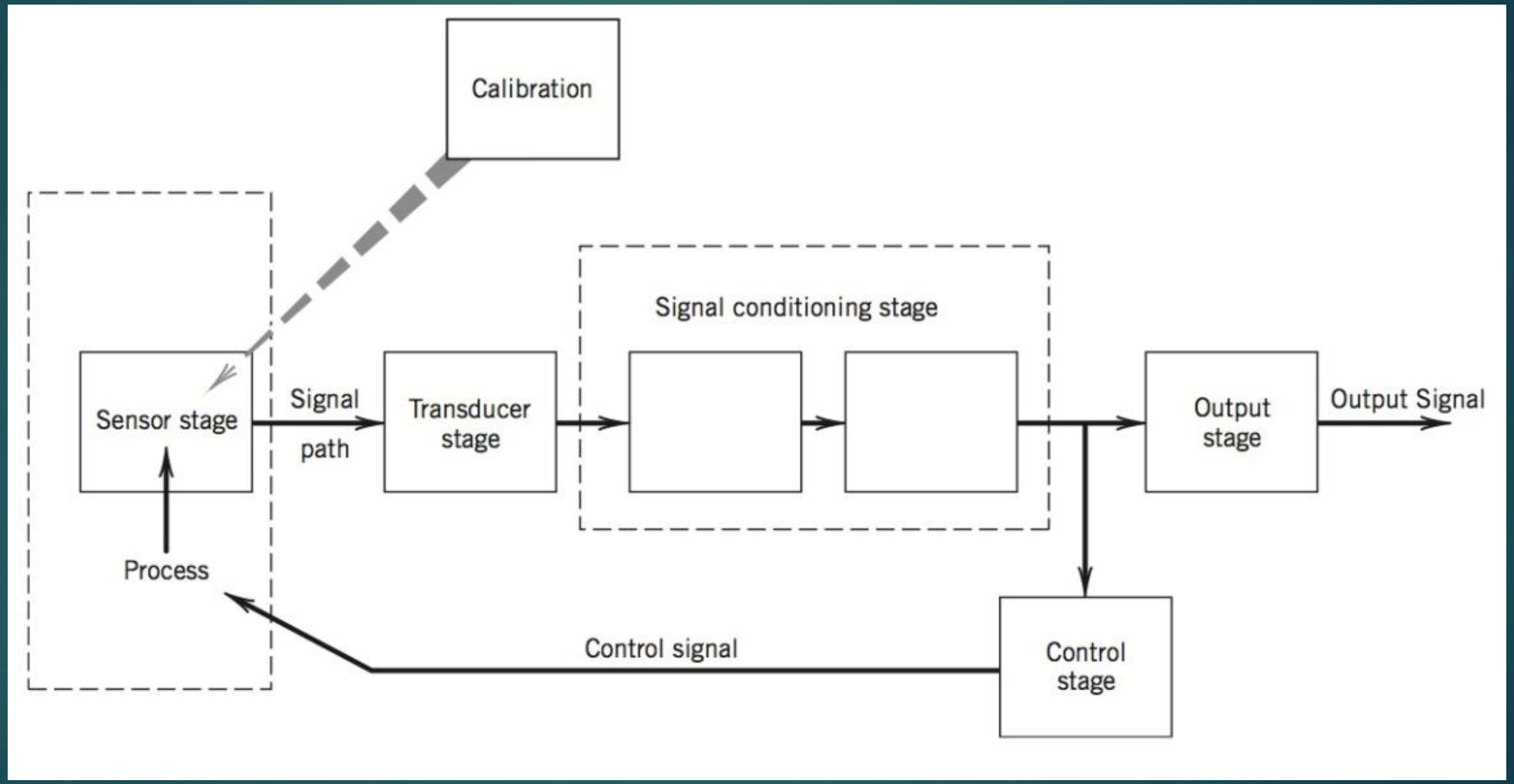
Mechanical Measurements 2

COURSE INTRODUCTION

General Template for a Measurement System



Mechanical Measurement II Goal

- Mechanical Measurement I Theory Foundation
  - 5 Labs + 1 Project
    - Data acquisition
    - Laboratory 1: Introduction to Instrumentation and Data Acquisition
    - Laboratory 2: Use of Accelerometers in the Measurements of Dynamic Systems
    - Laboratory 3: Temperature Sensors and Statistical Analysis of Data
    - Laboratory 4: Use of Strain Gages to Determine the Strain in Cantilever Beams
    - Laboratory 5: Characteristics of Passive & Active Filters
  - Memo report writing
- Goal: This course aims to advance the understanding of measurement systems and analyzing experimental data. Students will test laboratory scaled mechanical engineering systems and apply fundamental knowledge from mechanical engineering topics to analyze and rate those systems.

"不闻不若闻之，闻之不若见之，见之不若知之，知之不若行之"-荀子

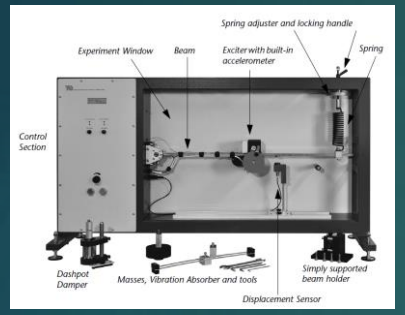
I see and I forget, I hear and I remember, I do and I understand

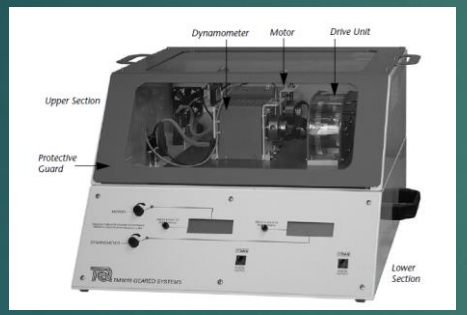
Course Introduction

- Mechanical Engineering Topics
  - Topic 1: Theory of Machines
  - Topic 2: Control System
  - Topic 3: Solid Mechanics
  - Topic 4: Thermal & Fluid Labs
- Topic & Session Selection
- Grading
- Group & Schedule
- Late Submission
- Report Guidelines
- Research Topics

Measurements 2 Syllabus Choose **three out of four.**

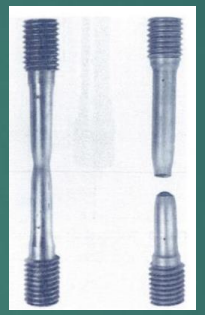
- **Topic 1: Theory of Machines**
  - Forced and Free Vibrations
  - Geared Systems



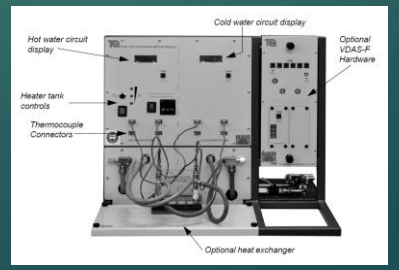


- **Topic 2: Control System Labs**
  - Fundamentals of Feedback Control
  - PD Control of Unstable Systems
  - Automated Level Control using Programmable Logic Controllers (PLCs)

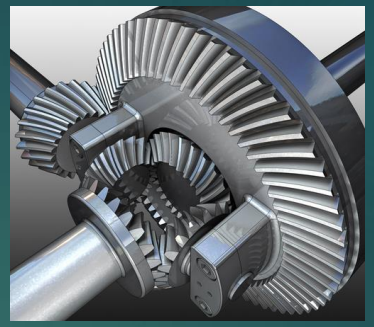
- **Topic 3: Solid Mechanics**
  - Uniaxial Tension Test of Materials
  - Heat Treatment of Materials



- **Topic 4: Thermal & Fluid Labs**
  - Fluid Mechanics
  - Bench-top Heat Exchangers
  - Radiation Heat Transfer



Tunned Mass Damper



Vehicle Differential

Fluid Systems

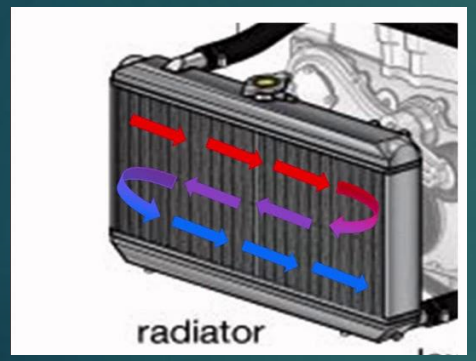
Topic 1: Theory of Machines

Topic 2: Control System

Topic 3: Solid Mechanics

Topic 4: Thermal & Fluid Labs

HDD Servo



Car Radiator

Quadrotor

Gears

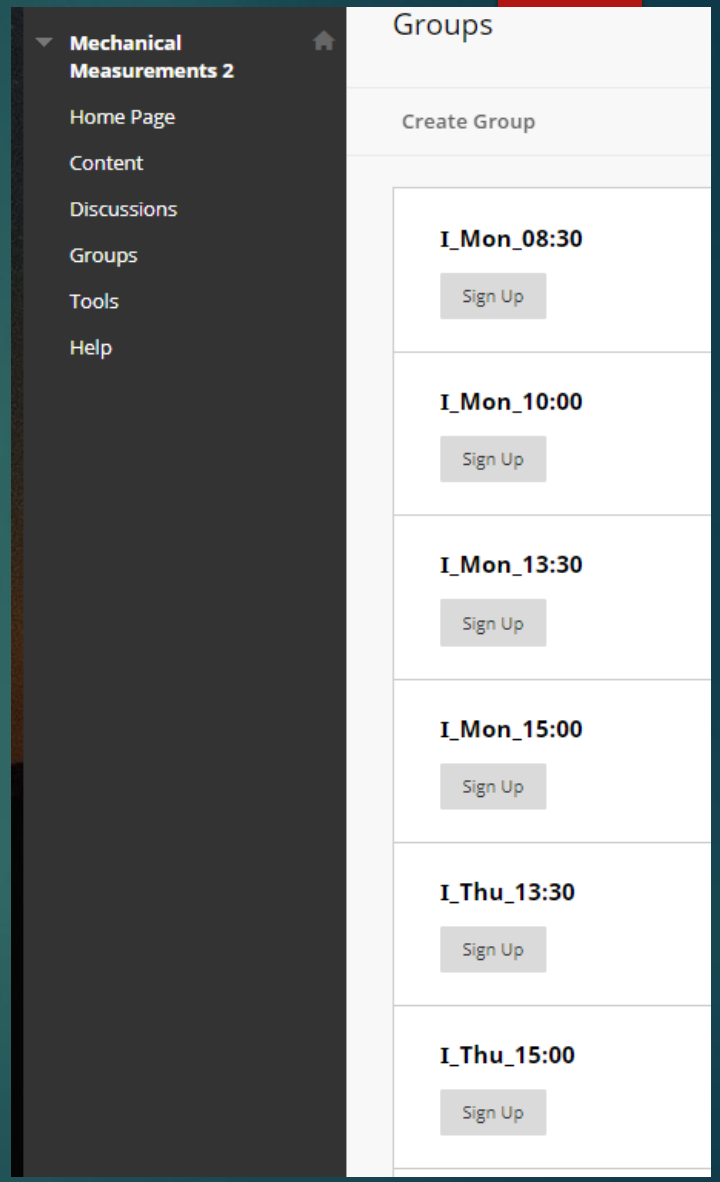
Hydraulic cylinder

Topic and Session Selection

- Blackboard → Groups→ Sign Up

方案	组合方式		
方案Ⅰ	Theory of Machines	Solid Mechanics	Control
方案Ⅱ	Theory of Machines	Solid Mechanics	Thermal & Fluid

Lecture time/location: Thu 08:15 - 11:55 AM/Zone 3-102 (odd weeks)
Laboratory location: Zone 3-113/116
Laboratory times: Mon 8:30 AM– 10:00 AM
Mon 10:00 AM– 11:30 AM
Mon 1:30 PM – 3:00 PM
Mon 3:00 PM – 4:30 PM
Thu 1:30 PM – 3:00 PM
Thu 3:00 PM – 4:30 PM



Grading

• Studio	15 %
• Lab reports	40 %
• Exam I	15 %
• Exam II	15 %
• Exam III	15 %
• Exam IV	15 %
• Note: group submission for studio and lab reports. • Note: take three out of four exams based on topics selected. The total weight of exams is 45%.	

Group & Schedule

- Group
  - 5 students
  - 10 groups
  - Studio & Lab reports submission
    - One group member, do not repeat
    - Every group members' names
    - Same grade for every group member
- Attendance is required, signup sheet

单个周期实验安排（两周）					
1个实验			2个实验		
组别	第一周	第二周	组别	第一周	第二周
I	Lab a		I	Lab a	Lab b
II		Lab a	II	Lab b	Lab a

3	September 16 Forced and Free Vibrations Part II Gear Systems	September 16, 20 Forced and Free Vibrations Part II Gear Systems
4	September 23 No Lecture	September 23, 27 Forced and Free Vibrations Part II Gear Systems
5	September 30 Exam I PLC Tank	September 30, October 4 PLC Tank
6	October 7 No Lecture	October 7, 11 PLC Tank
7	October 14 Control Theory Unstable Systems	October 14, 18 Control Theory Unstable Systems
8	October 21 No Lecture	October 21, 25 Control Theory Unstable Systems
9	October 28 Exam II Fracture Mechanics	October 28, November 1 Fracture Mechanics
10	November 4 No Lecture	November 4, 8 Fracture Mechanics
11	November 11 Heat Treatment Part I Fluid Mechanics	November 11, 15 Heat Treatment Part I Fluid Mechanics
12	November 18 No Lecture	November 18, 22 Heat Treatment Part I Fluid Mechanics
13	November 25 Heat Treatment Part II Heat Exchangers Part I	November 25, 29 Heat Treatment Part II Heat Exchangers Part I

Late Submission

- Studio
- Lab reports
- Exams

Late submission is allowed for the terms marked in yellow with the following rules

Late submission full mark = 100% × r^n

$r = 0.8$: discounted return coefficient

n : n : number of late weeks and n is an integer number which will be round up, e.g. $n = 1$ for the late submission within a week

Lab Handouts

- Print out and bring handout to lab!
- Read the handout
- Focus on the following:
  - What is the objective of the experiment?
  - “For the Report” and “For the Discussion” sections of the handout.

Recording Experimental Data

- Lab Notebook:
  - Title and number of the experiment
  - A list of the equipment used in the experiment
  - Tabulated data being recorded
  - Observations describing behavior or results
  - Computer aided measurements should be printed and attached
  - Sketch schematics important for experiment
  - Sign and date at the end of each lab day and sign up sheet

Lab # and title

Equipment list w/ model and serial numbers

LAB #9: USING LVDT'S FOR DISPLACEMENT MEASUREMENT

EQUIPMENT	MODEL #	SERIAL #
• FUNCTION GENERATOR	HP 3312A	2501A18C12
• ANALOG OSCILLOSCOPE	TEKTRONIX 220S	220S HK 52656
• MULTIMETER	HP 34401A	US36077282
• DIFFERENTIAL TRANSFORMER UNIT (LVDT)	—	—

Make sure you include headings and units!

PART A:

LVDT IS POWERED BY A SINE WAVE OPERATING WITH A 50 mV (RMS) AMPLITUDE AT 5,000 Hz.

MEASURED RMS OUTPUT VOLTAGE FROM LVDT AS A FUNCTION OF THE DISPLACEMENT OF THE MICROMETER

DISPL. (IN)	VOUT (mV)	DISPL. (IN)	VOUT (mV)
0.000	53.753	0.480	6.568
0.025	51.800	0.485	6.013
0.050	49.996	0.490	5.463
0.075	48.089	0.495	4.913
0.100	46.054	0.500	4.361
0.125	43.869	0.505	3.833
0.150	41.518	0.510	3.303
0.175	39.046	0.515	2.785
0.200	36.479	0.520	2.263
0.225	33.902	0.525	1.748
0.250	31.305	0.530	1.302
0.275	28.670	0.535	0.886
0.300	26.028	0.540	0.744
0.325	23.371	0.545	1.004
0.350	20.687	0.550	1.454
0.375	17.993	0.555	1.945
0.400	15.729	0.560	2.460
0.425	12.561	0.565	2.966
0.450	9.828	0.570	3.500
0.475	7.087	0.575	4.039

John Smith 01/20/03

Pay attention to significant digits when recording data!

Student Signature and date

If a data table is split, always repeat the headings and units

DISPL. (IN)	VOUT (mV)	DISPL. (IN)	VOUT (mV)
0.580	4.571	0.750	23.141
0.585	5.118	0.775	25.830
0.590	5.666	0.800	28.515
0.595	6.216	0.825	31.192
0.600	6.772	0.850	33.845
		0.875	36.481
0.625	9.529	0.900	39.075
0.650	12.260	0.925	41.508
0.675	14.983	0.950	43.913
0.700	17.723	0.975	46.056
0.725	20.447	1.000	48.068

Label the part of the experiment for which the data was recorded

PART B:

(1) THE MICROMETER WAS SET AT 0.400 IN DISPLACEMENT THE FREQUENCY WAS VARIED FROM 100 Hz TO 150,000 Hz. THE RMS OUTPUT VOLTAGE REMAINED CONSTANT FOR FREQUENCIES BETWEEN 950 Hz TO 11,000 Hz; FOR FREQUENCIES OUTSIDE THE RANGE THE RMS OUTPUT VOLTAGE WAS SIGNIFICANTLY LOWER.

(2) THE FUNCTION GENERATOR FREQUENCY WAS SET TO 100 Hz. THE MICROMETER WAS ADJUSTED THROUGH THE FULL RANGE OF TRAVEL (0 TO 1.0 INCHES). THE RMS OUTPUT VOLTAGE WAS OBSERVED TO BE SIGNIFICANTLY LESS (ALMOST ZERO) THAN THE VALUES OBSERVED IN PART A.

Examples of noting trends in data

Student Signature and date

John Smith 01/20/03

TA: Steve Jones 01/20/03

TA Signature and date

Report Guidelines

- Memo Writing
- The purpose of the memo format is to demonstrate the proper manner for reporting to a supervisor who is not interested in the details of the experiment, but just the outcome. Thus, the memo needs to be a CLEAR and CONCISE account of the experiment
  - What was done
  - What are the results
  - A discussion of the meaning of the results.
- Memos should include:
  - Memo To: , Memo From: , Date , Subject
  - Three paragraphs that make up main text.
    - Objective and Procedure
    - Summary of Results
    - Discussion
- What to avoid:
  - Headings
  - Equipment List
  - Large Report Length

Grading TA

MEMO TO: Steve Jones

FROM: John Smith *John Smith*

Student Signature

Objective and Procedure

DATE: January 12, 2003

SUBJECT: Lab #9: Linear Variable Differential Transformers for Displacement Measurements

---

Summary of results

On January 5th, Jane Miller and I conducted an experiment to determine the operating characteristics of a linear variable differential transformer (LVDT). In Part A of the experiment, power was supplied to the LVDT by using a 50 mV (RMS) sine wave at 5,000 Hz produced by a function generator. A micrometer connected to the LVDT core was adjusted from 0.0 to 1.0 inches, thus moving the LVDT core through its full range. The RMS output voltage from the LVDT was measured using a multimeter. In Part B of the experiment, the frequency of the power supply was varied from 100 Hz to 150,000 Hz in order to observe the change (if any) in the behavior of the LVDT response.

The LVDT output voltage, recorded as a function of the axial displacement, is listed in Table 1. The data was then plotted to determine the linear operating range of the LVDT. As shown in Figure 1, the shape of the curve indicates that the approximate linear range of the LVDT is from 0.21 inches to 0.83 inches of the axial displacement. The sensitivity of the LVDT is defined as the slope of the LVDT response in the linear range. Using Equation 1, the sensitivity was determined to be 2 12 mV per 0.001 inches of core displacement per 1V of the excitation signal.

The null point of an LVDT is defined as the point in the displacement where the output voltage from the LVDT is zero. As shown in the recorded data from Table 1, the output signal from the LVDT does not actually reach zero volts. This is primarily due to the size of the increment chosen for adjusting the axial displacement. A different increment, smaller than the 0.001 inches used, is needed to find the exact location of the null point. However, based on the recorded data, the null point occurs somewhere in the range of 0.535 to 0.540 inches of axial displacement.

The linear range is the range of the displacements over which the output voltage from the LVDT changes at a constant rate called the sensitivity. From Fig. 1, this range is found to be approximately +/- 0.300 inches from the null point. Beckwith et. al. [1995] provide specifications for LVDT's that indicate typical values for the sensitivity to be in the range of 0.05 to 4.0 mV/0.001 in. / V excitation and for the linear range to be +/- 0.005 inches to +/- 5.0 inches. The observed values for the sensitivity and linear range of the LVDT examined in this experiment fall approximately in the middle of the ranges for the operating characteristics of typical LVDTs.

In Part B of the experiment, the frequency of the excitation signal powering the LVDT was varied for a fixed core position. The RMS output voltage remained constant for frequencies between 950 Hz and 11,000 Hz. For frequencies outside that range, it was observed that the output voltage decreased. Finally, the power supply frequency was set to 100 Hz and the micrometer was adjusted over its full range. The RMS output voltage from the LVDT was significantly lower than that observed in Part A. These two observations confirm that the LVDT is not designed to operate for input frequencies outside the range of 1000 Hz to 10,000 Hz.

Reference to textbook

Discussion

Descriptive caption

Note the use of headings and units

Table 1: Recorded data – LVDT output voltage as a function of the axial displacement.

Displacement (inches)	V out (mV)	Displacement (inches)	V out (mV)	Displacement (inches)	V out (mV)
0.000	53.573	0.485	6.013	0.590	5.666
0.025	51.800	0.490	5.463	0.595	6.216
0.050	49.996	0.495	4.913	0.600	6.772
0.075	48.089	0.500	4.361	0.625	9.524
0.100	46.054	0.505	3.833	0.650	12.260
0.125	43.864	0.510	3.303	0.675	14.983
0.150	41.518	0.515	2.785	0.700	17.723
0.175	39.046	0.520	2.263	0.725	20.447
0.200	36.479	0.525	1.748	0.750	23.141
0.225	33.902	0.530	1.302	0.775	25.830
0.250	31.305	0.535	0.886	0.800	28.515
0.275	28.670	0.540	0.744	0.825	31.192
0.300	26.028	0.545	1.004	0.850	33.845
0.325	23.371	0.550	1.454	0.875	36.481
0.350	20.687	0.555	1.945	0.900	39.075
0.375	17.993	0.560	2.460	0.925	41.508
0.400	15.279	0.565	2.966	0.950	43.913
0.425	12.561	0.570	3.500	0.975	46.056
0.450	9.828	0.575	4.039	1.000	48.068
0.475	7.087	0.580	4.571		
0.480	6.568	0.585	5.118		

Use significant digits when reporting data

Equation for calculating sensitivity:

Sensitivity = ΔOutput signal of LVDT (mV) / 0.001 in (core displ.) / Excitation Signal (V) (1)

= [41.508- 2.460] mV / [0.925-0.560] in / 0.050 V

= 2.14 mV / 0.001 in / 1 V

Equation number

Always include units in calculations

Descriptive caption

Note the use of headings and units

Table 1: Recorded data – LVDT output voltage as a function of the axial displacement.

Displacement (inches)	V out (mV)	Displacement (inches)	V out (mV)	Displacement (inches)	V out (mV)
0.000	53.573	0.485	6.013	0.590	5.666
0.025	51.800	0.490	5.463	0.595	6.216
0.050	49.996	0.495	4.913	0.600	6.772
0.075	48.089	0.500	4.361	0.625	9.524
0.100	46.054	0.505	3.833	0.650	12.260
0.125	43.864	0.510	3.303	0.675	14.983
0.150	41.518	0.515	2.785	0.700	17.723
0.175	39.046	0.520	2.263	0.725	20.447
0.200	36.479	0.525	1.748	0.750	23.141
0.225	33.902	0.530	1.302	0.775	25.830
0.250	31.305	0.535	0.886	0.800	28.515
0.275	28.670	0.540	0.744	0.825	31.192
0.300	26.028	0.545	1.004	0.850	33.845
0.325	23.371	0.550	1.454	0.875	36.481
0.350	20.687	0.555	1.945	0.900	39.075
0.375	17.993	0.560	2.460	0.925	41.508
0.400	15.279	0.565	2.966	0.950	43.913
0.425	12.561	0.570	3.500	0.975	46.056
0.450	9.828	0.575	4.039	1.000	48.068
0.475	7.087	0.580	4.571		
0.480	6.568	0.585	5.118		

Use significant digits when reporting data

Equation for calculating sensitivity:

Sensitivity = ΔOutput signal of LVDT (mV) / 0.001 in (core displ.) / Excitation Signal (V) (1)

= [41.508- 2.460] mV / [0.925-0.560] in / 0.050 V

= 2.14 mV / 0.001 in / 1 V

Equation number

Always include units in calculations

Note the labeling of important features

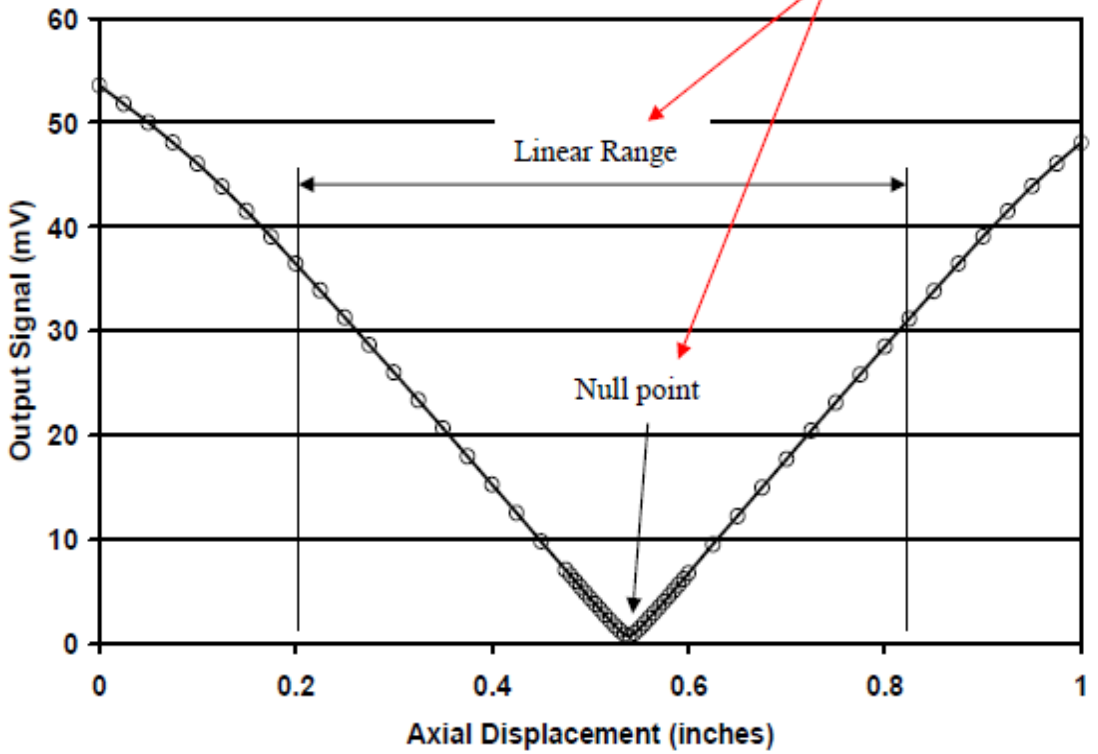


Figure 1: Plot of LVDT output voltage vs. axial displacement.

Reference:

Beckwith, Marangoni, and Lienhard, *Mechanical Measurements*, 5th edition, Addison Wesley, 1995.

Report Guidelines

- Extended Memo
- 3 Pages of Text
  - Introduction, Objective and Procedure
  - Methods and Procedure
  - Results
  - Discussion
  - Conclusion
- 3 Pages of Attachments
  - Tables
  - Figures

Research Topics

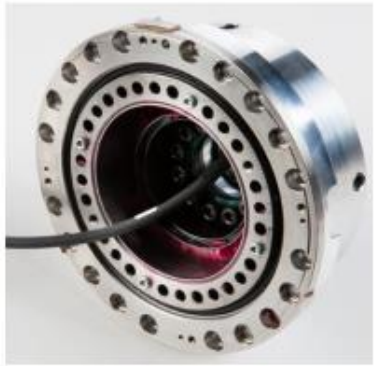
- Renewable Energy Systems
  - Solar Energy
  - Wind Power
- Intelligent Machines and Robotics
  - Autonomous Vehicles
  - Robotic Arms
- Computational Fluid Dynamics
- Micro/Nano-Engineering
  - Microelectromechanical Systems
  - Sensors

An Example

关节电子装置

关节转矩传感器

电机



齿轮机构

To Do

- Topic & lab session selection
- Safety quiz