# Engineering Measurements
# (0904422)
# Course Outline

| Cr. Hrs. | Program Outcomes / Course Name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | **Engineering Measurement** | 2 | 3 | | | | 3 | | | | 3 | 3 |

**0904422: Engineering Measurements** 3 Credit Hours

**Prerequisites by course:**

0904341: Thermodynamics (I)
0904222: Dynamics
0904361: Fluid Mechanics

***Prerequisites by topic:***

1. Basics of statistical analysis and probability.
2. Principles of electromagnetism.
3. Electrical circuits.
4. Bernoulli equation.
5. Basic stress-strain relations.
6. Heat transfer.
7. Interpolation of data and curve fitting.

Ch 1 . → from the website.

chapters → Technical report writing. Basic concept of metrology and measurement with their classifications and definitions. Errors and error analysis with statistical and uncertainty analysis. Characteristics of measurement systems. Electrical and mechanical transducers. Measurement of Force & Torque, Flow velocity, Temperature, Pressure, stress and strain. Design of experiment and Technical report writing. Engineering ethics. Design of experiment.

Book [A.K Sawhney] مكتبة الاخوة

## Course Outcomes

Students are expected to develop the following skills/understanding upon the successful completion of 0904423:

1. Calculate the errors in an experimental data. [PO2]
2. Design a measurement device. [PO2]
3. Calculate the fluid velocity, flow, pressure and force, analyze these devices and calculate the errors and uncertainty of readings. [PO1, PO10]
4. Ability to find parameters that characterizes the behavior of a thermometer and manometer. [PO1]
5. Identify the parameters that control the behavior and response of a measurement system. [PO1]
6. Analyze certain types of errors using statistical methods. [PO10]
7. Improve report writing skills. [PO2]
8. Chose the correct device for the least error or desired accuracy. [PO6]
9. Be familiar with various types of measurement devices and units of measurements. [PO11]

## Textbook(s) and References:

1. Experimental methods for engineers, by J. P. Holman [Textbook].
2. Theory and design for mechanical measurements, by Richard S. Figliola [Reference book].

## Course Outline

The following topics will be covered in this course:

1. Technical Report Writing.
2. Basics of metrology and measurements.
3. Errors and error analysis of data.
4. Dynamic characteristics of systems.
5. Basic Electrical and Mechanical Transducers.
6. Flow and velocity measurements.
7. Temperature measurement.
8. Pressure measurement.
9. Force, torque and strain measurement.
10. Design of experiments (If Time Permits).

## Evaluation of Outcomes

Evaluation will be done based on the following (percentages are up to the instructor):

| | | |
|---|---|---|
| 1. Class Attendance & Participation | : | 00 Marks 20 marks |
| No projects 2. Quizzes | : | ~~10~~ Marks |
| ~~3. Project~~ | : | ~~10 Marks~~ |
| 4. Mid-Term Exam. | : | 30 Marks |
| 5. Final Exam | : | 50 Marks |

## Lecture schedule:

| | | |
|---|---|---|
| Basics of Report Writing | : | 2 Lectures |
| Basics of Metrology | : | 2 Lectures |
| Basics of Measurement | : | 2 Lectures |
| Errors and error analysis | : | 6 Lectures |
| First Quiz (Date Decided Later) | | |
| Homework No. (1) | | |
| Characteristics of a system | : | 4 Lectures |
| Project Number (1) | | |
| Transducers | : | 4 Lectures |
| Second Quiz (Date Decided Later) | | |
| Homework (2) | | |
| Pressure Measurements | : | 1 week |
| Flow Measurements | : | 4 Lectures |
| Third Quiz and Mid-Term Exam. (Date Decided Later) | | |
| Temperature Measurements | : | 2 weeks |
| Fourth Quiz (Date Decided Later) | | |
| Homework (3) | | |
| Project Number (2) | | |
| Force & Torque Measurements | : | 1 week |
| Strain Gauges | : | 1 week |
| Design of Experiments | : | 1 week |

**The Final Exam will be held as decided by the university**

## Important Instructions:

The student should notice the following:

1. Maximum number of missed lectures allowed is 5 only.
2. Entrance to lecture room is not allowed after 10 minutes.
3. Close your mobile before entrance to the lecture room.
4. Programmable calculators like are not allowed.
5. All exams/tests/quizzes are closed-book. Extra sheet containing equations will be supplied.

6. The third quiz will be included with the Mid-Term exam.
7. Homework/Projects will not be accepted after the stipulated time.
8. Revision of the following topics is necessary: flow through orifices, Bernoulli equation, basic circuits (Wheatstone bridge) and Faraday's Law, and manometers.
9. There will be no makeup for the quizzes.
10. The makeup for the Mid-Term exam will be conducted at the end of the course. The syllabus will include more material.
11. A total of FOUR quizzes will be given and the average of all four will be taken.

### Office Location and hours:

My office is located in the second floor along with Industrial Engineering staff offices. My office number is C-207.
My Personal website is:

http://fetweb.ju.edu.jo/staff/me/jyamin/index.html

The office hours are announced on the door. For any suggestions, comments or questions please contact personally or by e-mail: yamin@ju.edu.jo

# (ch2)

No
Date

* Human Factors & experience:- are all effect on the operator.

⇒ Noise:- any unwanted signal, useless signal, Just made an error.

⇒ step unit input:- need a time to reach the steady state.

response time:- error source
selection criterion

⇒ Location of pointer:- Resolving power.
ability to exactly locate the pointer between two points. & It came from experience, & increase the Division, you'll be more accurate or use Digital Signs.

قراءات وتقسيمها ←

⇒ Energy exchange:- heat loss while measuring.

⇒ Random:- Causes, How it behaves, Cannot be eleminated, you Can only Control it.

At 20°C ⇒ no interaction between the ~~so~~ surrounding & the system.

Elliminate ≠ reduce.
↓
Friction.

29 Lines, 8mm

(ch 2)

No

Date

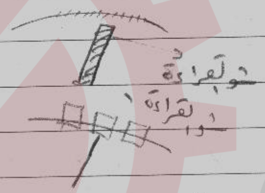
* Zero error:- إلها معطى وبعطي قراءة

* catastrophic errors:- * finite Dimension.

التدرج، pointer

* ٤,٣ بكونوا إلهم نفس الـ Dimension ولونهم غير الأهمية

thickness،




(test).

* multi sample more accurate:-

بتغير كل اشي ما بتعرف مصدر الـ random error.

ما تغير كل اشي ولغير التجربة وإلي بيعطيك error اكبر هوه مصدر

الـ error.

* new leacturer.

⇒ normal ; Gaussian Distribution ⇒ the shape of the Histogra

otherwise, is unstandard.
non Gaussian. عينة

⇒ True value :-
1. calculated. for you.
2. Design. on blueprint. = calculated + tolerance
3. theoretical ⇒ using simulation non Direct equ.
4. Average of values.

frequency of each value

$$\bar{x} = \frac{\sum (f \cdot x)}{\sum f}$$

True value in center values around it.

↑ wide of the curve or spread. ↑ Error. (Deviation) & precision ↓

* standard Deviation :- maximum acceptable error.
check 2 :-
Avg > standard ✗. there is an error problem

check 1 :- shape of curve.

No
Date

⇒ Precision index (h) :- curve ارتفاع
center عند
value. $h \uparrow \; \uparrow$ precision.

$h > 50\%$ ⇒ your reading Data is good.

Check 3 :- is $\bar{x}$ a true value or not.

⇒ probable Error of one reading : احتمالية وجود قراءات
حول قيمة حقيقية.

How much the Error that $\bar{x}$ is a true value.

after this $\sigma_m, \sigma_a$ are cancelled out.

⇒ Examples :-

multisample test.

known correction = known errors
We delete it
: Errors due to Random Sources.

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Step 1:-
The Data follows Normal Distribution with one central values at $T = 401°c$.

otherwise, you say the Data Do not follow the normal distribution

I need one (it two peak.

all values equal)

Due to max (peak) frequency. single peak.

Step 2:-

A- calculate the true value for Temp.

$$\bar{T} = \frac{\sum (F * T)}{\sum F}$$

B- calculate the Deviation.

$$d_i = T_i - \bar{T}$$

C- calculate average Deviation.

$$\bar{D} = \frac{\sum (|d * F|)}{\sum F} \Rightarrow \text{standard} > \text{avg.}$$

actual

max allowable. error

otherwise stop & say that there is a problem.



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No
Date

step 3:-

calculate the standard Deviation & compare it with $\bar{D}$

$$\sigma = \sqrt{\frac{\Sigma (F * d^2)}{\Sigma F}} =$$

⇒ comment:-

∴ Since $\bar{D} < \sigma$ hence the process is acceptable.

step 4:

test for the assumption that $\bar{T}$ is the true value by finding How many reading between $\bar{T} \mp r_1$

$$r_1 = 0.6745 * \sigma.$$

$$[408.78 + 0.9323 , 408.78 - 0.9523]$$

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## First Iteration

| Size mm | F | Size*F | Deviation | D*F | Deviation^2 | F*D^2 | d Ø/SD |
|---|---|---|---|---|---|---|---|
| 397 | 1 | 397 | -3.78 | 3.78 | 14.2884 | 14.2884 | 2.733967131 |
| 398 | 3 | 1194 | -2.78 | 8.34 | 7.7284 | 23.1852 | 2.010695403 |
| 399 | 12 | 4788 | -1.78 | 21.36 | 3.1684 | 38.0208 | 1.287423675 |
| 400 | 23 | 9200 | -0.78 | 17.94 | 0.6084 | 13.9932 | 0.564151948 |
| 401 | 37 | 14837 | 0.22 | 8.14 | 0.0484 | 1.7908 | 0.15911978 |
| 402 | 16 | 6432 | 1.22 | 19.52 | 1.4884 | 23.8144 | 0.882391508 |
| 403 | 4 | 1612 | 2.22 | 8.88 | 4.9284 | 19.7136 | 1.605663235 |
| 404 | 2 | 808 | 3.22 | 6.44 | 10.3684 | 20.7368 | 2.328934963 |
| 405 | 2 | 810 | 4.22 | 8.44 | 17.8084 | 35.6168 | 3.052206691 → rejected |
| Sum | 100 | 40078 | | 102.84 | | 191.16 | |

a) Average Size = $\boxed{400.78}$ mm
b) Mean Deviation = 1.0284 mm
c) Standard Deviation = 1.3826062 mm
d) Probabale Error of one reading = 0.9325679 mm
e) Standard deviation of the mean = 0.1382606 mm
Probabale error of the mean = 0.0932568 mm
f) Standard deviation of the standard deviation = 0.097765 mm
g) Precision Index = $\boxed{0.5114303}$

عندما نشطب قراءة شاذة فإن
الحسابات يعاد تكرارها وذلك
بطرح عدد القراءات المحذوفة
من ال (frequency) [100-2]
وعند إعادة الجدول نأخذ القيمة
الأقل وما نعمل interpol
بدل 100 ← 98 ← 50
غيرموجودة لـ 50 موجودة.

## Second Iteration

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 397 | 1 | 397 | -3.69387755 | 3.69 | 13.6447 | [illegible] | [illegible] |
| 398 | 3 | 1194 | -2.69387755 | 8.08 | 7.2569762 | [illegible] | [illegible] |
| 399 | 12 | 4788 | -1.69387755 | 20.33 | 2.8692211 | [illegible] | [illegible] |
| 400 | 23 | 9200 | -0.69387755 | 15.96 | 0.4814660 | [illegible] | [illegible] |
| 401 | 37 | 14837 | 0.306122449 | 11.33 | 0.0937109 | [illegible] | [illegible] |
| 402 | 16 | 6432 | 1.306122449 | 20.90 | 1.70595585 | 27.2952936 | 1.039174671 |
| 403 | 4 | 1612 | 2.306122449 | 9.22 | 5.31820075 | 21.272803 | 1.834792778 |
| 404 | 2 | 808 | 3.306122449 | 6.61 | 10.9304456 | 21.8608913 | 2.630410886 |
| Sum | 98 | 39268 | | 96.122449 | | 154.816327 | |

a) Average Size = $\boxed{400.69388}$ mm
b) Mean Deviation = 0.9808413 mm
c) Standard Deviation = 1.2568844 mm
d) Probabale Error of one reading = 0.8477685 mm
e) Standard deviation of the mean = 0.1269645 mm
Probabale error of the mean = 0.0856376 mm
f) Standard deviation of the standard deviation = 0.0897775 mm
g) Precision Index = $\boxed{0.562587}$

⇒ six segma :-
$\bar{X} \mp 3\sigma$
maximam or
boundary Error

## Third Iteration

| Size mm | F | Size*F | Deviation | D*F | Deviation^2 | | |
|---|---|---|---|---|---|---|---|
| 398 | 3 | 1194 | -2.66315789 | 7.99 | 7.09240997 | 21.2772299 | 2.377290433 |
| 399 | 12 | 4788 | -1.66315789 | 19.96 | 2.76609418 | 33.1931302 | 1.48463197 |
| 400 | 23 | 9200 | -0.66315789 | 15.25 | 0.43977839 | 10.114903 | 0.591973507 |
| 401 | 37 | 14837 | 0.336842105 | 12.46 | 0.1134626 | 4.19811634 | 0.300684956 |
| 402 | 16 | 6432 | 1.336842105 | 21.39 | 1.78714681 | 28.594349 | 1.193343419 |
| 403 | 4 | 1612 | 2.336842105 | 9.35 | 5.46083102 | 21.8433241 | 2.086001881 |
| Sum | 95 | 38063 | | 86.40 | | 119.221053 | |

a) Average Size = $\boxed{400.66316}$ mm
b) Mean Deviation = 0.9094737 mm
c) Standard Deviation = 1.1202493 mm
d) Probabale Error of one reading = 0.7556081 mm
e) Standard deviation of the mean = 0.1149352 mm
Probabale error of the mean = 0.0775238 mm
f) Standard deviation of the standard deviation = 0.0812714 mm

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* **Limiting Error:- (uncertainity):-**

$A = A_1 \mp \delta A$ → limits of error.

($A_1$ ← reading)

Ex: $R = (100 \mp 2)\ \Omega$

$[98, 102]$ ⇐ mean that

* **Relative limiting Error:- (Rel. L. E):-** → Fractional Error.

$\epsilon_{r_{A_1}} = \pm \dfrac{\delta A}{A_1}$ (δ ← Delta), $\epsilon_{r_{fs}} = \pm \dfrac{\delta A}{\text{Full scale}}$ (δ ← Delta)

$0.01 = \dfrac{1}{100}$ $\pm 1\%$.

من القراءة بتحمل

$\pm 1\%$. ← $\pm 1$ إذا انزاح من 100

محسوبة بناءً على fullscale

يعني إذا انزاح من 50 ∴ $\mp 2$

∴ الشغل هون بالمعادلة.

$\epsilon_{r_1} = \pm \epsilon_{r_{fs}} * \dfrac{Fs}{A_1}$

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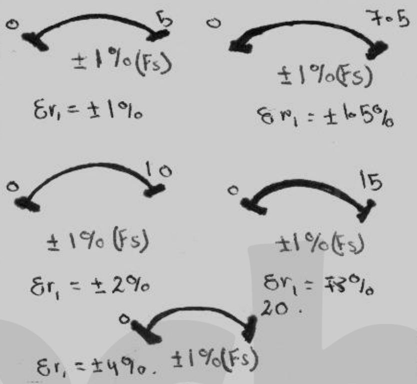
## ⇒ How to Know Which Suitable for us:-

Apply :-

$$\varepsilon r_1 = \varepsilon r_{(Fs)} * \frac{Fs}{A_1}$$




* كم الضغط عندنا ؟

5 bar.

علشان يكون أقل          علشان يكون أكثر

الأول تقريبًا مرفوض لأنو علشان جزيئين ،

اذا هو مرفوض Error عالي .

الرابع ~~مرفوض~~ مرفوض لأنه 5 (المطلوب) في الشكل الأول وقاعدة لا إنشاء .

الثاني أدق اشي .

* relative L. ε [Fractional Error] → $(\varepsilon r)$ measured $A_1$ - - - ①
→ $(\varepsilon r)$ Full scale - - - ②

$$1.\ \varepsilon r_1 = \pm \frac{\delta A}{A_1}$$

$$2.\ \varepsilon r_{(fs)} = \pm \frac{\delta A}{Fs}$$

$$\Longrightarrow \varepsilon r_1 = \pm \varepsilon_{Fs} * \frac{Fs}{A_1}$$



## * Known Error:-

$$A = A + \delta A$$

$$A = A - \delta A.$$

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limiting mean :- maximum error.

L.E + R.L.E :-- (For equation).

$X = f(x_1, x_2, x_3, x_4 - - - x_n)$.

$X = x_1 + x_2 + x_3 - -$

$X = x_1 - x_2 - x_3$.

$X = x_1 \cdot x_2 \cdot x_3$. , $X = \frac{x_1 \, x_2}{x_3}$.

$\Rightarrow X = x_1^a \cdot x_2^b \cdot x_3^c$.

* Having this equ:-

$X = X_1 + X_2$

Objective:- $\frac{\delta x}{X}$.

$dX = d(X_1 + X_2)$.

$= dx_1 + dx_2$

$\frac{dX}{X} = \frac{dX_1}{X} + \frac{dX_2}{X}$.

$= \frac{X_1}{X} \frac{dX_1}{X_1} + \frac{X_2}{X} \frac{dX_2}{X_2}$.

for small change in $X_1$ & $X_2$.

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$$\frac{\delta x}{x} = \pm\left[\frac{x_1}{x}|\varepsilon_{rx_1}| + \frac{x_2}{x}|\varepsilon_{rx_2}|\right] \rightarrow \delta x_2$$

$\frac{\delta x}{x} \rightarrow \varepsilon_{rx}$, $\frac{x_1}{x}|\varepsilon_{rx_1}| \rightarrow \delta x_1$

$\varepsilon_{rx_1} = \pm 1\%$.

$\varepsilon_{rx_2} = \pm 2\%$.

$$\delta x = \pm\left[|\delta x_1| + |\delta x_2|\right]. \rightarrow$$ في حالة الجمع والطرح

* Case 2:-

$$P \cdot V = mRT \implies P = m^1 R^1 T^1 V^{-1}.$$

$$\implies X = x_1^a \cdot x_2^b \cdot x_3^c.$$

$$\implies \ln X = a\ln x_1 + b\ln x_2 + c\ln x_3.$$

$$\implies \frac{1}{X} = a \cdot \frac{1}{x_1}\frac{dx_1}{dx} + b \cdot \frac{1}{x_2}\frac{dx_2}{dx} + c \cdot \frac{1}{x_3}\frac{dx_3}{dx}.$$

$$V = c\sqrt{2gH}$$
$$= c^1\, 2^{1/2}\, g^{1/2}\, H^{1/2}.$$

now:- $$\frac{dx}{x} = a \cdot \frac{dx_1}{x_1} + b\,\frac{dx_2}{x_2} + c \cdot \frac{dx_3}{x_3}.$$

$$\frac{\delta x}{x} = \pm\left[\left|a \cdot \frac{\delta x_1}{x_1}\right| + \left|b\,\frac{\delta x_2}{x_2}\right| + \left|c\,\frac{\delta x_3}{x_3}\right|\right]$$

29Lines, 8mm

$\Rightarrow \; P = MRTV^{-1}$

$$\frac{\delta P}{P} = \pm \left[ \left|\frac{\delta M}{M}\right| + \left|\frac{\delta R}{R}\right| + \left|\frac{\delta T}{T}\right| + \left|\frac{\delta V}{V}\right| \right]$$

$\Rightarrow \; P = \dfrac{2\pi g F L R}{t * 10^6}$

no. exact.

$$\frac{\delta P}{P} = \pm \left[ \frac{\delta 2}{2} + \frac{\delta \pi}{\pi} + \frac{\delta g}{g} + \frac{\delta F}{F} + \frac{\delta L}{L} + \frac{\delta R}{R} + \frac{\delta t}{t} + \cancel{\frac{\delta 10^6}{10^6}} \right.$$

no. Exact

may have a variation.

$\Rightarrow \; F = \dfrac{3 E b d^3 Y}{12 L^3}$

$F = E^a b^b d^{c\,(3)} L^{(-3)\,d} Y^{\epsilon}$.

Error calcul: $\dfrac{\delta g}{g}$

If $g = 9.81 \mp 0.01$

* uncertanity :- ($W_x$) omega.

Exact amount of error.

$A = A_1 \pm W_A$

$E_{W_1} = \dfrac{W_A}{A_1}$

$D = \sqrt{D_{max} * D_{min}}$

$X = f(x_1^a, x_2^b, x_3^c)$.

$\frac{w_X}{x_1} = \frac{dX}{dx_1}$.

$$w_X = \pm\sqrt{\underbrace{\left(a\frac{dX}{dx_1} w_{x_1}\right)^2}_{\text{max Effect.}} + \left(b\frac{dX}{dx_2} w_{x_2}\right)^2}$$

$\Rightarrow V = I_1 \cdot R$.

يعني اشتقه بالنسبة لـ $I_1$

اشتقه بالنسبة لـ $R$

$$w_V = \pm\sqrt{\left(1\cdot\frac{dV}{dI_1} w_{I_1}\right)^2 + \left(1\cdot\frac{dV}{dR} w_R\right)^2}$$

partial Derivative.

$$= \pm\sqrt{(1\cdot R\, w_{I_1})^2 + (1\cdot I_1 * w_R)^2}$$

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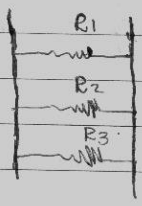
*new leacture:-




Example 12:-

$R_1 = 250 + 2.5\ \%$

$R_2 = 500 - 3.6\%$

$R_3 = 375 + 1.4\ \%$

Fractional Error

relative . Known Error

$\frac{\delta A}{A} = 0.0321$

$A = A_1 + \delta A$

True ← ... ↓ Erroneous.

True value. → (الحقيقة) صحيح

Erroneous → خطأ

$\delta$ 250, 500, 375 Erroneous.

$R_{eq}$ erro = 115.4 Ω.

$R_1$ true = $250 + \frac{2.5}{100} \times 250 = 256.25$ Ω.

$R_2$ true = 482 Ω

$R_3$ true = 380.25 Ω

$R_{eq}$ true = 116.3 Ω.

relative known Error = $\frac{R_{eq}\ \text{true} - R_{eq}\ \text{erro}}{R_{eq}\ \text{true}}$

$= 0.00776$



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$R_{equ.} = 115.4 + 0.776\%$

$R_{eq_{Erro}} = 116.3 - 0.776\%$

⇒ Example from an Exam :-

$I = 30.4A - 1.2\%$

$R = 0.105\,\Omega + 0.3\%$

find power, & relative known Error ???

$I = 30.4A - 1.2\% = 30.04A$

$R = 0.105\,\Omega \pm 0.3\% = 0.1053\,\Omega$

$P_{err} = I_{err}^2 * R_{err} = 97.04\,watt$

$P_{true} = 95.02\,watt$

$P_{true} = 97.04 - 2.125\%$

$$\frac{\delta P}{P} = 2\frac{\delta I}{I} + \frac{\delta R}{R}$$

$$= 2\left(\frac{-1.2}{100}\right) + \left(\frac{0.3}{100}\right)$$

$= -2.1\%$

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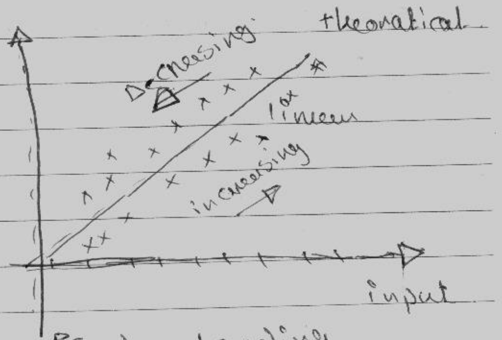
* new leactures:-




Random loading reading to avoid hystereses.

* Calibration of measurment Devices:-

| input (X) | output | | $(\bar{X})$ Avg. output true output | Deviation $X-\bar{X}$ | correction |
|---|---|---|---|---|---|
| | inc | Dec | | | |
| 5 | 4.5 | 7 | 5.75 | -0.75 | +0.75 |
| 10 | 9.6 | 11.4 | 10.5 | -0.5 | +0.5 |
| 15 | 14.2 | 16.2 | 15.2 | -0.2 | +0.2 |
| 20 | 18 | 21 | 19.5 | | |
| 25 | 22.5 | 26 | 24.25 | | |
| 30 | 28 | 28 | 28 | | |

hystreses.

limiting Error = hystneris = (inch, dec . أكبر فرق بين

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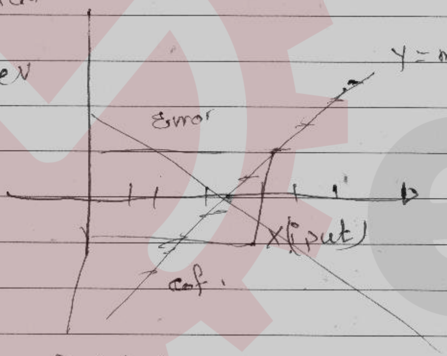
Span ( max output - min output ) 
7 - 4.05 = 2.5

$\omega$ ( uncertainty )
span / 2.
$\pm$ 1.25.

Avg = uncertainty
للجهاز ،

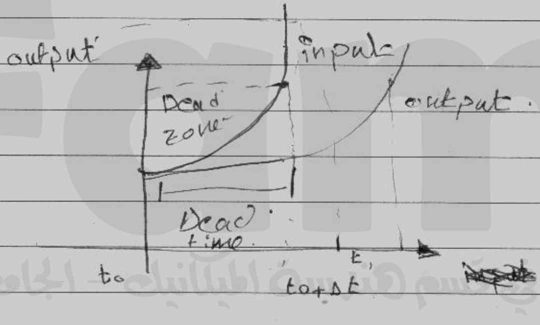



$R^2$ = --- %.

ماما قلتلهم بتحل كرة .
وصايغ هاد الاسبوع .

↑ trial.
↓ القراءات ، 5, 10, ⇒ 5, 7 ,

بدي أكتب ،
أسئلتي
يضربوا البعض .
shaking




Dynamic Error
يتغير مع الزمن .

max value of Dynamic Error
= Dead zone.

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No
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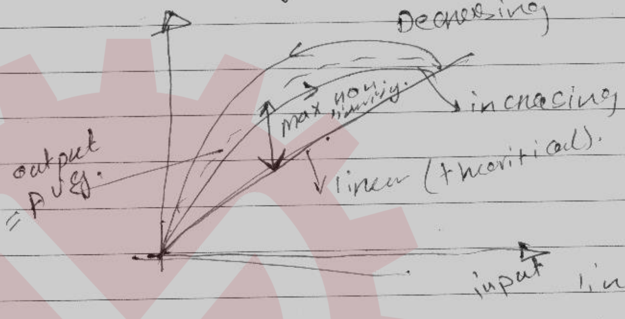
maximum Lag = Dead time.




another error
non linearity.
أبعد نقطة بين
linear &
non linear curve.

* system behavior =

Static

Dynamic
- impulse
- Ramp
- sinusoidal
- $\boxed{step}$

Error سببه الاهمال
Error تبعه

systems: -- Zero, 1st, 2nd
theoritical.
Damping, $\underline{\underline{\tau}}$
potentiometer. ($\tau$ speed of response).

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*new leacture:-

# Transducers.

## Ch 5

⇒ 1) Mechanical Transducers:- 1. Cantliever.
2. Spring.
3. Diaphragm.

⇒ for springs:- convert Force & pressure $\xrightarrow{\text{into}}$ deflection.
(F, P). (x).
output

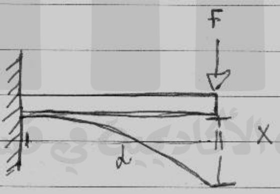
$$x = \frac{8FD^3n}{Gd^4}$$

$$\frac{x}{F} = \frac{8D^3n}{Gd^4} = K_s.$$

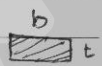
Spring stiffness:- "K" $= \frac{1}{K_s}$.

Max. shear stress $\tau_s = \frac{8FD}{\pi d^3}$.
(ultimate)

Ex:-
Cantliever beam.




Free end.




$$x = \frac{FL^3}{3EI}.$$

$$I = \frac{1}{12} bt^3. \qquad \downarrow t \quad \uparrow K.$$

$$k_s = \frac{x}{F} = \frac{L^3}{3EI}.$$

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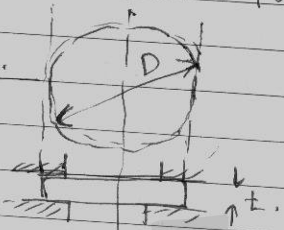
$K = \frac{1}{K_s}$. www.Nist.gov

* Diaphrams: Convert F & P ⟹ Deflection ($\delta m$).

Flat Diaphram.




Corrgatued.

UDL.


① We will Assume that the Load is uniformaly distributed Load, It will deflect.

Simply supported beam.

② so the deflection will be max at the center.

③ UDL.

مع جدول.

$$P = \frac{256 E t^3 \delta m}{3(1-\nu^2) D^4}.$$

$$K = \frac{\delta m}{P} = \frac{3(1-\nu^2) D^4}{256 E t^3}.$$

D & t

error. أكبر مصدر لل

$\delta m < \frac{1}{2} t$ to say that $\delta m$ max at the center.

$$\phi_1 \qquad \phi_2$$

$$K_s = \frac{3D^4}{256 E t^3} - \frac{3 \nu^2 D^4}{256 E t^3}.$$



$W_{Ks} = \pm (W\phi_1 + W\phi_2)$.

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$\sigma_s = \frac{3D^2P}{16t^2}$.

$\uparrow t \downarrow \delta m$.

the good sol:

$\boxed{\uparrow t \downarrow \delta m < \frac{t}{2}}$

$\boxed{\sigma_s \downarrow \sigma_s \text{ ultimate}}$

P, material $\begin{bmatrix} E \\ \nu \\ \sigma_{s max} \end{bmatrix}$, Application "D".

compare $\delta m$, ? t.

If pass $\sigma_{s max}$? $\sigma_{s\, actual}$.

$\Rightarrow w_n = \frac{20t}{D^2}\sqrt{\frac{E}{3P(1-\nu^2)}}$.

* the solved Examples:-

Flat, circular
D = 15 mm, Mild steel.
E = 200 G N/m.
$\nu$ = 0.28.
t = ???.
ضوابط
$\sigma_{max}$ = 300 MN/m$^2$
$\sigma_{max} \leq$
P = 300 kpa.

Find t to handle the maximum shear.

$\sigma_{s max} = 300 \times 10^6 \frac{N}{m^2} = \frac{3 * (\frac{15}{1000})^2 * 300 \times 10^3}{16 * t^2}$

t = 0.205 mm
$\times 10^{-3}$.

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now check for relation between $\delta_m$ & $t$.

$$\delta_m = \frac{3(1-\nu^2)D^4 p}{256\, E t^3}$$

If $\delta_m > \frac{1}{2} t$
not fit.

* Electrical Transducers:-

- Resistive $\Delta R$ → $\Delta L$, $\Delta A$, $\Delta T$
- Capacitive → $\Delta C$ → $\Delta \epsilon_0$, $\Delta t$, $\Delta A$ → overlap Area.
- piezo resistive
  $\Delta \forall \rightarrow \Delta(F, P)$.

resistivity ($\Omega \cdot m$)

$$R = \frac{\rho L}{A} \rightarrow \frac{m}{m^2}$$

$\Delta L \longrightarrow$ strain gauge $\frac{\Delta L}{L}$, potentiometer.

$\Delta T \rightarrow$ RTD, Thermistor.

$\Delta C \rightarrow$

$$C = \frac{\epsilon_r \epsilon_0 A}{t}$$

piezo Electric pickup.

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* selection criteria for
  Transducers:- cost, Accuracy.

1) Sensitivity.

2) cross sensitivity. :- of side phenomena which effect output value.

3) Dynamic & static characteristic.

4) Loading effect:- like internal resistance (embidence of measuring Devices).

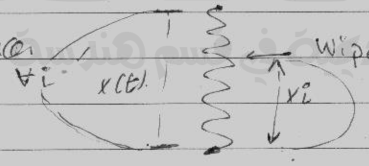
5) enviromental compatability.

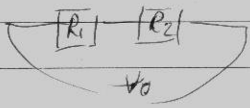
* potentiometer:- (pot).

Translational → θ, X, spiral, heli pot → into ⇒ $V_o$

mechanical signal → voltage signal.

potentiometer is a Resistance. Wiper/ slider (resistive element)





$$\frac{V_i}{X_{tot}} = \frac{V_o}{X_i} \Rightarrow V_o = \underbrace{\frac{V_i}{X_t}}_{K_s} X_i$$

$X_{tot} = X(t)$.

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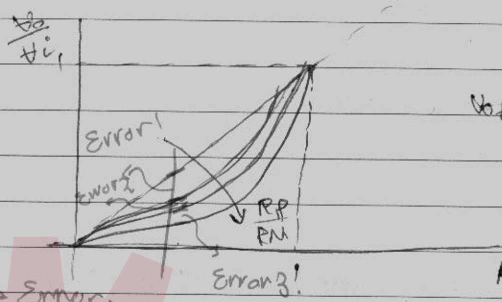


$V_{oth} = \frac{V_i}{X_t} X_i$ ---- (1)

$V_o < V_o$ actual (real)
You (measure)
theoritical (th)

$K = \frac{X_i}{X_t}$

↑ Error.

∴ $V_{oact} < V_{oth}$, ⇒ Loading Error, Voltage measuring Device

$$V_{oact} = V_i \left[ \frac{K}{K(1-K)\left(\frac{R_P}{R_m}\right) + 1} \right] \quad ---- (2)$$

Error = $V_{oact} - V_{oth}$

$$E = V_i \left[ \frac{K^2(1-K)}{K(1-K) + \left(\frac{R_P}{R_m}\right)} \right]$$

If you plug K=0, K=1

∴ $V_{oact} = 0$

$V_{oact} = 1$

$\left(\frac{R_P}{R_M}\right)$ ↑↑ Error.

↑, ↓ —, I dont know.

Ratio لـ 0, ∞ عوض ثم لـ كيف أفرق ⇐

$\left(\frac{R_P}{R_M}\right)$ → $R_P$ const → مداكوا؟

∴ كونو قدا ما $R_m$

ويتو نا علاقتهم مع Error.

$\% E_{max} = 15 * \frac{R_P}{R_m}$

$V_{i\,max} = \sqrt{R_P \cdot P}$ → power rating (KW).

5, قدرة بتفقد dissipate heate — max power allowed to be developed for this system.

① $\boxed{\text{For good linearity (Error zero)} \Rightarrow \text{What to do in}}$ Designing: ⇒ (((( $R_P \downarrow$ , $R_m \uparrow$ ))))

② For good sensitivity (Ks) ⇒ $V_i \uparrow$ , $X_t \downarrow$.

* $\boxed{P = \frac{V_i^2}{R_P}}$ ∴ limited by the max equ. above.

↑ power rating

رح يقوى الـ resistance
و قوة إثارة معينة على
كل الطاقة
Damage تعطيه

∴ ↑ $R_P$ ↑ Error.

Ks & Accuracy ∴
ما بتناسبن
they Do not match

$V_i$ ⇒ cannot be changed.

↑ P. dissipation. انتشار مجهودها

⇒ look at figure e.

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Ch5

Example [2]

Given

1) $R_p = 2000\,\Omega$.   [3] $R_m = 5000\,\Omega$

2) $V_i = 10\,V$.

for following K's find the Error.

a. $k = 0$ , $k = 0.25$ $= 0.174$,

$k = 1$. $k = 0.5$ . $= 0.484$

$k = 0.75 = 0.524$

at $k = 0$ & $k = 1$   $E_t = 0\%$



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# Resistance Temp – Detector. (RTD).
## + Thermistor.

(they use for Temp measurement).

→ ① DT → ΔR.

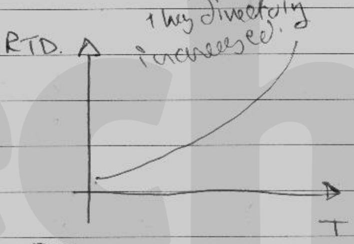
→ ② RTD → metal

measument Devices. → for Temp. / → for resistan

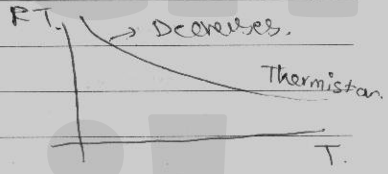
→ Thermists → semi conductor.

③ for. ⇒ RTD ⇒ | ↑T ↑R |

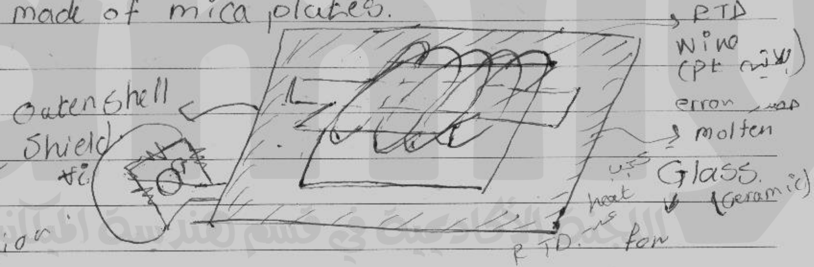
⇒ Thermistor ⇒ | ↑T ↓R. |




Thermistor → for Low Temp.
RTD → for high Temp.




* RTD is made of mica plates.




to protect it from outer condition

conductivity لا نعرف R

molten glass لا نعرف مصدر Error → Known Error source.

وجود أخطاء

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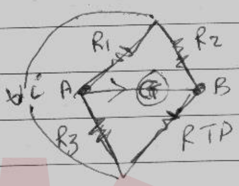
circuit.

What Are the type of ckt
⇒ Null type.




$V_A = V_B$

$I_{AB} \rightarrow$ current

$\therefore I_{AB} = 0.$

& $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ (RTD).

$R_1 = R_2$

$R_3 = R_4$.

math model ومعناها نعرف
T & R. إلي بيحكم ب

* Qualities of RTD material.
1. Cheap.
2. Available
3. conductive to prevent Damage.
4. linear( Error $\leq 0$). (change very slow).
   (linear variation between T & R.
5. Melting point Should be outside T range
   Temp range
   $T_m > T_{max}$ range.

$R = \frac{\rho L}{A}$.

6. geometrically uniform → shape
   Homogeneous concentration in (constituents)

linear
depends from geometrical uniform

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⇒ www.omega.com.

* Math model:

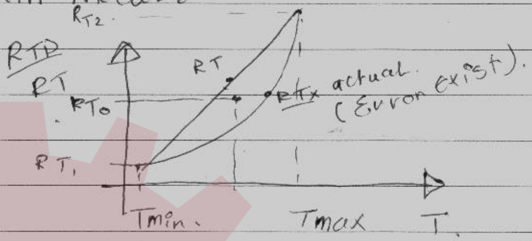
lockup Tables.

⇒ curve fitting techn.

spline method

Newtons.

Lagrange.




⇒ RTD follows:- → resistance at → reference condition. / calibration / standard.

$$RTD = R_{T_0}\left[1 + \alpha_1 \Delta T + \alpha_2 \Delta T_2^{2} + \cdots\right]$$

R@t =

come with manual → $R_{T_0}$; your unknown → $T$; zero ref. Tem. → $T_0$

$$R_T = R_{T_0}\left[1 + \alpha_{T_0}(T - T_0)\right]$$

$R_T$ ← measured from the ohm!

$\alpha_{T_0}$ ↓ material prop. (resist-Temp) coeffiant : $\frac{\Omega}{\Omega \cdot {}^\circ C}$

$\alpha$ → measured at $T_0$.

$T_0 = \frac{max + min}{2}$ ⇒ your Avg = your standared value calibrated too.

$\alpha$ = not exactaly the slope.

$$\alpha_{T_0} = \frac{1}{R_{T_0}}\underbrace{\left[\frac{R_{T_2} - R_{T_1}}{T_2 - T_1}\right]}_{slope}$$ = +ve alway for RTD.

to improve the accuracy we use.

$$R_T = R_{T_0}\left[1 + \alpha_1 \Delta T + \alpha_2 \Delta T^2\right]$$

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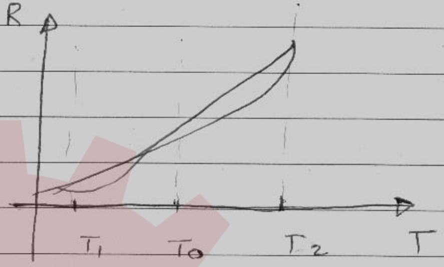


$[T_1 - T_0]$

$$R_{T_1} = R_{T_0}\left[1 + \alpha(T_1 - T_0) + \alpha_2 (T_1 - T_0)^2\right]$$

$[T_2 - T_0]$

$$R_{T_2} = R_{T_0}\left[1 + \alpha_1 (T_2 - T_0) + \alpha_2 (T_2 - T_0)^2\right]$$

$\Rightarrow$ in this technique you Are going to take As max As possible sign. figu.

$$\frac{R_{T_1}}{R_{T_0}} = 1 + \alpha_1(\ ) + \alpha_2(\ )^2$$

$$\frac{R_{T_2}}{R_{T_0}} = 1 - \alpha_1(\ ) + \alpha_2(\ )^2$$

اجمع

$$\frac{R_{T_1} + R_{T_2}}{R_{T_0}} = 2 + 2\alpha_2(\ \ )^2$$

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RTD

* $RT = R_{T_0} \cdot \left[1 + \alpha_{T_0}(T - T_0)\right]$

* $\alpha_{T_0} = \frac{1}{R_{T_0}}\left[\frac{RT_2 - RT_1}{T_2 - T_1}\right]$ linear

max min

* quadratic

$T_1 - T_0 \Rightarrow R_{T_1} = R_{T_0}\left[1 + \alpha_1(T_1 - T_0) + \alpha_2(T_1 - T_0)^2\right]$.

$T_2 - T_0 \Rightarrow RT_2 = R_{T_0}\left[1 + \alpha_1(T_2 - T_0) + \alpha_2(T_2 - T_0)^2\right]$

very small.

always positive.

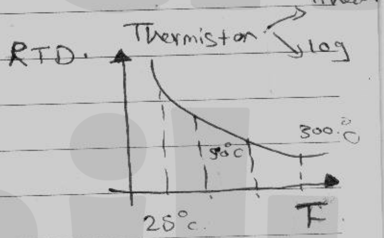
$T_2 - T_0 = \mathcal{T}(T_1 - T_0)$

50°C.

* R@ 0°C.

-ve

$RT = R_{T_0}\left[1 + \alpha_{T_0}(T - T_0)\right]$




Rang $\Delta T$ small = 50°C.
Range of Error

$T_0$ = Zero Degree Celicus (Ref Temp, freezing point)
It is fixed.

$\alpha_{T_0} = \frac{1}{RT}\left[\frac{R_{T_2} - R_{T_1}}{T_2 - T_1}\right]$

$RT = A\, R_{T_0} \cdot e^{B/T}$

always in kelvin.

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$T_o$ & $R_{T_o}$ (Temp عند صفر درجة).

Zero degree celsius) $T_o$ : عن إذا لم تعطى أي معلومة

$R_{T_o} \Rightarrow$ mean R at $T_o$.

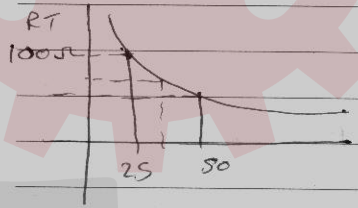
عادةً = β ← بالآلاف.

*Solved Examples:-

Ex:- 12

Thermister $\rightarrow$ $\alpha = -5\%$.

$= -0.05$.




25-50 $\Rightarrow$ Range in Temp.

find R at 35°c.

$$R_T = R_{T_o}[1 + \alpha(T - T_o)].$$ → linear هاي معادلة

إلها β range غير هيك لها بفرق أصل.

$$R(35^\circ C) = 100[1 - 0.05(35 - 25)] = 50\,\Omega.$$

Ex 13:- $R_1 = 794$ at $50^\circ C$. $R_2 = \_\_$ at 20

$R_o = 3980$ at $0^\circ C$.

$$R_T = R_{T_o}\, \overset{?}{A}\, e^{\overset{?}{B}/T}$$ ⤳ non linear هاي

ما إلها Range.

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$R(40°c)$ , $R(100°C)$ ??

AT $T=0$ , $R_T = R_{To} A e^{B/273}$

$T = \cancel{100}\ 50$ , $R_T = R_{To} A e^{B/323}$

$A = 30 \times 10^{-6}$ , $B = 2845$

$3980 = 3980 A e^{B/273}$

$794 = 3980 A e^{B/373}$

$\frac{3980}{794} = e^{\frac{B}{273} - \frac{B}{373}}$

$\ln \frac{3980}{794} = \frac{B}{273} - \frac{B}{373}$

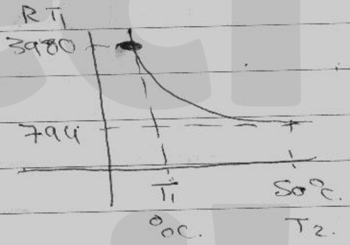
$1.612 = 9.8 \times 10^{-4} B$

* Another way to solve Ex 13°

for any Range & logarithmic approximation.

$R_{T_1} = R_{T_2} e^{\left[\frac{1}{T_1} - \frac{1}{T_2}\right] B}$

$\ln\left(\frac{R_{T_1}}{R_{T_2}}\right) = B\left[\frac{1}{T_1} - \frac{1}{T_2}\right]$




$R_T = R_{To} A e^{\frac{B}{T}}$

$$B = \frac{\ln\left(\frac{3980}{794}\right)}{\left[\frac{1}{273} - \frac{1}{323}\right]}$$

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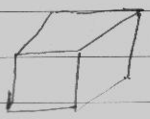
pressure
* piezo electric pickup :-
pressure
$\vec{P}$, F ⟹ emf , V voltage
Force. [electro motive force]

consists of crestal
produces emf, V of
How it work: Sparks as it gets deformed

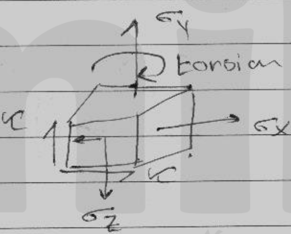


⟹ [get it a deformation & it will produce a voltage].

Natural → Quartz
→ Rochelle salts. } very cost, sensitivity very low.

شائع
Synthetic → Barium Titanate (BaT).
→ Lithium sulphate (LaS).

* Modes of Deformation
3. compression
3. tension
3. Shear
tonsion
Diagonal.




Compressive احنا ع فرص
stress. (Load).

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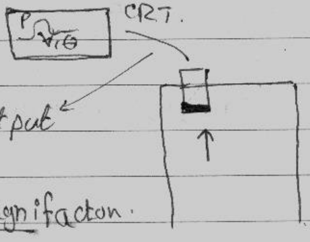
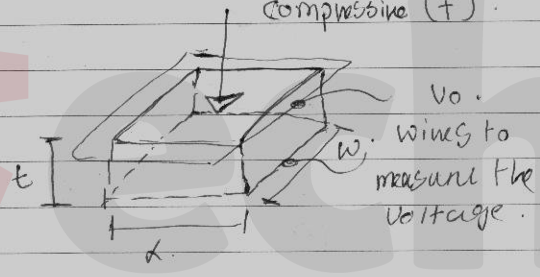
Between two Diaphrams in the can we have a piezo.




crystal connect to a capacitor.

$t_f = t_i - \Delta t$.
(compressive)




$\underline{\underline{w, L}}$ ↝ we assume it stay const.

change $Q$ = Force (F) * Charge sensitivity (KC).

$Q = F * KC$.
$Q \to C$, $F \to N$, $KC \to \frac{C}{N}$.

$F = \frac{EA}{t} \cdot \Delta t$. Hooke's Law.

$F/A = \sigma$, $\frac{\Delta t}{t} = \varepsilon$

$V_o = \frac{Q}{C}$, $C = \varepsilon_o \varepsilon_r \frac{A}{t}$

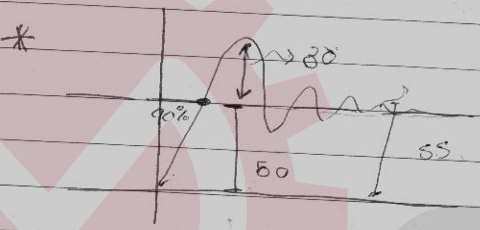
$\varepsilon_o$ → permittivity
$A$ → overlap area
$t$ → مسافة بين 2 plates

KVC.

$$V_o = \left(\frac{K_C}{\epsilon_o \epsilon_r}\right) \frac{F}{A} t$$

Crystal voltage sensitivity. $\left(\frac{V\,m}{N}\right)$

*




$M_P = \frac{30}{50}$ X

$$\frac{Y(t_p) - Y(\infty)}{Y(\infty)} = \frac{80 - SS}{SS} =$$

↓ SoS.

* flow measurment :-

⇒ Importance:-

Drip

flow rate

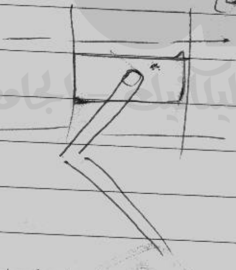
indirect measurment

⇒ How to Measure → Inferential measure phenomena throw another one. (one parameter)

طلع نزل

reciprocating ترددي → positive Displac Method. ↑ V ↑ Current like $Q \propto \Delta P$ (Bernoulli)

piston cylinder Device.



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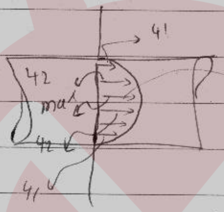
3. mass meter. (Obstruction flow meter) :-

* type of flow :- → 1. Laminar
2. Turbulent 3. Transmission.




→ we took the Avg. velocity $\bar{u}$.

$Re < 2*10^3$ Laminar $Re > 10 \times 10^3$ Turbulent.

velocity Diameter (Char. length)

$Re = \frac{\rho u d}{\mu} = \frac{ud}{\nu}$ → kinematic (static

$\mu$ → (Dynamic viscosity).

Dimensionless.

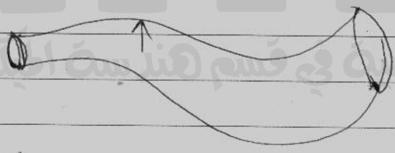
$\nu = m^2/s^2$.

type of flow

* Comp → $\rho = f(p)$ ' you measure mass flow rate.
* without it Error is huge.
* incomp → $\rho = C$. it up to you.
in Liquid ( $\dot{V}$ ) → volume flow rate

* stream Lines
no flow out
∴ we apply
continuity eqn.
∴ $\dot{m}_{in} = \dot{m}_{out}$
$\rho_1 u_1 A_1 = \rho_2 u_2 A_2$.

stream tube.



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✓ we will took stans.

* Infnential type:
- * head type → flow rate ~ you measure it using Manometer & change in $\Delta p$.
- Tarbine F.M.
- Swirl.
- Hot wire anamometer (Thermal F.M is an RTD) ✓ flow meter
  V* — sensor in can [Hot wire (H.W.A)]
- pneumatic.

* Bernoulli theorum:

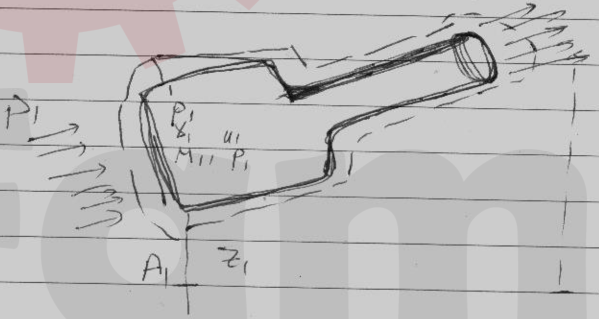
proportionally

$Q_{(1-2)} \propto (P_1 - P_2)^n$ ~ any index. $n = 1, 1.5$. flow حسب نوع → Laminar, Turbulent.

between section 1&2

$\Downarrow$

$f(u_2 - u_1)$.




& adiapatic.

$Z_2$

like this example

cross

one dimensional

circulasian

flow steady

frictionless ~ no heat ~ D.F دوامات nertex

no Energy transfer

no work.

No
Date

* types of pressure:-

because of interaction between molecules.

1. Atmospheric → own ref.
(Patm)

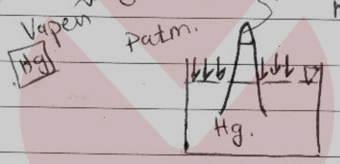
2. Absolute
(pabs)

3. Gauge or vacuum.
Pg., Pv.

4. Static

5. total/stagnation
(ps).

Vapor خلع عن (الفراغ) Torricelli

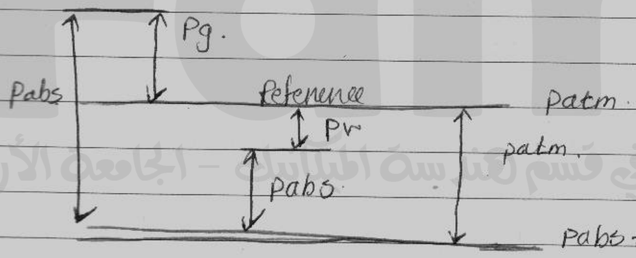



⇒ Static pressure
$= \boxed{\gamma h}$ 1. fluid at rest.
2. the fluid at motion & at the same level.

Patom − ~~pvap~~ = $\gamma$ (pvap → 0)

* pabs either = Patm + Pg.
or $= \boxed{patm - Pv}$ & $\underline{pabs = patm - Pg.}$ → what we are interested in.

Punknown − Patm
→ > 0 p gauge.
→ = 0 too small molecules to interact or there is no
→ < 0 p vacuum.



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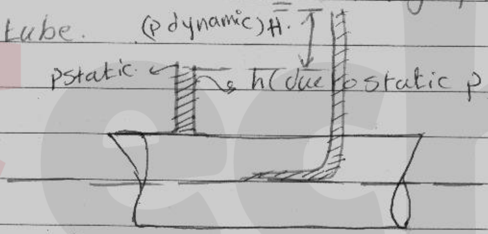
Stagnation pressure ($P_s$) $\Rightarrow$ Ptotal, is obtained from/ When fluid is suddenly stopped.

$P_{stag} = P_{static}(P) + P_{Dynamic}$

need velocity
on stop it & see the
h chang = $P_{Dynam}$

* We will use a pitot tube.




$$\frac{u_f^2}{2g} = \left(\frac{P_{ts} - P}{\gamma_f}\right)$$

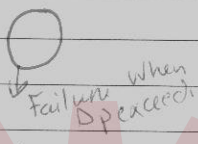
totall, static

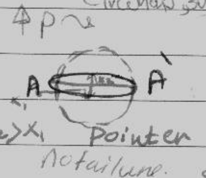
(m) (m)

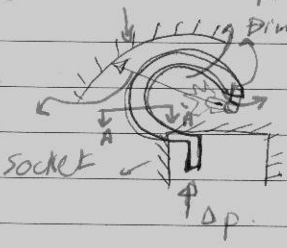
* Bourdon tube-
It convert P ~> displacement.
$P \longrightarrow \Delta x$.

types:-
1. C-type
2. Helical
3. spiral.

called due to the part Which will convert $\Delta P$ into deflection.

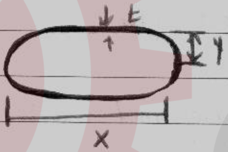


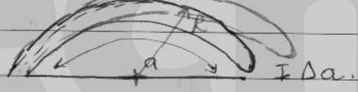




* Accuracy :-

$\pm 0.5\% \rightarrow \pm 2\%$.




$$\Delta a = 0.005 \frac{aP}{E} \left(\frac{r}{t}\right)^{0.2} \left(\frac{x}{y}\right)^{1/3} \left(\frac{x}{t}\right)^{3}.$$

* Bellows :-

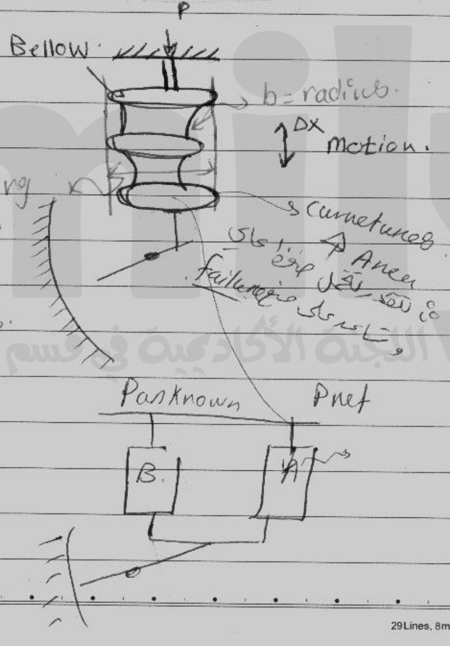
$$DX = \frac{0.453\, p b n D^2 \sqrt{1-\nu^2}}{E t^3}$$

n = no. of corrugation → curvatures.

t = Same for all.

If deflection Zero

$\therefore$ Pref = Punknown



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*New leacture:-

pressure calibration

Manometer

you have to use it → Anti parallex.

(magnifying glass + vernier scale.)

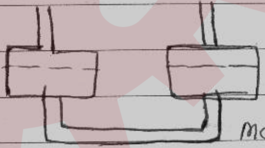
Exact reading

Exact hight.

→ use Resiorion (manometer well)

→ $P_{mc} < P_{devices}$

Well manometer



→ $\uparrow P$ to measure $< 200$ kpa

compressibity لعدم لبعد تأثير

ذاك وتعتبر $\Delta h$ كثيراً كبير

mano ولغرابك (cross sectional Area.

كثير كبير.

Change in volume $= a * \Delta h$

$K_S = \frac{1}{\rho g}$

manometer

$\uparrow a$ you avoide Damping but $K_S \downarrow$.

Dead weight Tester.

If use them all. We can say that is a mano, can use it for measu calibrate devices.

Other wise $p > 200$ kpa.
you use the Dead weight.

∴ What to do.
you use $P_{manomter}$ $\Sigma P$ devices
under test
What we want to calibrate.



29 Lines, 8mm

No
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* Temprature Measurment:- [1] (Def, introduction about scales).
[3] method of measurment.
Def:- Avg. K.E of molecules. [4] Sources of Errors in Temp measurment.

| Fresh Water | Soulting Water |
|---|---|
| Celicus | Fehrehiet. |
| freezing 0°c. | 32 f |
| boiling 100°c. | ~~2~~12 f. |
| (abs °c = Kelvin) | (abs f = Rankin). |

$PV = mRT.$

$PV = NR_uT.$ If N is very small.

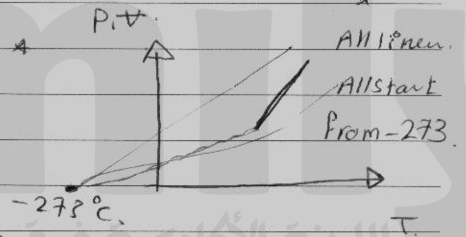
then apply

$$\frac{P_oV}{T} = \underbrace{NR_u}$$ = const. Do not depend on the type of gas.

دائماً نستخدم عدد قليل من N عشان الحكي تأثيره

* Gas thermometer more suitable.

$\frac{P_oV}{T} = NR_u.$




All lines All start from -273.

RTD.
Thermistor

* methods of measurment
1. ΔR (change in Resistance)
2. Expansion → L (Bimetalic), V (thermometer) (Volume)
3. Color
4. Voltage (thermo couple).
5. pressure.
6. Radiation (Pyrometer). temp.

note:- Bimetalic. LL تقصر ΔT
measure & control

Radiation
pyranometer

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الثلاثاء + الحسين كوز .

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Birometer / no contact.

RTD / thermister
thermometer.
Bimetallic.

Last thing
about it
on external
paper.



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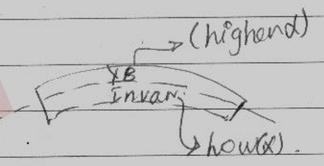
Examples to be Solved:-

no info about fixed or Free.
you took the free end.

Same shape.
& the order of $\alpha$.




$t\,tot = 0.5\times10^{-3}$

$$r = \frac{t}{6}\,\frac{\left[3(1+m)^2 + (1+mn)(m^2+1/mn)\right]}{(\alpha_A-\alpha_B)(T_2-T_1)(1+m)^2}$$

study this.
(this is right).

$$\frac{147}{96.5} = n = \frac{E}{E} = \frac{E_{invar}}{E_{YB}}$$

$T_1$ = bounded Temp = $30^\circ$c.

$m = \frac{t}{t} = 1$ (because same thick)


~ increasing.

$T_2$ = 50, 60, 70, 80, 90, 100.



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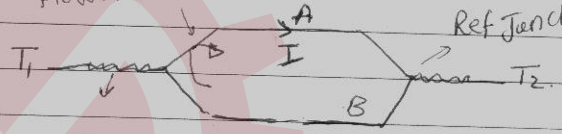
* Thermo Couple :-

different
→ Diffrnt metal (T) same
→ Same metal (T) Diffrnt

Flow of $\bar{e}$ = current




↑ T ↑ Flow of $\bar{e}$ ↑ $V_o$.

contact = (Junction) called → Thermal, Hot, Intended

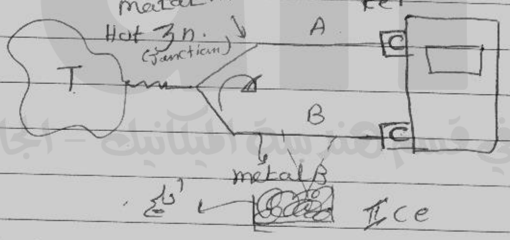
Vout. ($V_o$)

Thermo Electric effect
Seebeck effect.
phenomena where the T produce a voltage.

$$V_o = C_1 (T_1 - T_2) + C_2 (\quad)^2 \ldots$$

→ non Linear.

⇒ Thermo couple Always with microprocessor.




metal A → Thermo couple
B → " "
therocouple C → " " "

AB
AC
BC

V(AC)
V(BC)

I know from material prop.

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No
Date

current flow direction.

$$Vo = e_{A/B} (T_2 - T_1).$$

Specific voltage [V/°C]

Law 2 provement.

$$V_1 = e_{B/A} T_1$$

$$V_2 = e_{A/B} T_2$$

$$Vo = V_1 + V_2$$

$$= e_{B/A} T_1 + e_{A/B} T_2$$

same but opposit direction.

$$Vo = e_{B/A} (T_1 - T_2).$$

* Law 3 :-

same but opposit direction

$$Vo = e_{B/A} T_1 + e_{A/C} \cdot T_i + e_{C/A} T_j + e_{A/B} T_2.$$

Current

$$Vo = e_{B/A} (T_1 - T_2)$$

* Law 4 :

يساوي

$$Vo = \boxed{e_{B/C} T_1 + e_{C/A} T_1} + \boxed{e_{A/B} T_2.}$$

$$= e(T_1 - T_2)$$

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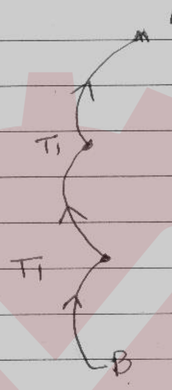
Law 4



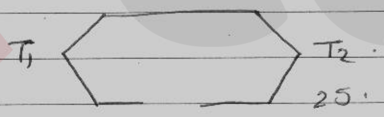

$V_0 = e_{B/C} T_1 + e_{C/A} T_1 + e_{A/B} T_2$.

$T_1 ( e_{B/C} + e_{C/A} ) = T_1 e_{B/A}$

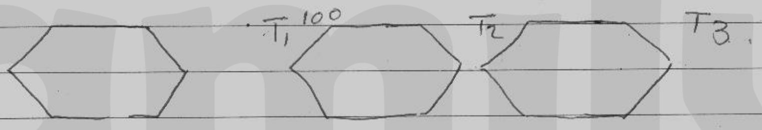
$= T_1 e_{B/A} + e_{A/B} T_2$

$= (T_1 - T_2) e_{B/A}$.

Laws:-




original case :- -- $V_0 = e_{B/A}$ (75). 28.




$T_2$ => intermediate = (62.5).

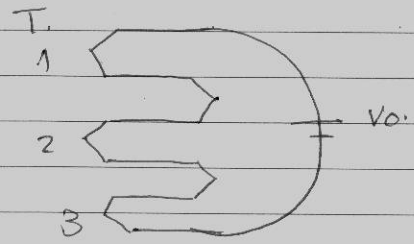
$V_{0\,1\to2} = e_{B/A}(37.5)$ $V_{2-3} = e_{B/A}(37.5)$

+

= original case.

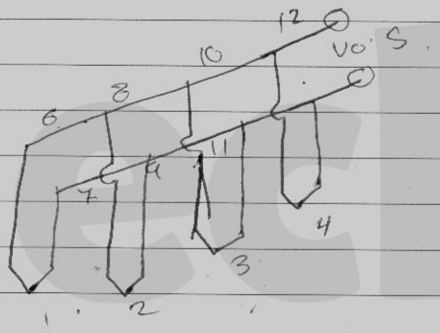
Thermopile system.

they are series connection.




* for Avg temp.

12 therocouple.




* Loading Error. in vo place