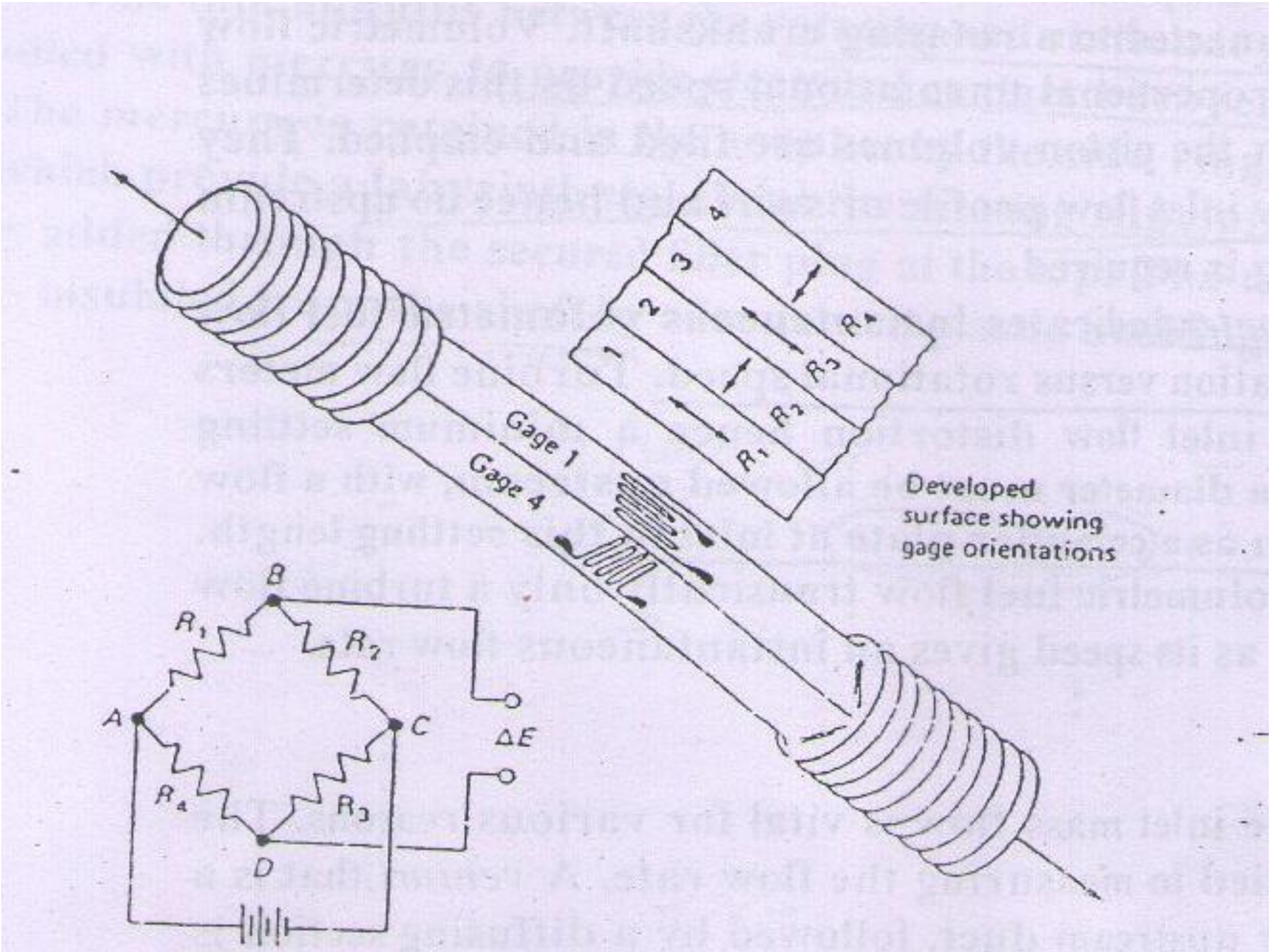
Transverse strain $\varepsilon_t = -vP/AE$

P=load

A=Sectional Area

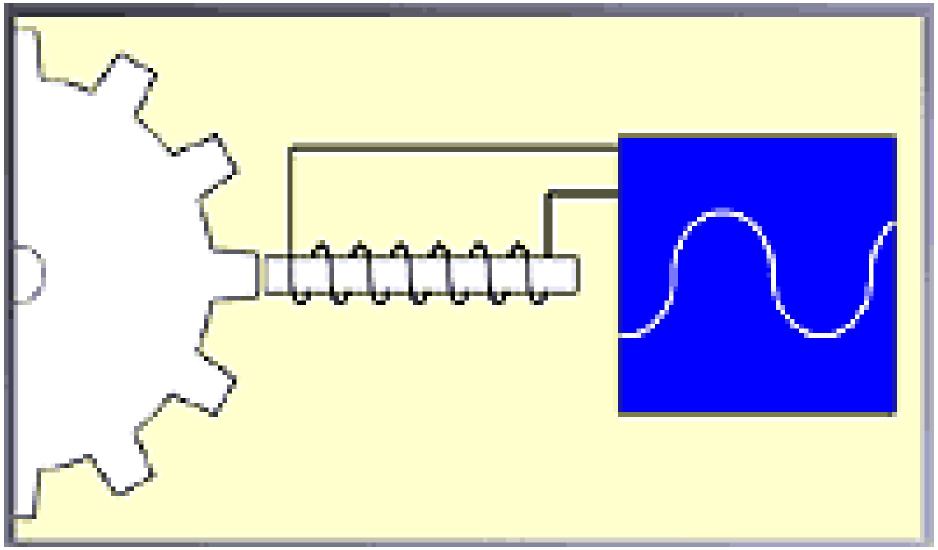
E=Modulus of elasticity of the material

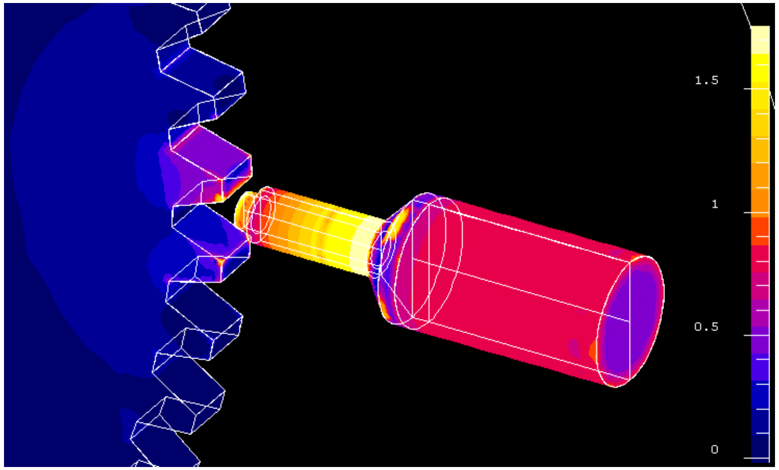
v=Poission's ratio of material



Strain gages mounted on a specimen to produce a load cell

Shaft speed





Phonic wheel

Shaft speed

- Phonic wheel
- Highly accurate and reliable
- Passing of teeth marked in a wheel integral with the shaft is sensed by an electromagnetic coil.
  - Clock and pulse counter.
  - Frequency to DC converter.

Engine output , shaft torque and power

- Power = torque X rotational speed
- Torque meter
  - Phonic wheel attached to shaft and an outer unloaded tube.
  - Changes in waveform picked up indicate angular displacement and hence torque.
- Strain gauges used to shaft twist.
  - Delicate and not widely used.

Humidity

- Capacitance sensors – changes in dielectric constant of a water absorbing material.
- Chilled mirrors – changes in reflected light level, due to condensation.
- Wet and dry bulb thermometers.

Humidity

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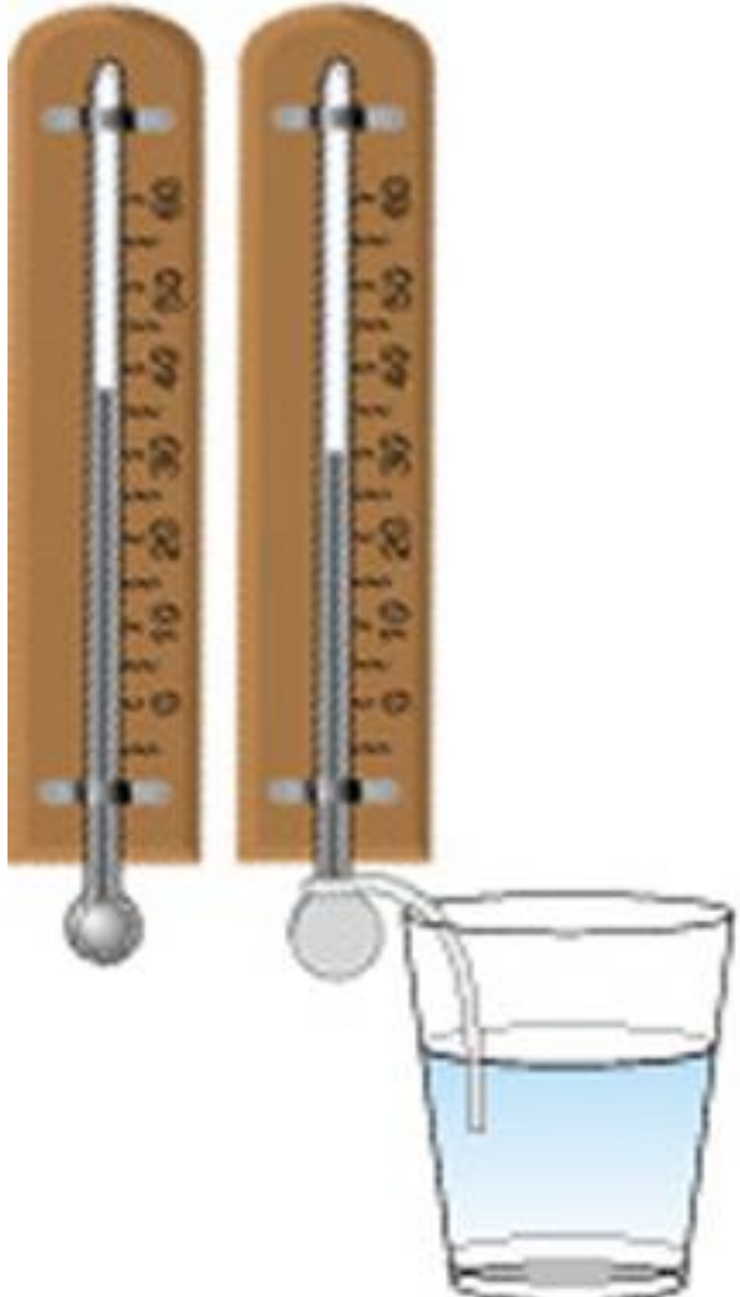


Experimental stress analysis

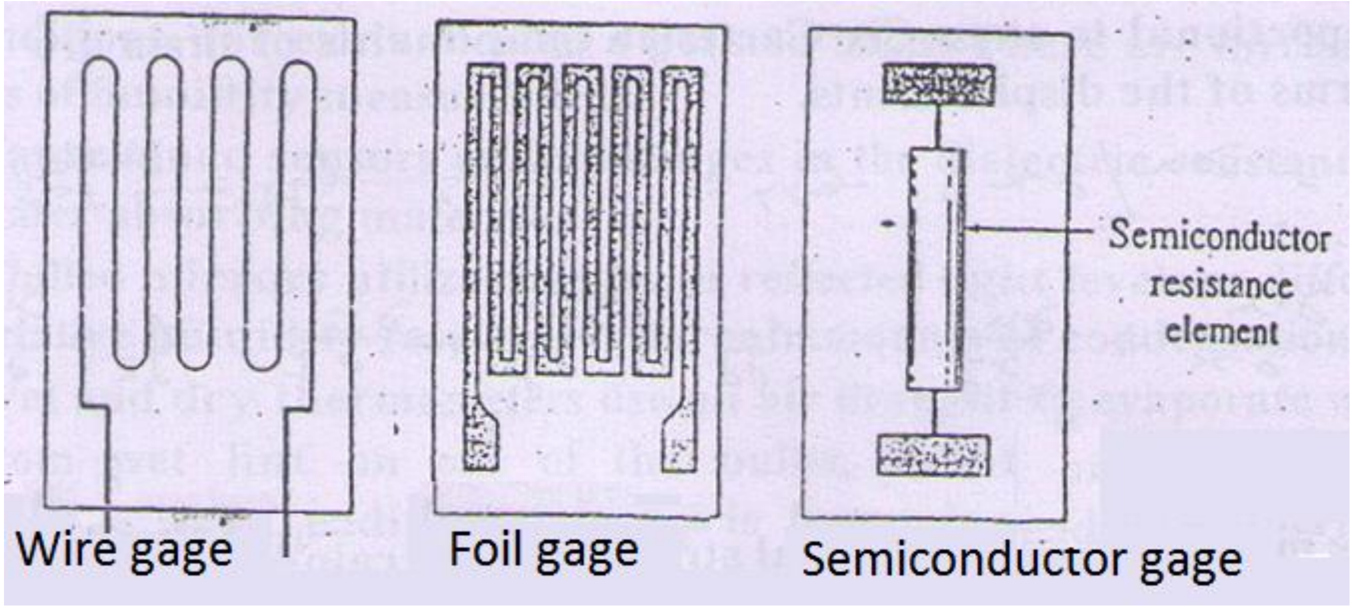
- Stress is proportional to strain.
- Six cartesian components in terms of displacement,

Experimental stress analysis

- Electrical strain gages.
  - Resistance of wire changes as a function of strain.
  - Wheatstone bridge used to measure the resistance change.
  - Adhesive

Types of resistance strain gages

- Wire gage
- Foil gage
- Semiconductor gage



Types of resistance strain gages

- Wire gage
  - Wire 0.0005 to 0.001 inch (12 to 25 micro meter).
- Foil gage
  - Foil less than 0.001 inch thick
- Semiconductor gage
  - Silicon base material
  - Has very high temperature coefficient of resistance.

Problems associated with strain gage installation

1. temperature effect: differential thermal expansion between the resistance element and the material to which it is bonded.
2. moisture effect: changes the electrical resistance between the gage and the ground potential.
3. wiring problem: faulty soldering.

Brittle coating method for stress analysis

- Ceramic based brittle coating is air sprayed.
- 0.002 to 0.008 inch (0.05 to 0.2 mm) thick.
- Dried at room temperature or cured in oven.
- Subject to load causing coating to fail by cracking.
- Crack pattern is analysed.

Brittle coating method for stress analysis

Advantages

1. Gives complete data for magnitude and direction of principal stresses.
2. Simulation is not required.
3. Value of the load acting on the component may be unknown.
4. Data are converted to stress in simple method without complex mathematical analysis.

Brittle coating method for stress analysis

Dis-advantages

1. Variable precision of stress distribution.
2. Temperature and humidity variation.
3. Thickness of the coating may not be uniform.
4. Brittle coating fails when it is strained to threshold strain.

Engine performance trends

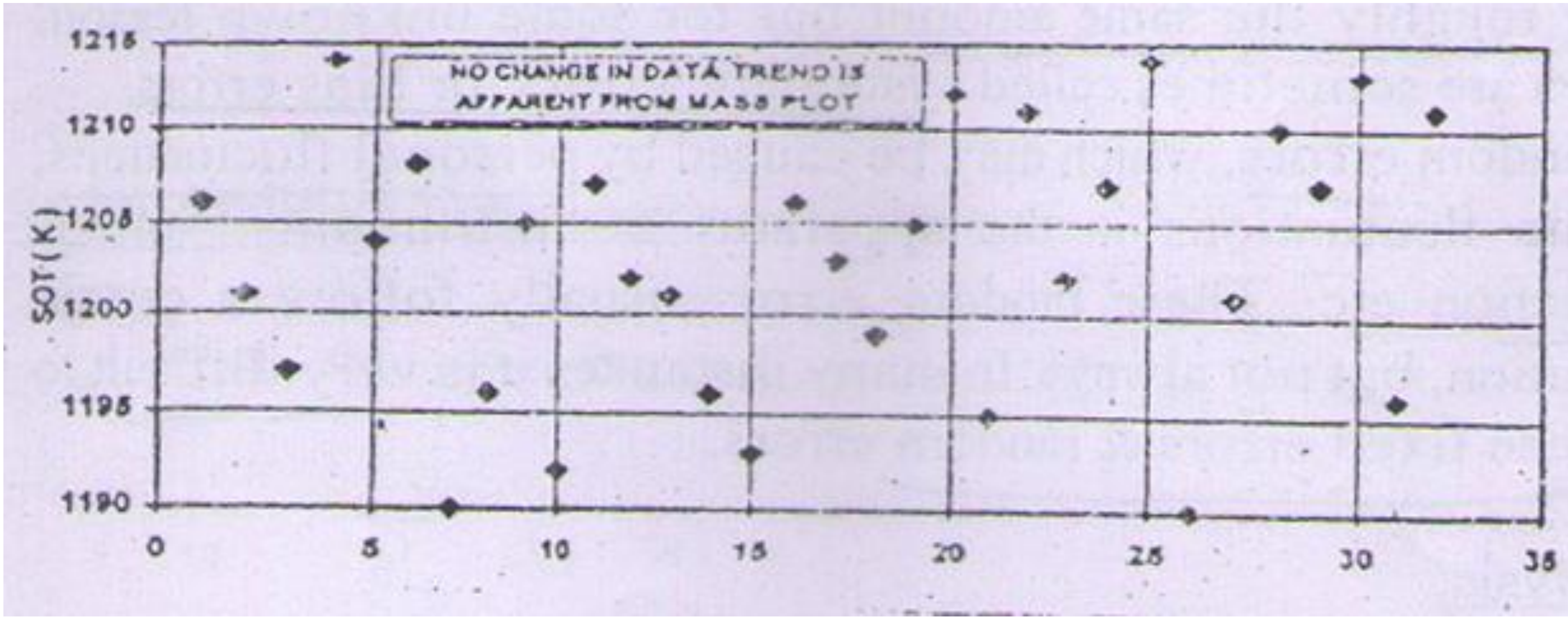
Engine performance trends

Engine no. (–)	SOT (K)	SOT-1200 (K)	CUSUM (K)	Engine no. (–)	SOT (K)	SOT-1200 (K)	CUSUM (K)
1	1206	6	6	17	1203	3	21
2	1201	1	7	18	1199	−1	20
3	1197	−3	4	19	1205	5	25
4	1214	14	18	20	1212	12	37
5	1204	4	22	21	1195	−5	32
6	1208	8	30	22	1211	11	43
7	1190	−10	20	23	1202	2	45
8	1196	−4	16	24	1207	7	52
9	1205	5	21	25	1214	14	66
10	1192	−8	13	26	1190	−10	56
11	1207	7	20	27	1201	1	57
12	1202	2	22	28	1210	10	67
13	1201	1	23	29	1207	7	74
14	1196	−4	19	30	1213	13	87
15	1193	−7	12	31	1196	−4	83
16	1208	8	18	32	1211	11	94

Tabular test data

SOT = Stator Output Temperature.

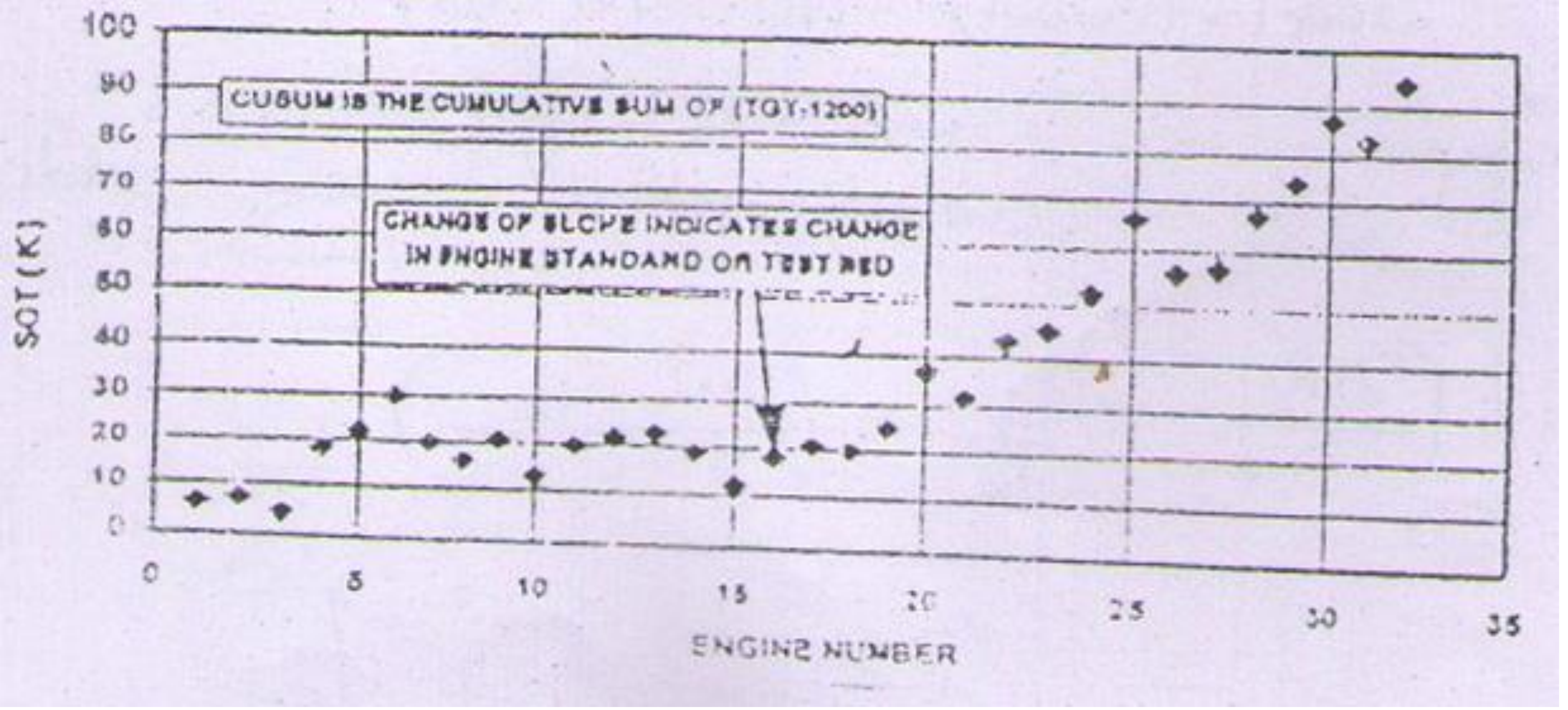
Engine performance trends



SOT = Stator Output Temperature.

Mass plot : SOT verses engine number

Engine performance trends



- CUSUM plot : SOT verses engine number

CUSUM plots

- Cumulative sum control chart
- It is a sequential analysis technique used for monitoring change detection.
- Example: mean.
- It gives a criterion for deciding when to take corrective action.
- When the CUSUM method is applied to changes in mean, it can be used for step detection of a time series.

CUSUM plots

Advantage:

- The CUSUM chart is very effective for small shifts and when the subgroup size n=1.

Disadvantage:

- The CUSUM is relatively slow to respond to large shifts. Also, special patterns are hard to see and analyze.