Electrical and Electronic Measurements

Short notes for B.Tech EE · EEE · EIE · GATE EE

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I. Measurement Basics and Errors

- **Measurement** = comparing an unknown quantity with a standard.
- **Accuracy**: closeness of the reading to the true value. **Precision**: closeness of repeated readings to each other.
- **Resolution**: smallest change the instrument can detect. **Sensitivity**: output change / input change.
- **Dead zone**: largest input change for which there is no output.
- Standards: international, primary, secondary, working.

➤ Types of errors

Error	Cause	How to reduce
Gross	Human mistakes (wrong reading, wrong connection)	Care, repeat readings
Systematic - instrumental	Defects in the instrument, loading effect	Calibration, correction
Systematic - environmental	Temperature, humidity, stray fields	Shielding, controlled conditions
Systematic - observational	Parallax	Mirror behind pointer
Random	Unknown small causes	Many readings + statistics

FORMULA Static error = measured value - true value. % error = (Am - At) / At x 100.

- **Limiting (guarantee) error** is given as % of full-scale. At low readings the % error of the reading becomes large.

EXAMPLE 0–150 V voltmeter, accuracy ±1% of full scale. Limiting error = 1.5 V. At a reading of 75 V, error = 1.5/75 = ±2% of reading. So use meters in the upper part of the scale.

- Combination of errors: for product or quotient, **% errors add** (worst case). For sum, absolute errors add.

2. Analog Indicating Instruments

- Three torques act on the moving system:
  - **Deflecting torque**: makes the pointer move (due to the quantity).
  - **Controlling torque**: brings pointer back to zero, gives steady reading (spring or gravity).
  - **Damping torque**: stops oscillation (air friction, fluid friction, eddy current).

Instrument	Works on	Scale	Damping	Used for
PMMC	DC only	Uniform ($T \propto I$)	Eddy current	DC ammeter, voltmeter, galvanometer
Moving iron (MI)	AC and DC	Non-uniform ($T \propto I^2$)	Air friction	Cheap AC meters
Electrodynamometer	AC and DC	Non-uniform	Air friction	Wattmeter, transfer instrument
Induction type	AC only	-	Eddy current (brake magnet)	Energy meter

FORMULA PMMC: $T_d = B\,I\,N\,A$ (N·m). Spring torque $T_c = K\,\theta$. So $\theta = B\,N\,A\,I / K$ (uniform scale).

FORMULA MI and electrodynamometer: $T_d = (1/2)\,I^2\,dL/d\theta$ (MI). Reading is RMS.

- PMMC reads average value; on pure AC it reads zero.
- **Electrodynamometer** instruments read the same on DC and AC (RMS), so they are used as **transfer instruments** for calibration.
- Errors in MI: hysteresis, stray fields, frequency (eddy current), temperature.

➤ Range extension

FORMULA Ammeter shunt $R_{sh} = R_m / (m - 1)$, $m = I / I_m$. Voltmeter multiplier $R_{se} = R_m (m - 1)$, $m = V / V_m$.

EXAMPLE PMMC meter: full scale 10 mA, $R_m = 5\ \Omega$. As 0–1 A ammeter: $m = 100$, $R_{sh} = 5/99 = 0.0505\ \Omega$. As 0–100 V voltmeter: total $R = 100/0.01 = 10\ k\Omega$, so $R_{se} = 10000 - 5 = 9995\ \Omega$.

- Voltmeter **sensitivity** = $1 / I_{fs}$ (Ω/V). Higher sensitivity → less loading effect.
- Ammeter must have very low resistance (in series). Voltmeter must have very high resistance (in parallel).

3. Measurement of Power and Energy

➤ Wattmeter (electrodynamometer type)

- **Current coil (CC)**: fixed, in series with load. **Pressure coil (PC)**: moving, across the supply, with high series resistance.
- Deflection $\propto V I \cos\phi$, i.e. average power.
- Errors: pressure-coil inductance, power loss in coils, eddy currents. **Low power factor wattmeter** has compensating coil and is used in OC tests.

➤ 3-phase power

- n-wire system needs $(n - 1)$ wattmeters (Blondel's theorem).
- Two-wattmeter method: $P = W_1 + W_2$, $\tan\phi = \sqrt{3}(W_1 - W_2) / (W_1 + W_2)$. Reactive power $Q = \sqrt{3}(W_1 - W_2)$.

EXAMPLE $W_1 = 6$ kW, $W_2 = 2$ kW (balanced load). $P = 8$ kW. $\tan\phi = \sqrt{3} \times 4/8 = 0.866$, $\phi = 40.9°$, pf = cos 40.9° = 0.756 lagging. $Q = \sqrt{3} \times 4 = 6.93$ kVAR.

pf	Wattmeter readings
1	$W_1 = W_2$
0.5	One reads zero
Less than 0.5	One reads negative (reverse its PC or CC)
0	$W_1 = -W_2$

➤ Energy meter (induction type)

- Aluminium disc rotates due to two fluxes (series and shunt magnets). **Brake magnet** gives braking torque proportional to speed.
- **Meter constant** K = revolutions per kWh.
- Adjustments: **lag adjustment** (shunt flux lags voltage by exactly 90°), friction compensation (light-load adjustment), **creep** prevention (two holes in the disc).
- **Creeping**: disc rotates slowly with only voltage applied and no load.
- Modern meters are electronic (static) and digital.

EXAMPLE Meter constant 1200 rev/kWh. A 2 kW load runs for 30 min, so true energy = 1 kWh (should be 1200 rev). The disc makes 1180 rev, so registered = 1180/1200 = 0.983 kWh. Error = (0.983 − 1)/1 = -1.67% (meter runs slow).

4. Instrument Transformers

- Used to measure high current and voltage with standard low-range meters, and for isolation.
- **CT** (current transformer): primary in series, secondary rated 5 A or 1 A. **PT/NT**: primary across the line, secondary rated 110 V (line).

FORMULA Ratio error = (K x Is − Ip) / Ip x 100 for CT (K = nominal ratio). Phase angle error = angle between primary and reversed secondary phasor.

REMEMBER Never open the CT secondary while primary carries current. All primary current then magnetises the core: very high voltage appears and the core saturates. Always short it first. A PT secondary must never be shorted.

Point	CT	PT
Connection	Series	Parallel
Primary current	Decided by load	Decided by secondary burden
Secondary	Nearly short-circuited (ammeter)	Nearly open (voltmeter)
Danger	Open secondary	Shorted secondary

5. Measurement of Resistance

Range	Method
Low (below 1 Ω)	Kelvin double bridge, potentiometer, ammeter-voltmeter
Medium (1 Ω to 100 kΩ)	Wheatstone bridge, substitution, ohmmeter
High (above 100 kΩ)	Megger, loss of charge, direct deflection

FORMULA Wheatstone balance: P/Q = R/S, so unknown R = S x P / Q.

- **Kelvin double bridge** removes the effect of lead and contact resistance (uses a second set of ratio arms).
- **Megger** measures insulation resistance (hand-driven or electronic, gives high DC test voltage like 500 V or 1 kV).
- **Earth resistance**: fall-of-potential method with two auxiliary electrodes (earth tester).
- **Guard ring** in high-resistance measurement removes surface leakage current.

6. AC Bridges

- Balance condition: Z1 Z4 = Z2 Z3 → both **magnitude** and **angle** must balance.

Bridge	Measures	Note
Maxwell inductance bridge	L (by comparison with standard L)	Medium Q
Maxwell L-C bridge	L using a standard capacitor	For medium Q (1 < Q < 10)
Hay's bridge	L	For high Q (Q > 10)
Anderson bridge	L	Accurate for a wide range, low Q coils too
Schering bridge	C and dissipation factor	Also used at high voltage for insulation testing
Wien bridge	Frequency	Also used in oscillators
De Sauty bridge	C	Only for loss-free capacitors

FORMULA Maxwell L-C bridge (R1 parallel C1 in arm 1): Lx = R2 R3 C1, Rx = R2 R3 / R1, Q = ω C1 R1.

FORMULA Schering bridge: $C_x = C_2 R_4 / R_3$, $r_x = R_3 C_4 / C_2$, dissipation factor $D = \omega C_4 R_4$.

FORMULA Wien bridge: $f = 1 / (2\pi \sqrt{R_1 R_2 C_1 C_2})$. If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, $f = 1 / (2\pi R C)$.

- Sources of error: stray capacitance, earth capacitance. **Wagner earth device** removes earth capacitance effects.
- Detectors: headphones (audio range), vibration galvanometer (low frequency), electronic null detector.

7. Potentiometers and Magnetic Measurements

- **DC potentiometer**: compares unknown EMF with a standard cell (null method, no current drawn, so very accurate).
- Used to calibrate voltmeters and ammeters, and to measure EMF.
- **AC potentiometers**: polar type (magnitude and angle), coordinate type (in-phase and quadrature).
- **Ballistic galvanometer**: measures charge (first throw $\propto$ charge). Used to find flux and B-H curve.
- **Flux meter**: measures flux; controlling torque is almost zero.
- Iron loss of samples: **Epstein square**, wattmeter method.

8. Electronic Instruments

➤ CRO (cathode ray oscilloscope)

- Parts: electron gun, deflection plates (vertical, horizontal), screen with phosphor, time base (sweep) generator.
- Displays voltage vs time. Can measure amplitude, period, frequency, phase.
- **Lissajous figures** (X-Y mode): f_y / f_x = number of horizontal tangencies / number of vertical tangencies.
- Phase from ellipse: $\sin\phi$ = Y-intercept / Y-max.

- **DSO** (digital storage oscilloscope) samples and stores the signal; can show single events.

➤ Digital voltmeters and ADC

DVM type	Feature
Ramp type	Simple, lower accuracy
Dual-slope integrating	Good noise rejection, accurate, slow (used in multimeters)
Successive approximation	Fast, medium resolution
Flash (parallel)	Fastest, needs 2^n - 1 comparators

FORMULA Resolution of an n-bit ADC = Vfs / 2^n. A 3½-digit display counts up to 1999, so resolution = 1/1000 of the range.

EXAMPLE 10-bit ADC with 5 V full scale. Resolution = 5 / 1024 = 4.88 mV.

- **Q-meter**: measures quality factor of coils using series resonance. Q = VC / V at resonance.
- **Spectrum analyser**: shows the signal in frequency domain. **Wave analyser**: measures one harmonic at a time.

9. Transducers (Sensors)

- **Active**: make their own signal (thermocouple, piezoelectric). **Passive**: need external power (RTD, strain gauge, LVDT).

Transducer	Measures	Principle
Strain gauge	Strain, force, pressure	Resistance changes with strain
LVDT	Displacement	Mutual induction, AC excitation, differential output
RTD (platinum)	Temperature	Resistance rises with temperature (linear)
Thermistor	Temperature	Resistance usually falls (NTC), non-linear, very sensitive
Thermocouple	Temperature	Seebeck effect, EMF at junction of two metals
Piezoelectric	Force, vibration	Charge from stress; only dynamic measurement
Hall effect sensor	Magnetic field, current	Voltage across a current-carrying conductor in a field

FORMULA Gauge factor $GF = (\Delta R / R) / (\Delta L / L) = 1 + 2\nu + (\Delta\rho/\rho)/(\Delta L/L)$, ν = Poisson's ratio. Metal foil gauges have GF about 2.

- LVDT output phase tells direction, magnitude tells displacement. Null at the centre position.

10. Most Asked Questions (practice)

1. Define accuracy, precision, resolution and sensitivity. Classify errors.
2. Explain construction and working of PMMC instrument. Why is its scale uniform?
3. Compare PMMC, MI and electrodynamometer instruments.
4. Find shunt and multiplier resistance to extend a meter's range.
5. Explain the two-wattmeter method; find pf from readings.
6. Explain the induction energy meter, creeping and the adjustments in it.
7. Why should the CT secondary never be left open? Define ratio and phase angle error.
8. Derive the balance equations of Maxwell, Hay's and Schering bridges.
9. Explain Kelvin's double bridge for low resistance measurement.
10. Explain the dual-slope DVM. How are Lissajous figures used to find frequency?

TIP GATE EE measurements: errors and limiting error, meter range extension, two-wattmeter, energy meter constant, AC bridge balance and CT/PT. These are formula-based and quick to score.