Implementing Fast Fourier Transform (FFT) Method In Determining The Speed Of The Rotary Encoder For The Tribotronic System In The Pin-On-Disc Tribometer (PODT)

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(Received: 20 July 2015; published: 2 December 2015)

Abstract. A study has been conducted for utilizing Fast Fourier Transform (FFT) method in order to calculate the speed in revolutions per minute (rpm) of rotary encoder for the Tribotronic System. The value of pulses signal from rotary encoder are captured directly into the data logger and read by MATLAB inside PC. FFT method is used to convert this pulses signal into the frequency domain. The value of the speed will be taken into account when the speed frequency domain correspond to the highest amplitude. The results of these experimental values are compared to the industrial standard Pulse Meter in order to evaluate its performance in term of fluctuation and error in each speed region from 100 rpm to 800 rpm. It is revealed that the highest fluctuation difference of 0.21% and highest error difference of 0.0018% at 200 rpm and 100 rpm respectively. As a conclusion the FFT method proved competent for rpm measurement of the rotary encoder for the Tribotronic System

Keywords: Fast Fourier Transform (FFT), Tribotronic System, rotary encoder

I. INTRODUCTION

In tribology measurement, Pin-On-Disc Tribometer (PODT) is probably the most widely used apparatus [1]. PODT is basically a static pin hold by elastic arm. The pin under applied load is made into contact with rotating disc [2]. Tribology characteristic such as friction is measure between the pin and the disc. The disc is rotated on electric motor and at constant rate throughout the test [3, 4] but adjustable when on demand. This speed is required for calculating the sliding speed of the disc. For monitoring purpose, rotary encoder are used for providing a feedback on speed information in digital or analog signal [5].

The rotary encoder is mounted inside the PODT as shown in Fig. 1. The rotary encoder produce 600 pulses per-revolution [6]. This pulses are translated as square wave and captured by measurement device for speed calculation in RPM. Data logger will log this speed data along with other data (friction, wear and temperature) in order to be monitored via PC in real time manner. It is also important for those data to be recorded synchronously for further analysis.

Nonetheless, this technique add complexity on the monitoring system. Another hardware usually microcontroller and programmed software is required to translate the square wave into the RPM before logging into the data logger. This will also add into cost for having more hardware component into the system.

This paper has proposed a simple method by having the data logger itself capturing incoming pulses from the encoder and utilizing the FFT to simply transform the square wave data from the data logger into frequency domain, detecting the highest frequency hence calculating the RPM.

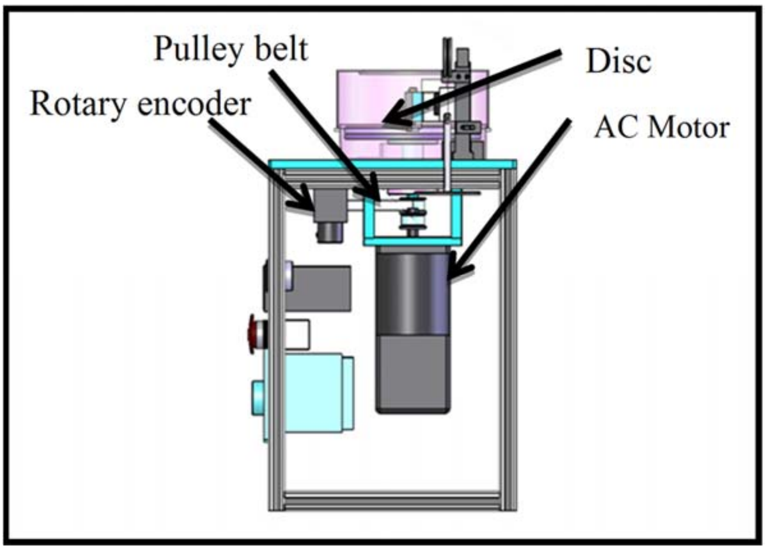

FIGURE 1. Rotary encoder mounted inside POD Tribometer

II. METHODOLOGY

A. Fast Fourier Transform

This method has been proposed by [7] and has its accuracy enhanced in [8] by interpolation technique and has been compared with other measurement method in [5]. For this paper, it will utilized on recording a preprogrammed static speed from the PODT as mentioned in introduction earlier. Captured square wave is processed via MATLAB using Fast Fourier Transform (FFT). FFT is a simple but powerful signal processing tool to analyze composition on signal into frequency domain and useful in for multi-frequency analysis [8].

FFT convert the speed data into frequency spectrums and the highest amplitude inside the spectrum is correspond to the motor speed and subsequently using that frequency to calculate the RPM. Using this method, no additional hardware need to use for measuring the RPM other than connecting the rotary encoder directly to the data logger.

B. Block and Circuit Diagram

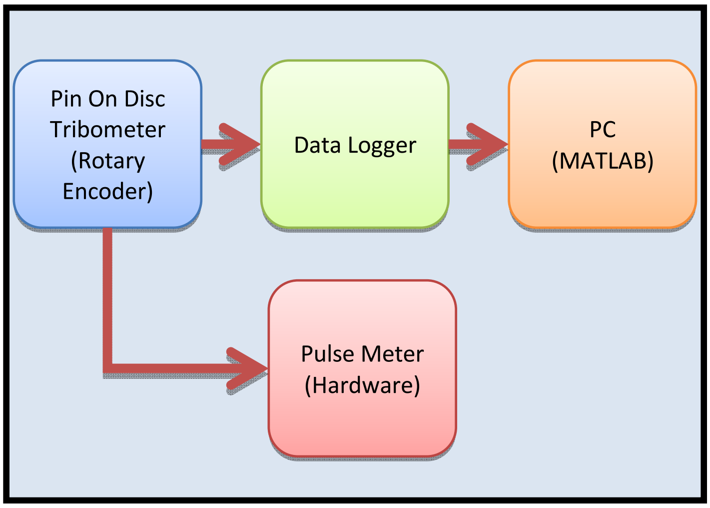

FIGURE 2. System Block Diagram

The block diagram in Fig. 2 shows the principal on implementing the system. The pulse meter is industrial standard hardware implemented on PODT for speed references when retrieving the samples. The circuit connection are shown in Fig. 3. The voltage divider used in the circuit is important to reduce higher output voltage from the encoder into acceptable value of maximum 2.5V as the encoder produce maximum voltage of 5V.

Each test sample is captured by data logger in analog mode as variation of voltage between 0 to 2.5V at rate of 25 kHz at 0.1 second interval and converted it into digital data. This made 2500 of samples data that form sequence of square wave on every interval. This samples represent constant speed region of 100, 200, 300, 400 500, 600, 700 and 800 RPM respectively and plotted inside MATLAB software. Example of the data captured by data logger are as shown in Fig.4.

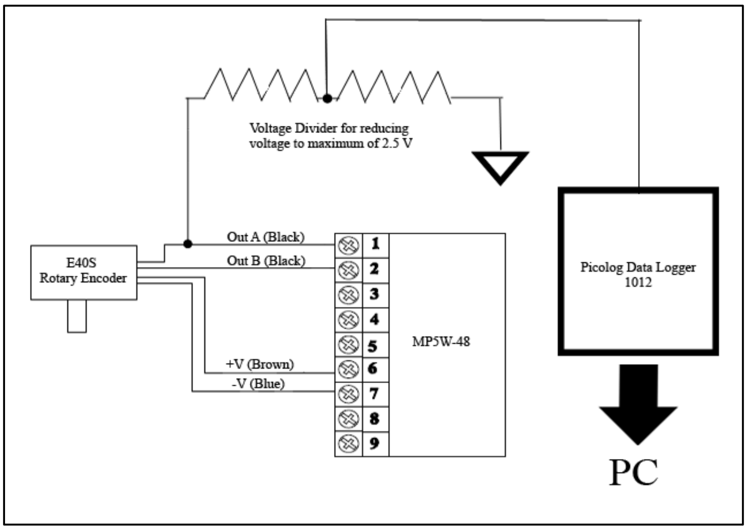

FIGURE 3. Circuit diagram of the connection between data logger and pulse meter from the encoder.

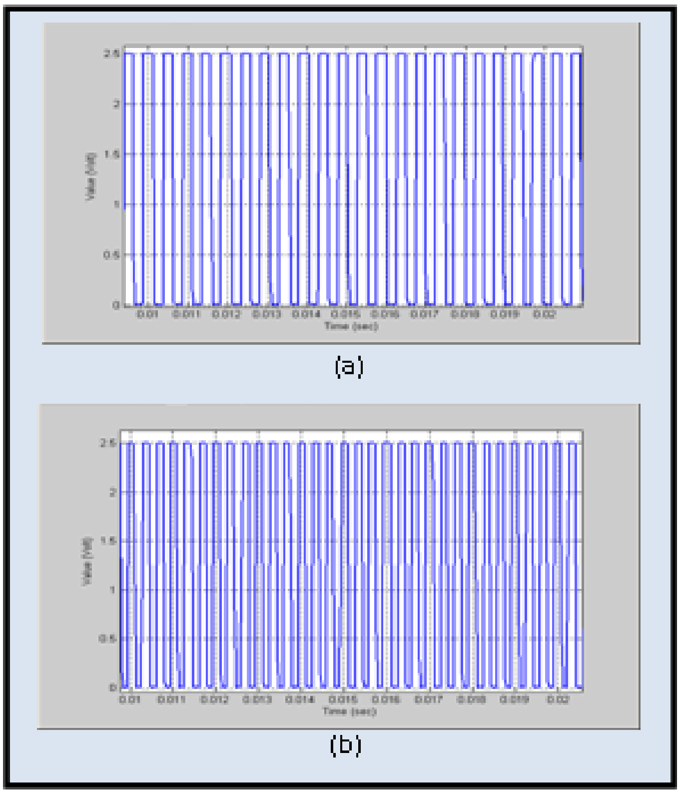

FIGURE 4. Example square wave sample captured by Data logger at (a) 200 RPM and (b) 300 RPM

Each of these samples are used to create a frequency spectrum using FFT. The algorithm starting from capturing the speed data until to find the frequency for correspond RPM as in Fig. 5.

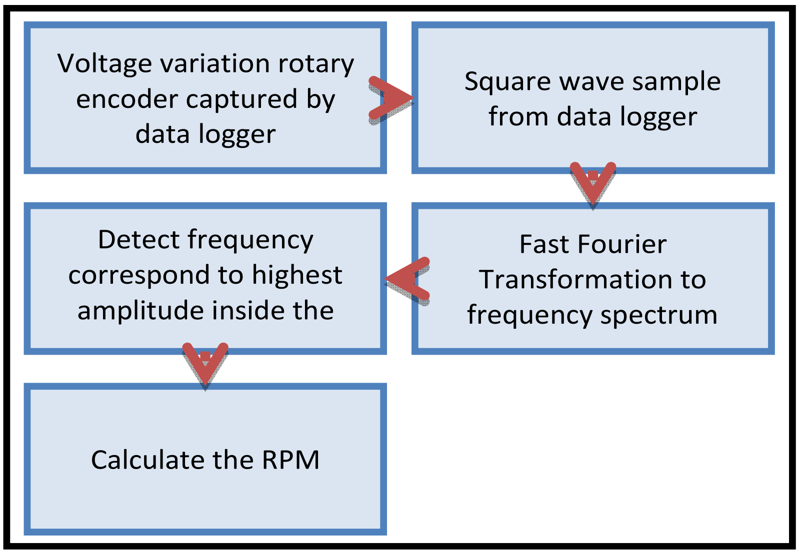

FIGURE 5. Algorithm for finding the RPM

The MATLAB calculated the square wave data using FFT and plotted in frequency spectrum for each samples. Fig. 6 showed example of frequency spectrum on 200 RPM and 300 RPM. Both samples are showing the spectrum in both continuous and discrete form. From Fig. 6, the MATLAB is programmed to detect the highest amplitude inside the spectrum frequency and confirm its frequency range. That frequency is then used to calculate RPM using Eq. (1) below [5, 9]

$$RPM = \frac{fmax.amplitude}{pulsesper-revproducebyrotaryencoder}.60 \quad (1)$$

Where the $f_{max.amplitude}$ is the frequency detected with highest amplitude by MATLAB. As mentioned in the introduction, the rotary encoder produce 600 pulses per-revolution.

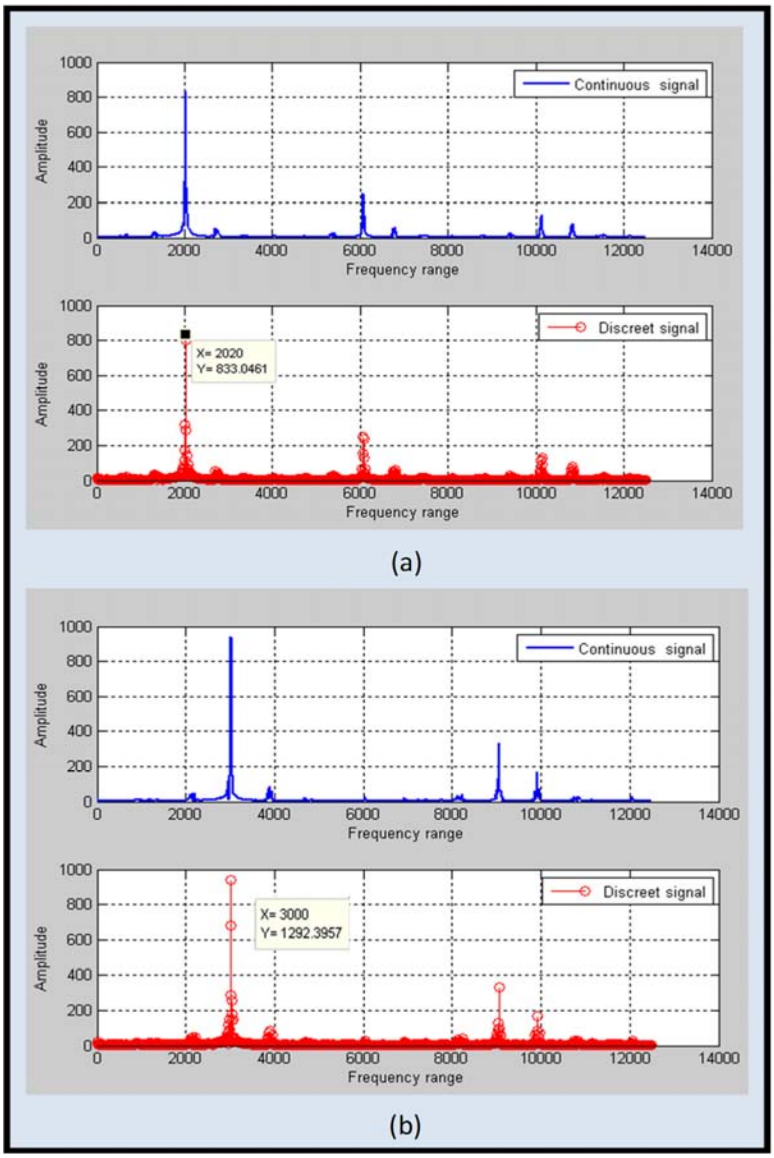

FIGURE 6. Frequency spectrum of sample for (a) 200 RPM and (b) 300 RPM

In order to validate the results, analysis of Fluctuation and Calculation error are used. The method is compared with industrial designed hardware MP5W-48 series Pulse Meter by Autonic to determine its accuracy [9]. The MP5W series Pulse Meter is specifically design to use with E40S, thus the calibration for the pulse meter is already done in the factory. Each speed region are taken simultaneously by both proposed method and hardware counter meter for 900 seconds (15 minutes) at 1 measurement every second. The Max and Min value are taken from the 900 seconds data while Mean value is the average of the data. The Real Value is the value taken from reading of the MP5W-48 meter display. To find the fluctuation, Eq. (2) below are used [5].

$$Fluctuation = \frac{|Max.Value - Min.Value|}{RealValue}\ \% \tag{2}$$

For Error calculation, Eq. (3) below are used [5].

$$Error = \frac{|MeanValue - RealValue|}{RealValue}\ \%$$
(3)

Error on Equation (3) is required to compare how much the RPM value taken using FFT method, deviated from the Real Value. This Error will be used to determine whether the FFT method can be utilized for RPM calculation.

III. RESULTS AND DISCUSSIONS

Table 1 shows the result of Fluctuation and Error in percent on each tested speed region. The results on both categories are compared side by side between pulse meter and FFT method. The speed are only sampled at maximum value of 800 RPM due to limitation of the single phase AC motor.

In Fluctuation, due to low torque at lower RPM, the motor is struggled to rotate the heavy stainless disc to target value. This resulting high fluctuation percentage at 100 RPM but gradually become stable as the RPM increased. Comparing both pulse meter and FFT method, the fluctuation show less significant differences to each other where the highest difference between the two are 0.21% at 200 RPM. The result in Table 1 is also shows and improvement from [5, 8] that recorded a fluctuation between 3.15% to 0.06%.

Looking at the Error, the error percentage is significantly low and nearing zero error. Drastically lower comparing to [5, 8] that estimated error of speed from 5.87% to 0.29%. The highest difference between the two are 0.000187% at 100 RPM.

From the result, it can be concluded that FFT method is capable to sample the speed with accuracy on par with industrial standard pulse meter hardware.

TABLE 1. Comparison between Pulse Meter and FFT Method on Fluctuation and Error

Speed	Fluctuation (%)		Error (%)	
	Pulse Meter	FFT Method	Pulse Meter	FFT Method
100 RPM	3.00	3.17	0.0019	0.0037
200 RPM	1.71	1.50	0.0001	0.0003
300 RPM	0.91	1.0	0.0004	0.0006
400 RPM	1.60	1.63	0.0018	0.0018
500 RPM	1.60	1.50	0.0009	0.0011
600 RPM	0.61	0.50	0.0003	0.0011
700 RPM	0.27	0.36	0.0006	0.0007
800 RPM	0.125	0.275	0.0002	0.0006

IV. CONCLUSIONS

This study shows that FFT can be used for calculating speed in RPM with minimal fluctuation and error as compared to pulse meter hardware. With this capabilities, the usage of extra hardware for counting the pulses and convert it into RPM before logged into data logger can be omitted by captured and logged the pulses itself and utilized the FFT method for RPM calculation.

Acknowledgements

The author would like to thank Ministry of Higher Education (MOHE) for funding this research (MOHE grant no: 20110105 FRGS) and UNITEN seed fund (grant no: JS10050449)

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