Lab 1

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I. INTRODUCTION

This report showcases the analysis and discussion of measurements errors due to ambient change and resistance tolerance for a measurement system.

II. ENVIRONMENTAL IMPACT ON MEASUREMENT SYSTEMS

A. Linearity

Linearity is the measure of how accurate the data is to be a pure straight-line. The linearity error of the measurement system was calculated using equation 1 below, N is the maximum deviation, O_{MAX} and O_{MIN} is the maximum and minimum outputs.

$$non-linearity = \frac{N}{O_{MAX} - O_{MIN}} \times 100\% \tag{1}$$

Applying the above equation on Matlab with the given measurements the value of linearity error was found to be 3.4219% which gives the linearity of 96.5781%. Refer to Appendix B, Figure 2 for the Matlab code used to perform the calculations.

B. Zero-bias

Zero-bias is the output of the measurement system at zero input. The data of the calibration at 21$°C$ where scatter plotted and the line of best fit referenced with Microsoft Excel was calculated. The solution is expressed by equation 2 below.

$$y = 1.425 \times x + 4.8839 \tag{2}$$

where x denotes the input to the system in kg and y is the output of the measurement in mV. By equating the input to zero, the value of the zero-bias was found to be 4.8839 from equation 2.

The zero-bias at 40$°C$ was also calculated and found to be 4.9339 as depicted by its corresponding line of best fit in equation 3 below.

$$y = 1.625 \times x + 4.9339 \tag{3}$$

C. Zero-bias drift

Zero-bias drift is measure of how the bias point change with ambient change as show by equation 4 below:

$$0-biasdrift = \frac{0-biasA - 0-biasB}{temperatureA - temperatureB} \tag{4}$$

where A denotes the measurement at calibration and B the measurement after the ambient change. The zero-bias drift was obtained to be 0.0026 $mV/kg/°C$

D. Sensitivity

The sensitivity is the measure of how quickly the system responds to an input change. Under calibration conditions, the sensitivity of the system was obtained to be 1.4250 mV/kg.

E. Sensitivity drift

Sensitivity drift defines the amount by which an instrument's sensitivity of measurement varies as ambient conditions change. Using equation 5 below the sensitivity drift of the measurement instrument was calculated to be 0.0105 $mV/kg/°C$.

$$sensitivitydrift = \frac{sensitivityA - sensitivityB}{temperatureA - temperatureB} \tag{5}$$

where A denotes the measurements under calibration and B denotes the measurement after the ambient change.

III. ERRORS ON A MEASUREMENT SYSTEM AS A RESULT OF RESISTOR TOLERANCES

The goal of this section is to determine the effect of resistor tolerance on the error band of the output voltage of the measurement system.

A. Tolerance

Equation 6 below was employed to determine the values of resistors due to the tolerance effect.

$$R_{X_{max/min}} = R_X(1 \pm tolerance) \tag{6}$$

$R_{X_{max/min}}$ denotes the value of resistance which can either be minimum or maximum depending on arithmetic notation of the tolerance used.

B. Maximum, minimum and nominal output voltages

The Thevenin equivalent circuit of the system was obtained. The mathematical model of the system is expressed by equation 7 below.

$$V_{TH} = \frac{V_{in} \times R_3}{R_3 + R_n} - \frac{V_{in} \times R_2}{R_1 + R_2} \tag{7}$$

The nominal voltages for ranging values of R_n were calculated using equation 6 and 7 with the tolerance of zero. The maximum voltage for ranging R_n were calculate in a similar manner but selecting the arrangement of resistors that will yield maximum voltage, this set of resistors is expressed by equation 8 below.

$$V_{TH_{MAX}} = \frac{V_{in} \times R_{3_{MAX}}}{R_{3_{MAX}} + R_n} - \frac{V_{in} \times R_{2_{MIN}}}{R_{1_{MAX}} + R_{2_{MIN}}} \tag{8}$$

Finally, the minimum voltages were obtained using the set of resistors expressed by equation 9 below.

$$V_{TH_{MIN}} = \frac{V_{in} \times R_{3_{MIN}}}{R_{3_{MIN}} + R_n} - \frac{V_{in} \times R_{2_{MAX}}}{R_{1_{MIN}} + R_{2_{MAX}}} \tag{9}$$

Appendix D, Table 1 shows the values of resistor sets that will give maximum and minimum output voltage to the system.

C. Error band

The errors of the system for different R_n values were calculated using equation 10 below. Figure 2, Appendix A shows the curve of errors of the system as well, for both maximum and minimum tolerance values ($\pm 5\%$).

$$Error = V_{TH_{max}} - V_{TH_{min}} \tag{10}$$

The maximum and minimum errors of the systems were tracked and used to obtain the error band of the system using equation 11 below.

$$ErrorBand = \frac{Error_{max}}{V_{nom_{maxVoltage}}} \times 100\% \tag{11}$$

The error band of the system was found to be 14.3884%.

IV. RELIABILITY ISSUES

The aim of this section was to determine the availability of the measurement from the given data specifying times before breakdown and repair times. From the data available it was required to calculate the MTBF and MTTR in order to obtain the availability.

A. Mean Time Before Failure (MTBT)

The MTBF of the measurement system was calculated using equation 12 below.

$$MTBF = \frac{1}{\lambda} \tag{12}$$

where λ is the total number of failures per hour. The MTBF was calculated to be 562.80.

B. Mean Time To Repair (MTTR)

Equation 13 below was used to calculate the MTTR of the measurement system lastly required to obtain the availability of the system. The MTTR was obtained to be 24.24.

$$MTTR = \frac{\sum repairTime}{totalNumberOfReapirs} \tag{13}$$

C. Availability

Finally equation 14 below was applied to obtain the availability of the system using the aforementioned values for MTBF and MTTR,

$$Availability = \frac{MTBF}{MTBF + MTTR} \tag{14}$$

the calculated value of the availability was obtained to be 0.9587.

V. ANALYSIS OF RESULTS

The linearity of the system aforementioned implies that it will register a value of 96.5781 *kg* for a system weighing 100 *kg* in reality. The error of the system is small allowing the measurement system to be precise and accurate. Even though the error is small, the measurement system will fail in chemistry application since the system should record the exact reality measurement.

The zero-bias drift of the system is small but cannot be ignored. It can be observed in Figure 1, Appendix A that this drift caused the voltage response curve to raise which resulted in the system registering higher voltage output for similar masses compare to calibration conditions. The sensitivity drift forced the slope to increase compared to calibration conditions, which also forced the output voltage of the system to increase for the same weight compare to calibration. Using the lines of best fit for both calibration and after the ambient change, it can be observed an object weighing 10.61 *kg* at calibration will weigh 9.271 *kg* at 41 °C. Temperature has a great impact on this system and therefore it will require a compensation system if is to be applied in reality.

Knowing the tolerance of resistors is vital since it is responsible for the error band. The greater the tolerance the greater the difference between the maximum and minimum output voltage which results into larger error band. The error band of the system was obtained using the worst case value of the tolerance and the error band value is large enough which allow the measurement system to deviate too much from reality.

Imperfect humans always build imperfect machines, it was observed that the sensor failed from time to time. The sensor was operating most of the time compared to repair time which gave the sensor and opportunity to attain 95.87% of availability. The availability calculation is important in measurement systems as it allows the determination of productivity of the system, which is vital in the business world. The availability of the system can be improved by decreasing the amount of time spent doing repair or increasing the mean time between repairs ($MTBF$)

VI. CONCLUSION

Knowledge of linearity, sensitivity and zero-bias drift is important as it allows determination of accuracy and precision of a system and how the system is able to withstand environmental changes. The tolerance of the resistors is directly proportional error band of the output, thus the error band may be improved reducing tolerance. Availability is important as it allows the determination of maintenance and productivity of the system.

Appendix A

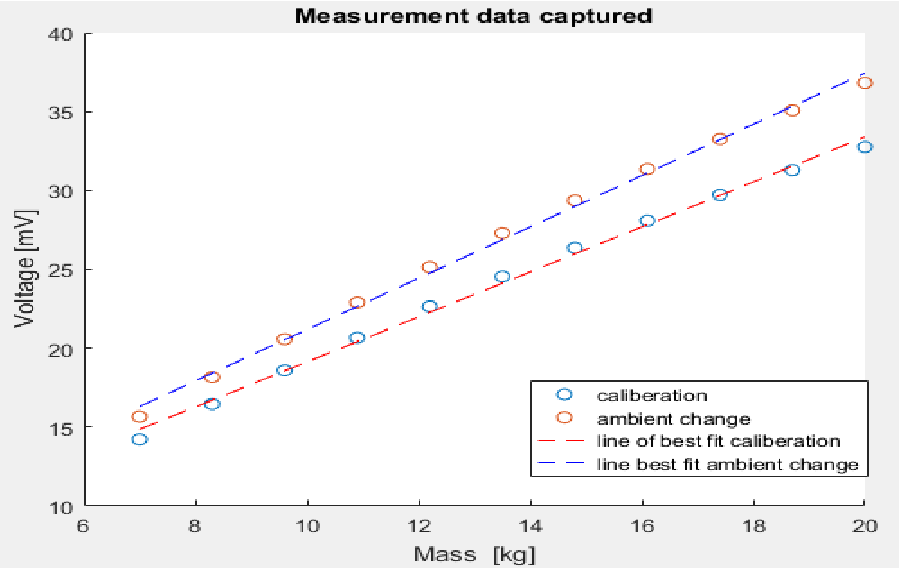

Figure 1: The change of voltage in relation to mass for a measurement system.

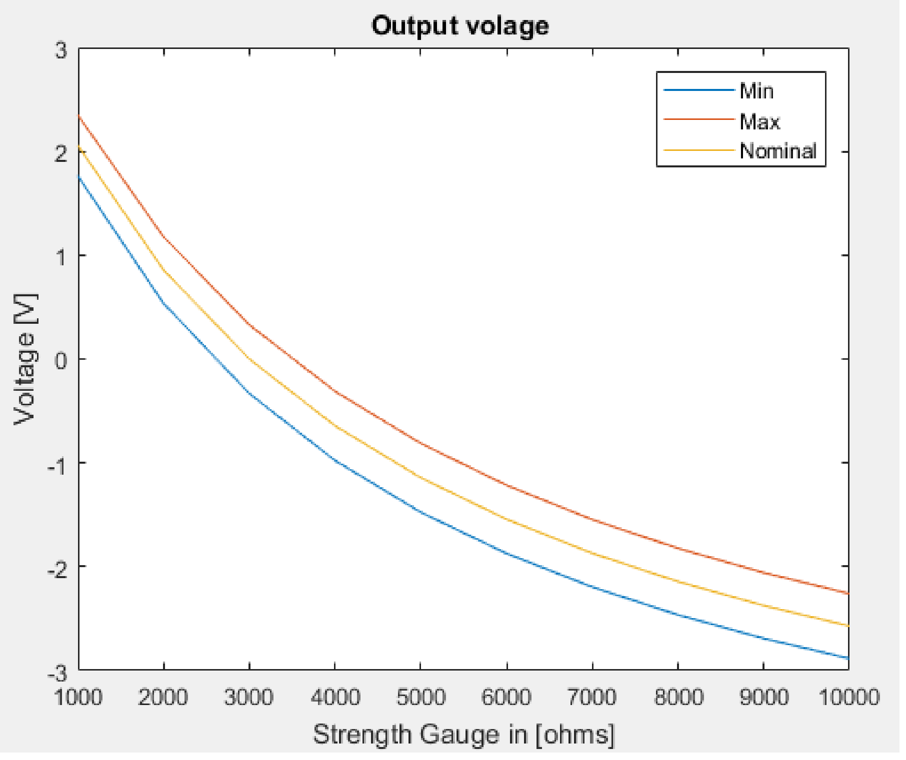

Figure 2: Output voltage relationship to strength gauge curves using 5% tolerance.

Appendix B

```matlab
%%Measurements Lab 1
%%Kwena Mtshali 867040
%%Teboho Lekeno 1130992
%%------------------------Part I -------------------------------------

%GIVEN DATA FOR DIFFERENT OPERATING TEMPERATURES
x = [7.0 8.3 9.6 10.9 12.2 13.5 14.8 16.1 17.4 12.7 20.0];                    % weight (kg)
y1 = [14.225 16.458 18.606 20.670 22.649 24.544 26.354 28.080 29.721 31.278 32.750];  % calibration data (21 degrees celcius)
y2 = [15.675 18.168 20.576 22.900 25.139 27.294  29.364 31.350 33.251 35.068 36.800];  % after ambient change (40 degrees celcius)

temperatureA = 21;
temperatureB = 40;

%line of best fit for calibration data and for ambient change data
line_of_bestfit_caliberation = 1.425.*x + 4.8839;
line_of_bestfit_ambientTemp = 1.625.*x +4.9339;

% calculating Linearity caliberation measurements
maximumDeviation = max(line_of_bestfit_caliberation - y1);
%maximum non linearity as a percentage of full scale deflection
nonLinearity = (maximumDeviation/(max(y1)-min(y1)))*100

zero_bias_caliberation = 4.8839 % zero bias at zero input
zero_bias_ambientTemp = 4.9339;
zero_bias_drift = (zero_bias_caliberation - zero_bias_ambientTemp)/(temperatureA -temperatureB)

sensitivity_caliberation = 1.425
sensitivity_ambientTemp = 1.625;
sensitivity_drift = (sensitivity_caliberation - sensitivity_ambientTemp)/(temperatureA -temperatureB)
figure
scatter (x,y1);
hold on
scatter (x,y2);


p = polyfit(x,y1,1);
f = polyval(p,x);
hold on
plot(x,f,'--r');


p = polyfit(x,y2,1);
f = polyval(p,x);
hold on
plot(x,f,'--b')
legend('caliberation','ambient change','line of best fit caliberation','line best fit ambient change');
title ('Measurement data captured')
xlabel('Mass  [kg]') ;
```

Figure 3: Matlab code for part I of the experiment.

Appendix C

```matlab

%% ----------------Part II----------------------------------------
tolerance = 0.05;
Rn = 1000:1000:10000;
R1 = 6000;
R2 = 8000;
R3 = 4000;
Vi = 9;
R1max = R1*(1+tolerance);
R2max = R2*(1+tolerance);
R3max = R3*(1+tolerance);
R1min = R1*(1-tolerance);
R2min = R2*(1-tolerance);
R3min = R3*(1-tolerance);

Vth_max = ((Vi*R3max)./(R3max+Rn)-Vi*(R2min/(R1max+R2min)));
Vth_min = ((Vi*R3min)./(R3min+Rn)-Vi*(R2max/(R1min+R2max)));
Vth_nominal= ((Vi*R3)./(R3+Rn)-Vi*(R2/(R1+R2)));
error = Vth_max - Vth_min;
errorBand = (max(error)-min(error))/(max(Vth_nominal) - min(Vth_nominal))*100

figure
plot(Rn,Vth_min,Rn,Vth_max,Rn,Vth_nominal,Rn,errorBand);
title ('Output volage ')
legend('Min','Max','Nominal','error band');
xlabel('Strength Gauge in [ohms]') ;
ylabel('Voltage [V]') ;
%%-----------------------Part III --------------------------------------

time_before_breakdown = [21.4,18.5,36.7,19.8,22.3,27.9,24.1,30.2,25,8.6];
time_to_repair = [0.4,0.7,2.0,0.1,0.6,3.5,0.5,0.2,1.3,0.8];
number_of_fails = 10;
number_of_repairs = 10;
number_of_failures_per_hour = number_of_fails/(sum(time_before_breakdown)*24);
MTBF = 1/number_of_failures_per_hour;
MTTR =(sum(time_to_repair))*24/number_of_repairs;
availability = MTBF/(MTBF+MTTR);
```

Figure 4: Matlab code for part II and III.

Appendix D

Figure 5: The value of resistor pairs that resuslt into maximum and minimum output voltage.

System resistors	Resistor value for minimum voltage (Ω)	Resistor value for maximum voltage (Ω)
R1	5700	6300
R2	4200	3800
R3	3800	4200
Rn	10000	1000