LAB 10
Part A: Calibration of Pressure scanner
Part B: Calibration of six component force balance
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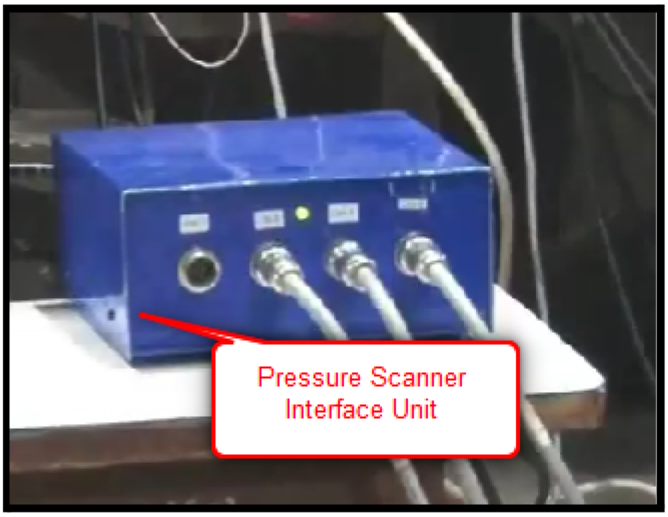
- ***EXPERIMENT [A] :*** Calibration of Pressure scanner

- **OBJECTIVE :** To study the calibration procedure of pressure scanner

- **EQUIPMENT AND OPERATING CONDITIONS:**

1. Electronically Scanned Pressure sensor:
32-HD ESP scanners are differential pressure measurement units. The pressure range of this scanner is ± 2.5 KPa. It houses an array of 32 piezo-resistive sensors. The output of sensors is in voltage. Pressure sensors are connected to multiplexers which can acquire data up to 1 kHz. Each pressure port consists of a Wheatstone bridge diffused onto a single silicon crystal. This scanner needs a 12 V DC supply to operate and 5V for excitation of sensors. These scanners have a two-position manifold, one is run mode, and The other is calibration mode. The various positions can be changed by applying a momentary pulse of control pressure. Run-mode is used to acquire pressure data, and calibration mode is used for the calibration of pressure ports. In the calibration mode position, all sensors are connected to a common calibration pressure port. The accuracy of the scanners is maintained within ±0.05% of the full-scale pressure range through their periodic calibration. The frequency calibration is dependent on ambient conditions, and it changes with time. Calibration performed immediately before a set of data is acquired assures the highest accuracy of the scanners.

2. Multiplexer Unit:
Each sensor output is selectively routed to the onboard instrumentation amplifier by applying its unique binary address to the multiplexers. The multiplexed and amplified analog outputs of the scanners can drive long lengths (up to 30 fts) of cable to the remote A/D converter of the DAQ board. Scanners require a 12V DC power supply to operate built-in analog/digital devices and a +5V DC power supply as the excitation voltage source for the sensors.



3. Digital Interface and Line Driver (DILD) unit for ESP Scanners:
The DAQ board provides 5-volts (TTL) logic level signals through its digital I/O lines, whereas the pressure scanners require 12-Volt (CMOS) logic level signals for binary addressing. Thus, there is a logic (TTL-CMOS) level mismatch between the DAQ board and scanners. The logic level shifters of the DILD unit compensate for this logic level mismatch. The DILD unit also provides a digital fan-out to drive up to 8 pressure scanners and long cable (30 ft) drive capability. The regulated DC power (12V and 5V) required for the operation of pressure scanners is also supplied by this unit.

4. Data Acquisition Board:
A 14-bit high-speed data acquisition board from National Instruments is used for the pressure measurement, which acts as an interface between sensors and computers. The data acquired is digitized and transferred to a computer by the DAQ board.

5. Pressure Data Acquisition and Analysis Software:
Data acquisition and control are made by the LabVIEW 12.0 application software. In-house developed pressure data acquisition and analysis software are capable of acquiring the data at desired data acquisition parameters, analyzing, and presenting in the engineering units.

6. Digital manometer: It directly measures the gauge pressure between the two terminals.

7. Calibration Setup: The electronic output of the ESPs is calibrated to convert electronic signals to pressure data. For that purpose, known pressure is applied using a hand pump measured using a digital manometer, which is used to calibrate the electronic data from the ESP.

Fig. 2: Digital manometer

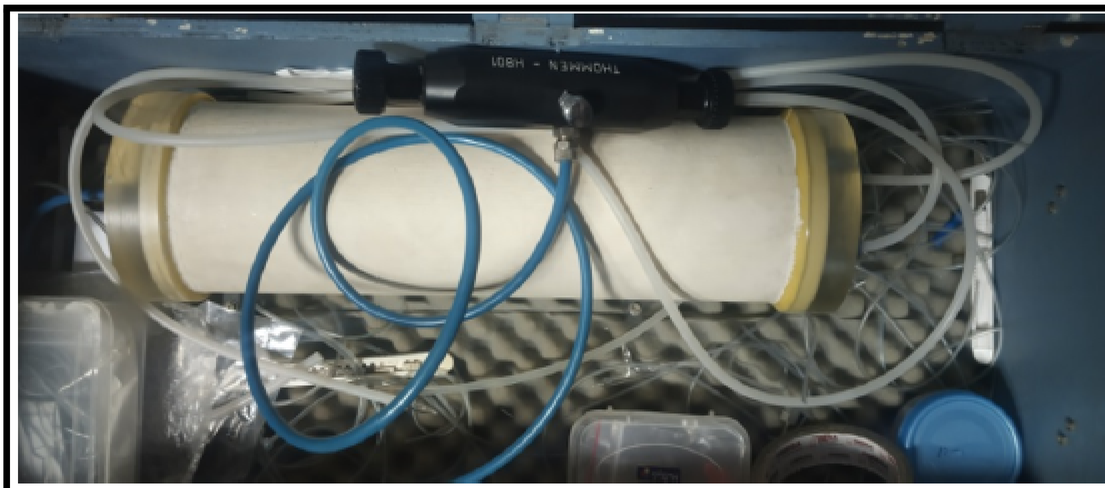


Fig. 1: Hand pump

- **PROCEDURE:**

    1. Connect pressure scanner reference port of run mode and digital manometer to hand pump via T-joint pressure tube.

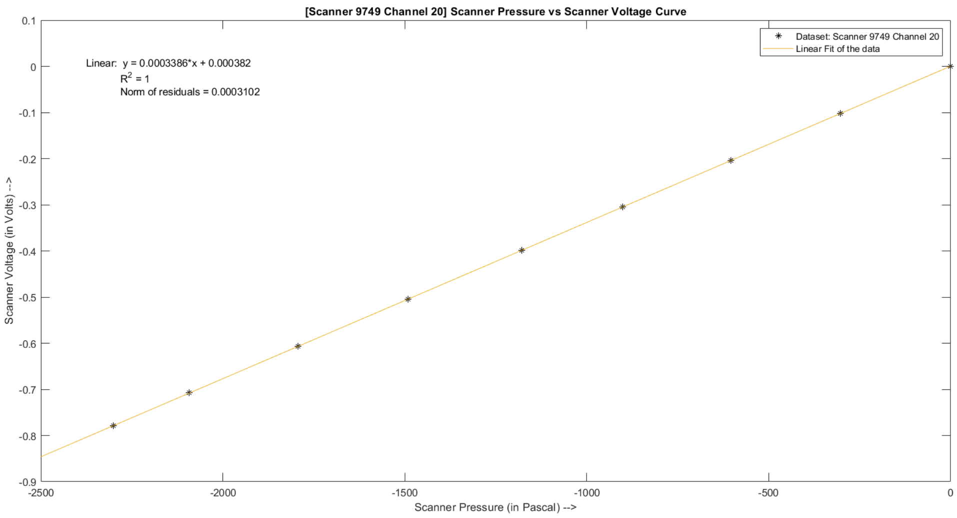
2. Apply multiple pressures using the hand pump.
3. Save voltage output of scanner and pressure output from digital manometer (negative pressure will obtain as pressure is applied on reference port)
4. Plot voltage vs pressure to obtain slope and fit equation of sensors.

- **RESULTS AND DISCUSSION :**

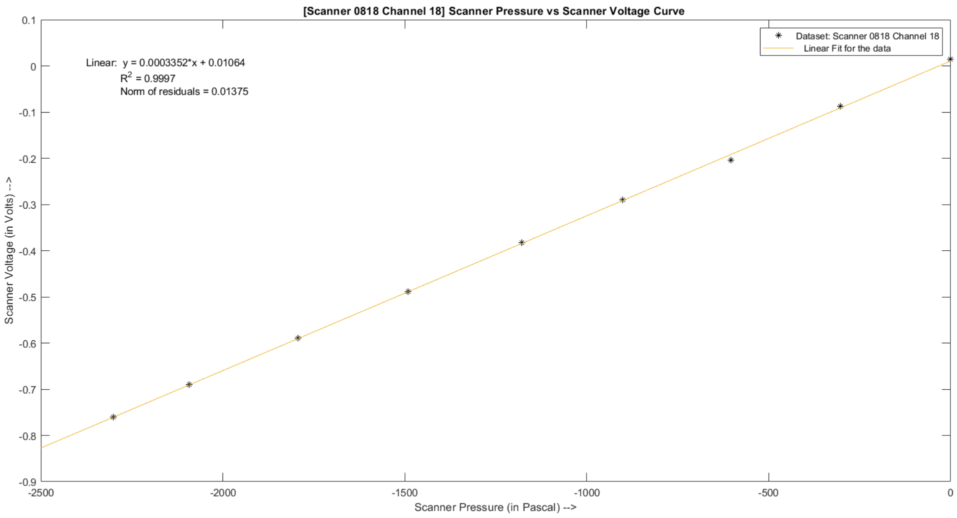
assigned Dataset :
Scanner 9749 → Channel 20
Scanner 0818 → Channel 18
Scanner 0916 → Channel 24

(a) Observations :

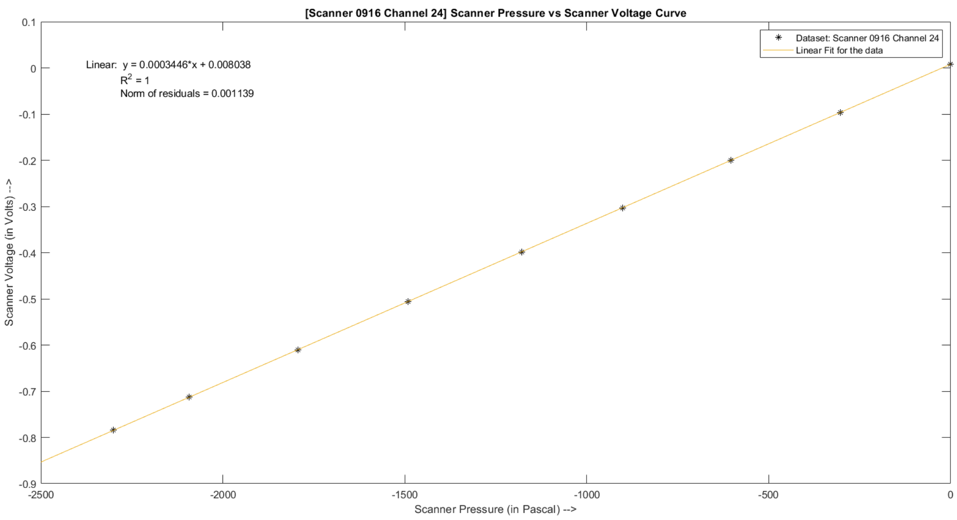
1. Plot pressure vs voltage for pressure scanner.
2. Obtain the equation and R^2 of the plotted graph .



Calibration Equation : Voltage= 0.0003386*Pressure + 0.000382
Slope = 0.0003386
R^2 = 1
Norm of Residuals = 0.0003102



Calibration Equation : Voltage= 0.0003352*Pressure + 0.01064
Slope = 0.0003352
R2 = 0.997
Norm of residuals = 0.01375



Calibration Equation : Voltage= 0.0003446*Pressure + 0.008038
Slope =0.0003446
R^2 = 1
Norm of residuals = 0.001139

(b) Precaution:

1. Ensure that the maximum pressure at any port should be within the range of the sensor.
2. While calibrating, sufficient time should be given for the pressure to stabilize.
3. Make sure that there are no blockages or leakage in the tubes.
4. The excitation voltage given to the scanner must be within the range of 5V.
5. There should not be any obstacle near the entry or exit of wind tunnel flow, causing a disturbance in the freestream flow.

- ***The MATLAB Code used for the Calculations:***

```
%% Importing the Dataset
% Scanner 9749 --> Channel_20
% Scanner 0818 --> Channel_18
% Scanner 0916 --> Channel_24
% Column1 Scanner Pressure
% Column2 Scanner Voltage
% Scanner 9749 --> Channel_20
channel_20 = [
   -1 0.000212;
   -303     -0.102226;
   -604     -0.204231;
   -901     -0.304763;
   -1179    -0.399051;
   -1491    -0.504427;
   -1794    -0.607035;
   -2092    -0.707918;
   -2301    -0.778766
];
% Scanner 0818 --> Channel_18
channel_18 = [
   -1 0.014538;
-303  -0.087709;
-604  -0.204234;
-901  -0.289509;
-1179 -0.383353;
-1491 -0.488122;
-1794 -0.590048;
-2092 -0.690164;
-2301 -0.760414;
];
% Scanner 0916 --> Channel_24
channel_24 = [
   -1 0.008361;
-303  -0.096297;
-604  -0.200301;
-901  -0.302775;
-1179 -0.398819;
-1491 -0.505928;
-1794 -0.61021;
-2092 -0.712554;
-2301 -0.784385;
   ];
% Scanner 9749 --> Channel_20 Scanner Pressure Vs Voltage Curve
plot(channel_20(:,1),channel_20(:,2),"*k");
xlabel("Scanner Pressure (in Pascal) -->");
ylabel("Scanner Voltage (in Volts) -->");
title("[Scanner 9749 Channel 20] Scanner Pressure vs Scanner
Voltage Curve");
% Scanner 0818 --> Channel 18 Scanner Pressure Vs Voltage Curve
plot(channel_18(:,1),channel_18(:,2),"*k");
xlabel("Scanner Pressure (in Pascal) -->");
ylabel("Scanner Voltage (in Volts) -->");
title("[Scanner 0818 Channel 18] Scanner Pressure vs Scanner
Voltage Curve ");
% Scanner 0916 --> Channel 24 Scanner Pressure Vs Voltage Curve
plot(channel_24(:,1),channel_24(:,2),"*k");
```

```
xlabel("Scanner Pressure (in Pascal) -->");
ylabel("Scanner Voltage (in Volts) -->");
title("[Scanner 0916 Channel 24] Scanner Pressure vs Scanner
Voltage Curve");
```

- **References:**

1. Pictures and descriptions from Google, Lectures and Lecture Notes of AE351 (Lab10)
2. Schlichting, ``Boundary Layer Theory,'' McGraw Hill Book Co., New York, 1960.

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- ***EXPERIMENT [B] :*** **Calibration of six component force balance**

- **OBJECTIVE :** To study the calibration procedure of a six-component force balance

- **EQUIPMENT AND OPERATING CONDITIONS:**

1. **Six component force balance:** It is a cylindrical body, with a maximum diameter of 5 mm and a length of 210 mm. An aerodynamics model has to be mounted to measure forces acting on it. It consists of 2 normal force gauge stations for determining normal force and pitching moment, 2-side force gauges to determine side force and yaw moment, two axial force measuring bridges and one rolling moment bridge. The load range for the 6-component balance is 5kg for Axial force, 15kg for N1 force, 15kg for N2 force, 5kg for S1, 5kg for S2 and 100kgmm for Rolling moment.
2. **Calibration body:** It is used to facilitate loading of the balance with pure loads (in specific directions at particular locations) in order to calibrate it.

Fig. 3: Installed Load cell (for N1 force measurement)

3. **Calibration rig:** It is a truss structure with leveling screws on which the force balance fitted with the calibration body is mounted to apply the desired pure loads. The leveling screws are required to align the force balance in a horizontal position under the action of the force due to dead weights.
4. **Precise level gauge:** A digital level gauge is used to align the balance in the horizontal position.
5. **Dead weights:** These are used to load the balance with constant loads.
6. **NI SCXI-1520:** is an 8-channel universal strain gauge input module that offers all of the features you need for simple or advanced strain- and bridge-based sensor measurement.

7. **NI SCXI-1314:** terminal block is used with the SCXI-1520 universal strain/bridge module enabling you to connect strain gauges through screw terminals conveniently.
8. **Data acquisition card:** The voltage output of the strain gauges is required to be measured under the loading on balance. A data acquisition card PXI1002 with a maximum of 16 voltage input channels is used.
9. **Labview software:** Labview software facilitates providing/acquiring the input/output voltage signals to/from the strain gauge bridges using a specially built VI program.

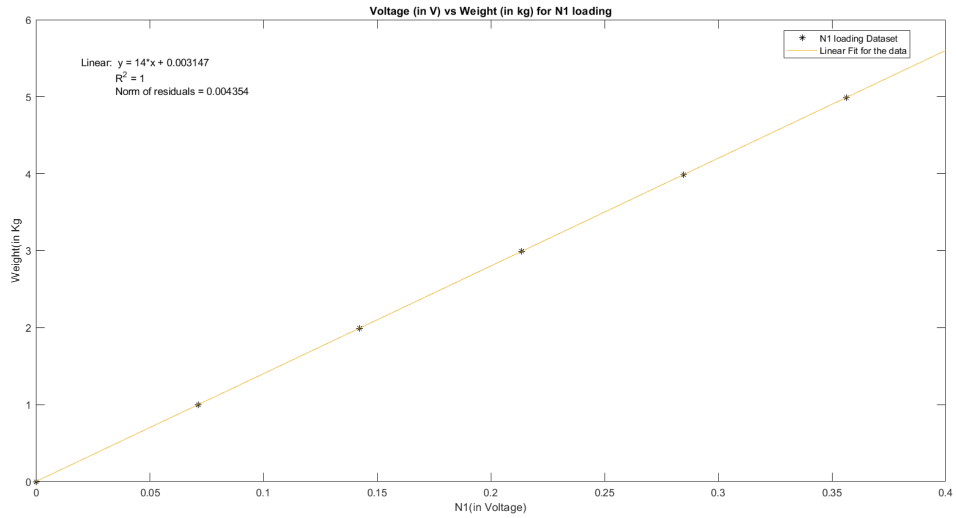
- **PROCEDURE:**

1. Fix and connect force balance to the DAQ system.
2. Perform bridge nulling to remove force generated due to empty pan weight.
3. Put a load of 992 gm on the pan and note down N1 force.
4. Exceed load in a step manner.
5. Rotate force load balance by 900.
6. Perform bridge nulling to remove force generated due to empty pan weight.
7. Put step loads on the pan and note down S1 force.
8. Measure the output voltages of the bridges at all locations (AX, N1, N2, S1, S2, RM) at each known applied load at a particular bridge location (say N1).
9. Repeat steps to obtain other loads also.

- **RESULTS AND DISCUSSION :**

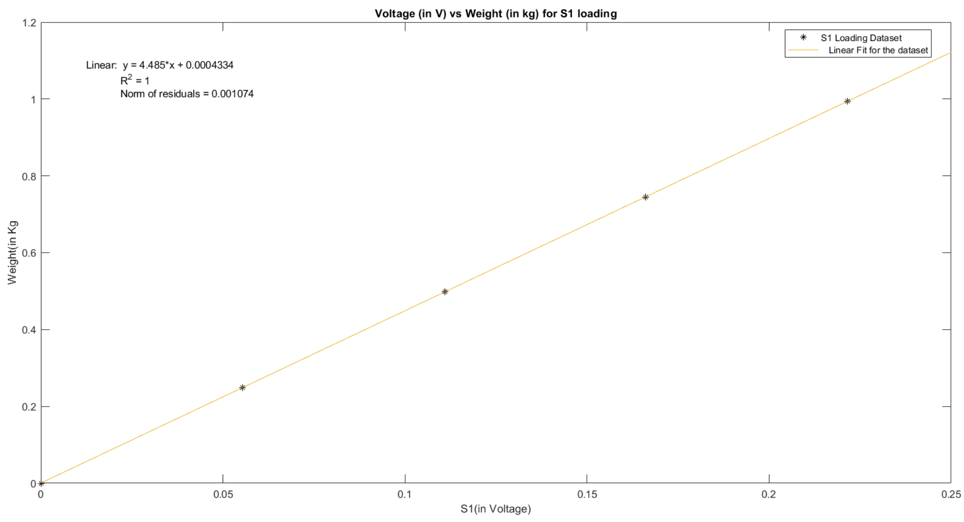
(a) observation

1. Plot and obtain equation for Weight vs Voltage
2. Calculate voltage for given load and discuss



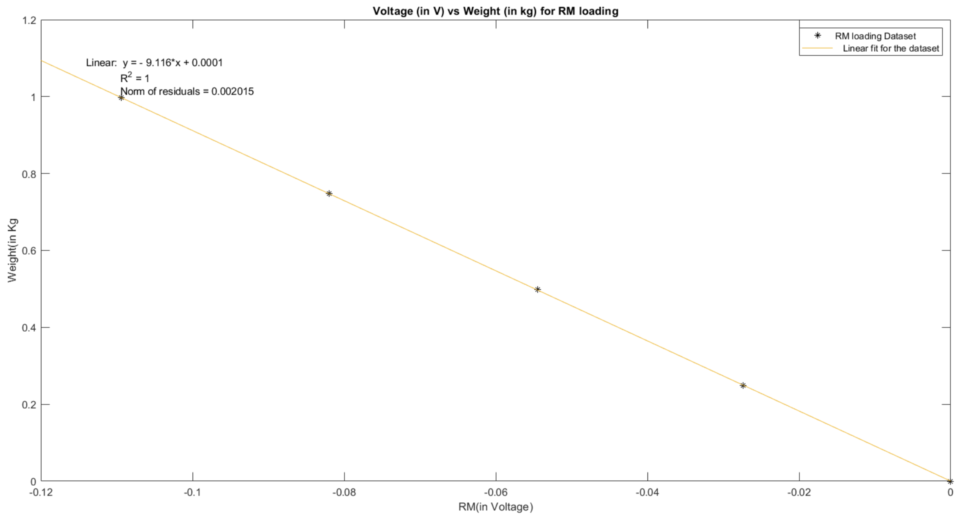
Calibration Equation : Weight = 14*Voltage + 0.003147
Slope = 14
R^2 = 1
Norm of Residuals = 0.004354

For Weight = 2 kg → N1 = 0.1426
For Weight = 8 kg → N1 = 0.5712



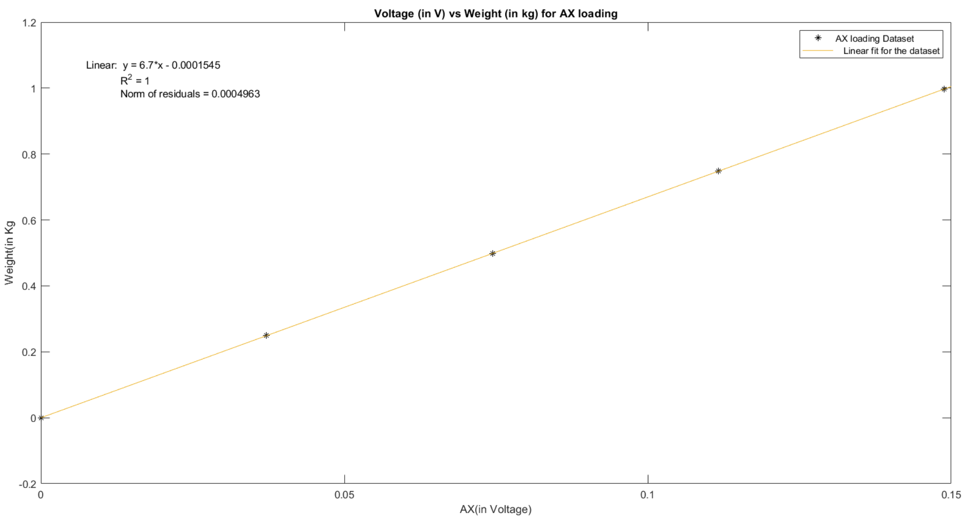
Calibration Equation : Weight = 4.485*Voltage + 0.0004334
Slope = 4.485
R^2 = 1
Norm of Residuals = 0.001074

For Weight = 0.3 kg → S1 = 0.0668
For Weight = 3 kg → S1 = 0.6688



Calibration Equation : Weight = -9.116 *Voltage + 0.0001
Slope = -9.116
R2 = 1
Norm of Residuals = 0.002015

For Weight = 0.8 kg → RM1 = -0.0877
For Weight = 1 kg → RM1 = -0.1097



Calibration Equation : Weight = 6.7 *Voltage – 0.0001545
Slope = 6.7
R^2 = 1
Norm of Residuals = 0.0004963

For Weight = 0.9 kg → AX1 = 0.1344
For Weight = 4 kg → AX1 = 0.5970

Sources of Error:

1. Do not load the transducer over the weight limit.
2. Do not exceed the weight limit of the loads that can be put on the setup.
3. Make sure the setup is sturdy and do not create any disturbance while taking the reading.

- ***The MATLAB code used for the calculation :***

```
%% Importing the Dataset
% Column1 Weight and Column2 Voltage
% N1 loading
N1_dataset = [
0 -0.000167;
0.9972 0.071126;
1.9945 0.142133;
2.9918 0.213486;
3.9892 0.284649;
4.9866 0.356253;
];
% S1 loading
S1_dataset = [
  0 0.000021;
0.2494 0.055423;
0.4987 0.110942;
0.7448 0.166075;
0.9942 0.221599;
];
%RM loading
RM_dataset = [
0 -0.000025;
0.2492 -0.027407;
0.4982 -0.054461;
0.7476 -0.081971;
0.9966 -0.109403;
];
%AX loading
AX_dataset = [
0 0.000033;
0.2492 0.037166;
0.4982 0.07442;
0.748 0.111681;
0.9974 0.148855;
];
%% plot of Voltage vs Weight for N1 loading
plot(N1_dataset(:,2),N1_dataset(:,1),"*k");
xlabel("N1(in Voltage)");
ylabel("Weight(in Kg)");
title("Voltage (in V) vs Weight (in kg) for N1 loading");
%% plot of Weight vs Voltage for S1 loading
plot(S1_dataset(:,2),S1_dataset(:,1),"*k");
xlabel("S1(in Voltage)");
ylabel("Weight(in Kg)");
title("Voltage (in V) vs Weight (in kg) for S1 loading");
%% plot of Weight vs Voltage for RM loading
plot(RM_dataset(:,2),RM_dataset(:,1),"*k");
xlabel("RM(in Voltage)");
ylabel("Weight(in Kg)");
title("Voltage (in V) vs Weight (in kg) for RM loading");
%% plot of Weight vs Voltage for AX loading
```

```
plot(AX_dataset(:,2),AX_dataset(:,1),"*k");
xlabel("AX(in Voltage)");
ylabel("Weight(in Kg");
title("Voltage (in V) vs Weight (in kg) for AX loading");
```

- **References:**

3. Pictures and descriptions from Google, Lectures and Lecture Notes of AE351 (Lab10)
4. Low-speed wind tunnel testing - W. E. Rae, Jr. and Alan Pope.
5. Fundamental of Aerodynamics - J. D. Anderson.
6. NI manual for DAQ cards used.

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