STUDY OF THE DEVELOPMENT OF INTELLIGENCE SENSING UTILIZING THERMOCOUPLE IN TRIBOTRONICS SYSTEM

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ABSTRACT

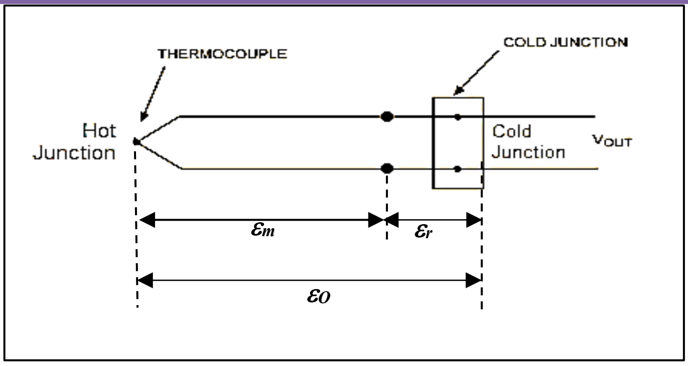
A huge demand in industrial monitoring system for more compact machinery without increasing the loss output emphasized the importance of tribotronics system or active tribology. The implementation of sensing element on pin-on-disc (POD) tribometer has improved significantly, especially in terms of real-time data acquisition technique in tribotronics system. The tribotronics system existed in Universiti Tenaga Nasional (UNITEN) provides with several sensing elements. This paper focused on the thermocouple as sensing device that is capable of measuring the lubricant oil temperature from POD tribometer. The result is saved in the data logger (picolog) and finally the data collection is interpreted and analyzed by using MATLAB software. The result provided the justification on the suitability of the electronic amplification for thermocouple output voltage.

Keywords: Pin-on-disc, tribology, tribometer, tribotronics.

INTRODUCTION

The term tribotroncs is a combination of word and integration system between tribology and electronic (Sergei Glavatskih & Eric Hoglund, 2007). Tribology is basically a system to study about friction, wear and lubrication of mechanical parts. Integration between electronic and tribology system enable real-time data transfer for data monitoring and analyzing purposes. Tribotronics system has been used as a smart tribology system in the industry in order to measure friction and wear of the mechanical parts. Wear and tear occur from friction produces by mechanical contact between two surfaces that are in motion. Friction will result in energy loss while wear material lead to shortened the service life of a machine. Lubricant employed in order to minimize the friction and wear of a machine. The purpose of tribotronics is to control these loss outputs (i.e. friction, wear, vibration, etc.), consequently improve performance, efficiency and reliability of the tribological units and finally the entire machinery system.
The fuzzy logic controller, which is one of the tribotronics components that help to calculate the amount of lubricant needed to be employed between two mechanical parts in order to reduce the friction between them. Useful data collected from various sensors such as load cell, speed encoder and temperature sensor enable the fuzzy logic to conduct calculation for an accurate amount of lubricant to be employed which contribute in minimizing the cost and material consumption. In the simplest way, the system will be more efficient and accurate as the number of data collected increases. **Figure 1** shows the overview of the tribotronics system in UNITEN. Thermoelectricity was discovered by the German physicist, Thomas Johann Seebeck in 1821 (Arman Molki, 2017). As observed by Seebeck, across the junction of two wires compose of different metals, there is a potential difference, depending on the metals used and the temperature of the junctions which known as the Seebeck effect.

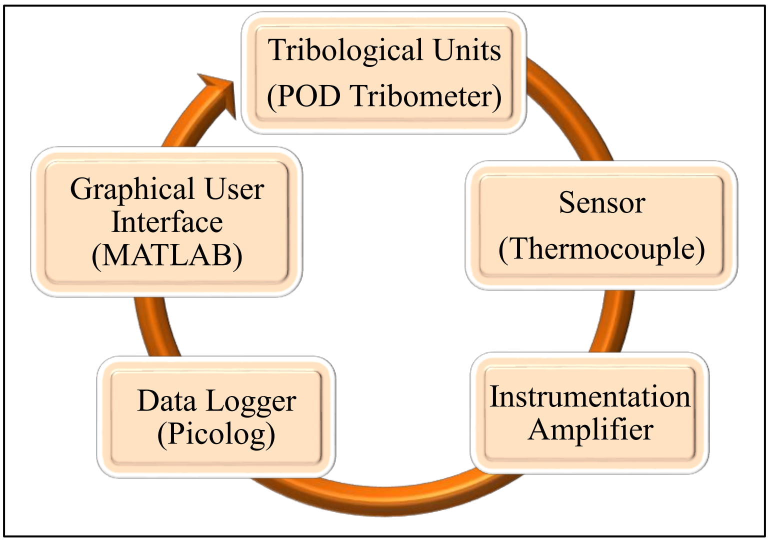
Figure 1: Overview of the tribotronics system (with thermocouple sensor) in UNITEN



MATERIALS AND METHODS

In general, thermocouple is a temperature sensor device used to measure the temperature variation at a specific surface. Thermocouple provide a flexible range of temperature based on their types. The utilization of thermocouple provide low cost investment and simple circuit construction compared to other temperature sensor. Thermocouple consist of two junctions known as measuring (hot) junction and reference (cold) junction as shown in **Figure 2**.

Figure 2: Basic construction of thermocouple



Where:
ε_O: Output voltage measured by instrument
ε_m: Equivalent voltage developed at the measurement junction
ε_r: Equivalent voltage developed at the reference junction

In order to calculate the thermocouple output voltage, the equation (1) is conducted.

$$\varepsilon_O = \varepsilon_m - \varepsilon_r \quad (1)$$

Let the reference junction is 0°C and temperature of 40°C is measured as the maximum of POD may be up to 40°C. The standard thermocouple can be referred (Emerson P. M., 2002). It is given the voltage developed at measuring junction for 40°C is 2.419 mV. Hence, the output voltage generated is 2.419 mV at 40°C temperature measured and 0°C reference junction. It is also important to consider the effect of environment during measurement of the temperature was conducted. Typically, the temperature is measured in an area where the room temperature (approximately 23°C) will continuously affect the temperature reading which result in inaccurate measurements. In order to avoid the temperature reading being affected by the room temperature, cold junction compensation is crucial to be implemented. The reference junction compensation is aiming to minimize the measurement error (David Potter, 1996). Basically, the simplest cold junction compensation may be made by using an ice bath because the water freezes at 0°C (Carr K. E., 2017). The 0°C help to eliminate room temperature affected to the reading and improve the accuracy. **Figure 3** shows an example of a construction of cold junction compensation circuit.

Figure 3: Example construction of cold junction compensation circuit

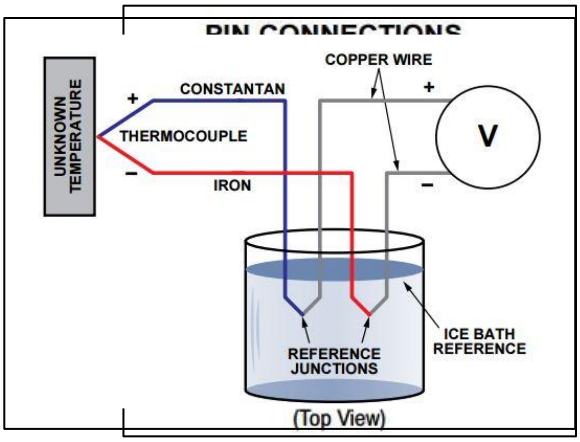
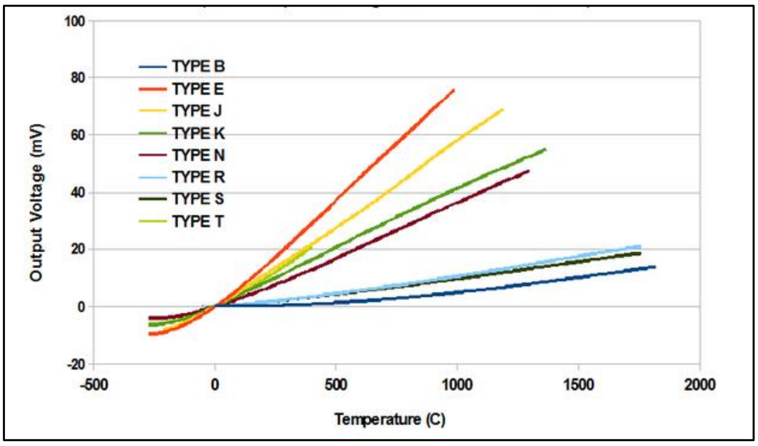


Table 1 shows different types of standard thermocouple where a selection of thermocouple may be made based upon application and temperature range needed and **Figure 4** shows the output voltage with respect to temperature for common thermocouple types. As previously mentioned, the selection of thermocouple is based on the required application. Throughout this project, the type E thermocouple is selected because of its ability to provide high sensitivity for every change in temperature.

Table 1: Standard thermocouple types

Type	Materials	Normal Range
J	Iron-constantan	-190°C to 760°C
T	Copper-constantan	-200°C to 371°C
K	Chromel-alumel	-190°C to 260°C
E	Chromel-constantan	-100°C to 1260°C
S	90% platinum – 10% rhadium-platinum	0°C to 1482°C
R	87% platinum – 13% rhodium-platinum	0°C to 1482°C

Figure 4: Output voltage versus temperature for common thermocouple types



RESULTS AND DISCUSSION

Instrumentation amplifier (**Figure 5**) is an electronic circuit which enables the normalization process of thermocouple output voltage (M. S. Bahrudin et al., 2013). As we noticed, the main disadvantage of thermocouple is because of the output voltage produced is relatively small. Signal amplification is needed in order to convert the temperature variation recorded by thermocouple into a readable value.

Figure 5: Standard Instrumentation amplifier circuit

The readable measurement provides to the Graphical User Interface (GUI) using MATLAB is able to plot an accurate graph for further analysis and monitoring purposes. The standard instrumentation amplifier as shown in **Figure 5** utilized 3 numbers of op-amp. In order to enable for large gain, range between 25 kΩ to 1 MΩ may be selected. Throughout this project, 25 kΩ is selected for all resistors except for the gain resistor, R_G. There are various types of operational amplifier offered to design the instrumentation amplifier circuit. Throughout this project, LM324 operational amplifier applied. **Figure 6** shows the overall construction circuit of LM324 operational amplifier and **Table 2** shows the LM324 Technical specification.

Figure 6: LM324 operational amplifier construction circuit

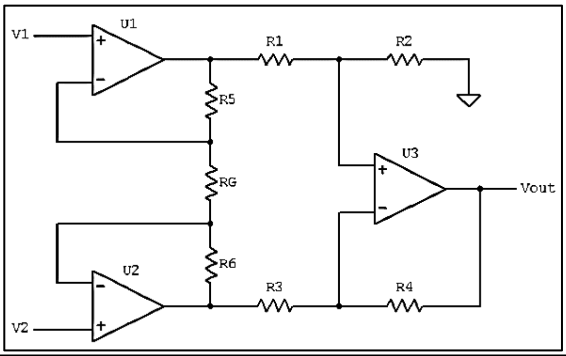


Table 2: LM324 Technical specification

Mounting type	Through hole
Number of channels per chip	4
Total pin	14
Typical single supply voltage	5 – 28 V
Typical dual supply voltage	±12 V, ±15 V, ±3 V, ±5 V, ±9 V
Minimum operating temperature	0°C
Maximum operating temperature	70°C
Dimensions	19.05 x 6.35 x 3.3 mm

The instrumentation amplifier transfer function is given as:

$$\mathbf{Vout} = (\mathbf{V1} - \mathbf{V2}).\frac{\mathbf{R1}}{\mathbf{R2}}.\left(\mathbf{1} + \frac{\mathbf{2.R5}}{\mathbf{RG}}\right) \qquad (\mathbf{2})$$

For: R5 = R6, R2 = R4 and R1 = R3

Simplified the transfer function by equalizing all the value of resistance except for gain resistance, R_G

R = R1 = R2 = R3 = R4 = R6 = R6 = 25 kΩ

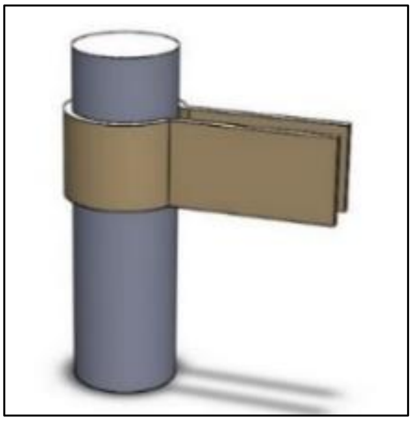
Hence, the transfer function will further reduced.

$$\mathbf{Vout} = (\mathbf{V1} - \mathbf{V2}).\left(\mathbf{1} + \frac{\mathbf{2.R5}}{\mathbf{RG}}\right) \qquad (\mathbf{3})$$

By using the classic instrumentation amplifier where 3 numbers of op-amp utilized, only one resistor (R_G) value needed to be determined. Simple calculation may be conducted in order to obtain the value of needed gain.

Table 3: Different value of gain resistor, R_G with respect to the desired gain

R_G (Ω)	Desired gain
None	1
50 k	2
12.5 k	5
5.556 k	10
2.632 k	20
1.02 k	50
505.1	100
251.3	200
100.2	500
50.05	1000
25.01	2000
10	5000
5.001	10000



$$\text{Gain} = \frac{\text{Vout}}{\text{Vin}} \qquad (4)$$

As recall, the value of input voltage at 40°C is approximately 2.419mV. Hence,

$$Gain = \frac{2.5V}{2.419\text{mV}}$$
$$Gain = 1033.48 \approx \mathbf{1000}$$

Thus, the gain of approximately 1000 selected based upon a simple calculation conducted. The value of gain resistor, R_G is selected from Table 3 which is 50.05 Ω.

From equation (3):

$$\boldsymbol{Vout} = (\boldsymbol{V1} - \boldsymbol{V2}).(\mathbf{1} + \frac{\mathbf{50}\boldsymbol{k}\Omega}{\boldsymbol{RG}})$$

Substitute the value of R_G

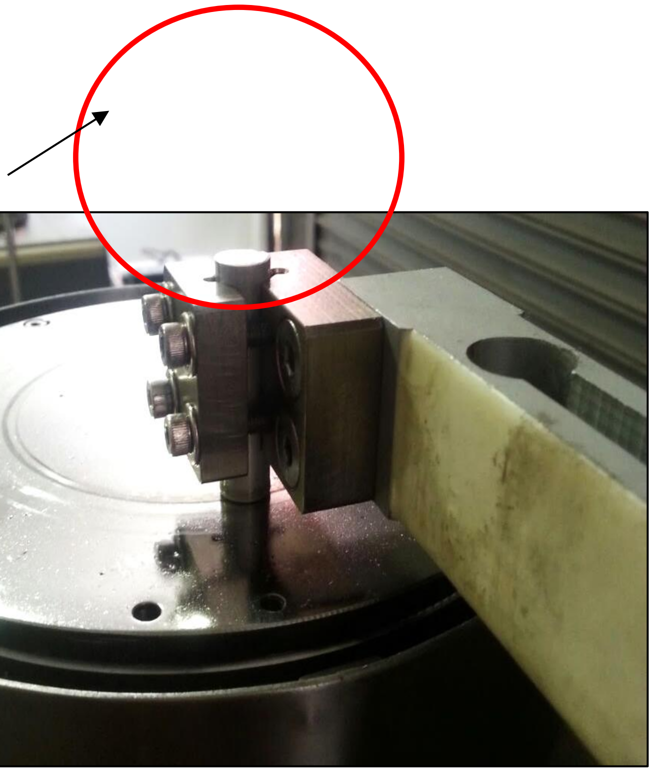
$$\boldsymbol{Vout} = (\mathbf{2.419}\ \boldsymbol{mV} - \mathbf{0}\boldsymbol{V}).(\mathbf{1} + \frac{\mathbf{50}\boldsymbol{k}\Omega}{\mathbf{50.05}\Omega})$$

Output voltage, $\boldsymbol{Vout} = \mathbf{2.419}\ \boldsymbol{V}$

Hence, by conducting theoretical output voltage calculation, it is proved that the value of the resistor and gain selection coincide with the required value of output voltage. This circuit design is relevant as the output voltage value is within the range of data logger which ranging from 0 V to 2.5 V. Next, measuring point is also an important part that need to be considered. The proper measurement procedure is needed in order to obtain an accurate reading of measurement. Hence, POD holder as shown in **Figure 7** was fabricated which applied and designed by using a conductive material in order to guarantee better heat absorption. The conductive material of POD holder allowed temperature variation along the surface. The measuring (hot) junction may be placed right onto the POD holder in order to measure the temperature variation of POD (**Figure 8**).

Figure 7: Designed POD holder

Figure 8: The location of the designed POD holder on the POD tribometer



Copper has been selected as a material for POD tribometer holder as it offered good heat conductivity and provide several advantages including strength, hardness, wear and shock, ductility, and resistance to corrosion. Besides, the copper material is widely used in industrial application which easier to be found. Another interesting part of copper is malleability. The malleability advantage that copper possessed enable the POD holder be developed according to the design where it can be bent and shaped without cracking, during hot or cold condition. Hence, copper is the suitable material for POD holder as it provide advantages mentioned and low cost. The data logger is an electronic device used to capture (record and monitor) automatically signal parameters over a certain period and used to transfer data obtained from thermocouple and instrumentation amplifier to the Graphical User Interface using MATLAB software. Throughout this project, picolog (1012 model) data logger was used to transfer output voltage value obtained from temperature measured. Moreover it has ability to gather different type of information from the measurement field to the Graphical User Interface through 12-channel port. **Table 4** shows some of the data logger specification for 1012 model (Picolog 1000 Specifications, 2017).

Table 4: Picolog (1012 model) data logger specifications

GENERAL	
PC connectivity	USB 2.0 full speed

Power requirements	Powered from USB port
Dimensions	45 mm x 100 mm x 140 mm (1.77” x 3.94” x 5.51”)
Weight	< 200 g
INPUTS	
Analog inputs	12 channels
Resolution	10 bits
Sampling rate	1 kS/s per channel in PicoLog, 100 kS/s using API
Voltage range	0 - 2.5 V
OUTPUTS	
Digital outputs	2 digital outputs
Output power for sensors	2.5 V @ 10 mA. Current-limited

CONCLUSION

As a conclusion, the project is successfully designed according to the specification needed. Type E thermocouple selected in order to observe and determine temperature variation for POD. Besides that, the type E thermocouple also have an ability of high sensitivity which is suitable to be used for low temperature application as it provide a reasonable and readable value of required output voltage. Next, the instrumentation amplifier has an ability to amplify the small output voltage value of thermocouple into a readable value without ignoring the specification of the input voltage of data logger. The 12-channel data logger (Picolog 1012) enable the information to be transferred directly to the Graphical User Interface (GUI) after the voltage amplification stage. By utilizing 12-channel port of data logger, different type of measurement is able to be processed and the balance amount of data logger port may be used for future improvement by adding any other sensor which helps to improve the performance of the system as well.

DISCUSSION

The purpose of introducing this concept is to define the guidelines for development of smart tribological systems in terms of intelligent sensing utilizing thermocouple for the next generation and to consolidate engineering efforts from the relevant fields for realization of this vision. At last but not least can be used to improve functional performance of industrial machinery.

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