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Measurement of Mechanical Vibration Using Opto-Coupler Sensor and Pressure Sensor Based System

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Abstract: ***The mechanical vibration is the important physical quantity in industries that is characterized by two principal quantities as frequency and amplitude. The characterization setup at low frequency instrumentation for mechanical vibration measurement using opto-coupler based sensors is developed with the used of microcontroller ATMEGA 16. The realization of optocoupler sensor based system consists of light emitting diode (LED) and phototransistor 2N2555 arrangement . The LED is placed on the fixed-point end and phototransistor is placed on oscillating point. The frequency of mechanical vibration on the vertical direction gives variation of light intensity signal detected by phototransistor. The cantilever based mechanical vibration sensor is construct using stainless steel razor blade having a natural frequency of 2.98 Hz at the weight of 0.28X10^{-3} kg (mp) and 0.21X10^{-3} kg of cantilever weight (mk). The measured frequencies are ranged from 1 – 2.98 Hz. The output of microcontroller based system is designed with compatibility data and standard pattern with computer by serial interfacing feature of microcontroller ATmega 16 and MAX232 circuit.***

Keyword: mechanical vibration sensor, optic implemented cantilever, microcontroller, phototransistor.

1. Introduction

The vibration is the importance physical quantity in industries, characterized by two principal quantities; frequency and amplitude. The vibration transducer in different manners; piezoelectric system [1-3], magnetic sensor, optical system and cantilever system, MEMS, NEMS [4-10] are also available. The use of piezoelectric ceramics disks type sensors and actuators are used to suppress the vibration of the smart flexible clamped plate [1]. The vibration measurement using cantilever principle is fabricated by combining positive position feedback and proportional-derivative control. such optic based system is used in medical science for body vibration measurement based on light reflectance method [11].

Non-contact measurement techniques are of fundamental importance in vibration measurements in all measurement. In this area, Laser Doppler Vibrometry (LDV) has represented the most common choice. Since the probe has been industrially developed gives an interesting alternative, and flexibility related to the fact of being sound intensity probe. Several industrial applications are available and developed in both the field of noise and vibrations measurement . In the latter, in particular, it has become possible to use the micro-flown in the areas of experimental and operational modal analysis using the so-called Very Near Field (VNF) assumption. the region really close to a vibrating surface, the air particle velocity measured by the micro flown in that point where the probe is positioned give the velocity of the corresponding point on the surface.

The measuring accuracy of temperature and vibration measurement using the optic system is practically independent of the properties of the optic system [13].The accuracy of system in temperature measurement is 0.1 °C in the temperature range 0 to + 70°C and a 0.05 g/cm resolution is best for vibration measurements with a dynamic range of 35 dB has introduced [13,14]. The Micro-Electro-Mechanical Systems of a laser Doppler interferometer system for measuring motion of vibrating combs is developed with the improved feature [15]. Fiber optic based displacement sensor for the measurement of amplitude and frequency of vibration has been also developed and found satisfactory measuring unit [16]. In measuring of vibration amplitude, the system possess the sensitivity of 0.004878 V/mm over 0.6 to 4.1 mm range with in a frequency range of 35 to 300 Hz. Recently, the low vibration frequencies measurement by using the Michelson inter-aerometry system has been developed [17]. The use of razor blade for developing the vibration sensor combined with a commercial silicon nitride cantilever in carbon-nano-tube (CNT) probe investigation has been also developed for obtaining nano-meter scale resolution of friction measured by atomic force microscope [18].

In this research, certain demands as monitoring and system based analysis with common PC is employed with a low cost, flexible more accurate and high resolution system implement task is bring in as application module. The microcontroller based application in machine industry is a new research area, based on fundamental research [13] as well as on industrial automation [14, 15].

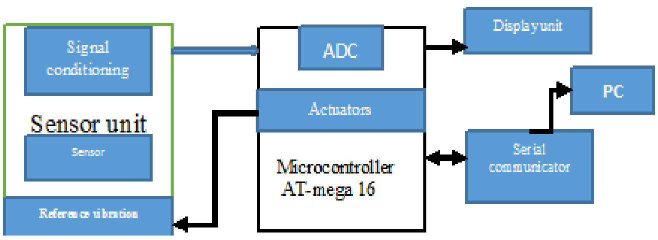


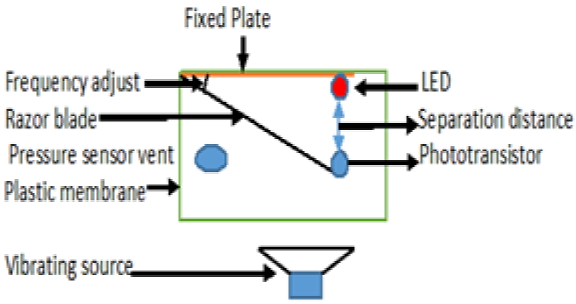
Figure 1: block diagram of system

We have developed the simple system for measurement of low frequency vibration by using razor based opto coupler sensors made up with the 2N2555 and BWP34 photo-transistor as application of cantilever principle based system. We use the light emitting diode (LED) as the light source in the system [19] and the simple phototransistor 2N2555 as light detection sensor. The cantilever principle has been realized by using stainless steel razor blade packed in flexible but pressure sustainable poleythin membrane. The system is fully equipped with the microcontroller base data processing with serial data acquisition and transmission system.

2. Methods

2.1. Design of Vibration Transducer System

The vibration transducer system with razor and cantilever based system with optical sensing is developed by placing LED as light source placed at fix point and phototransistor at cantilever tip fixed with blade. A cantilever is a one side beam supported as shown in Fig. 2(a), (b).



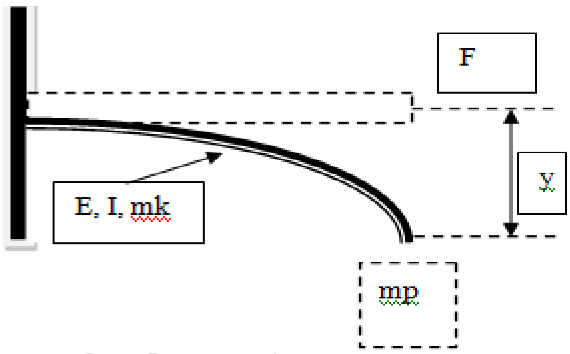
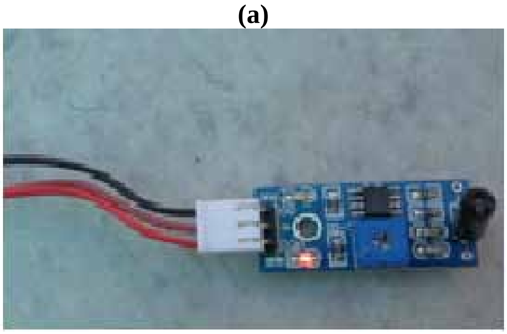


Figure 2: Design of (a) mechanical vibration (b) cantilever principle system.

The vibration transducer converts the physical vibration quantities to electric quantities. The output voltage signal produce by the vibration transducer system is very weak, and need to be amplify by signal conditioning circuit to bring the voltage within the range from 0 to5 Volt. The analog signal is converted to digital signal with inbuilt ADC of 10-Bit resolution available in ATmega-16 microcontroller and serially transferred to the pc using MAX-232circuit. In the signal conditioning circuit, the output voltage obtained by phototransistor sensor is very low rang from0.1–0.5Volt,this value is not adaptable to the ADC analog input channel .

(a)



(b)

Figure 3: (a) Design of Vibration Transducer System, (b) vibration sensor

The beam material used in cantilever with the shear stress with the stainless steel razor blade. These blades are having steel alloy with a minimum of 10.5% - 11% chromium content by mass. The cantilever possesses 0.273×10^{-3} kg of weight (*mk*). In order to minimize the external light noise, the casing has been fully painted in black color.

2.2. Hardware Design

Microcontrollers (MC) are designed for digitally controlled with analog input. With the use of such systems it is possible to control several physical process alonge with various electric and non-electric quantities. The microcontrollers are programme to perform distinct processing depending on the control condition of circuit. The optimal microcontroller configuration for vibration monitoring is designed with simple electronic components selection and cross verified with the digital vibration sensor module [16]. The basic idea in the design is with boundary condition that is maintained in this designed sensor is the moment of inertia of the blade and holding rod shear vale for vibration monitoring. In order to define all components of the micro configuration it is necessary to define functional requirements of the system and the conditions in which the system will be tested.

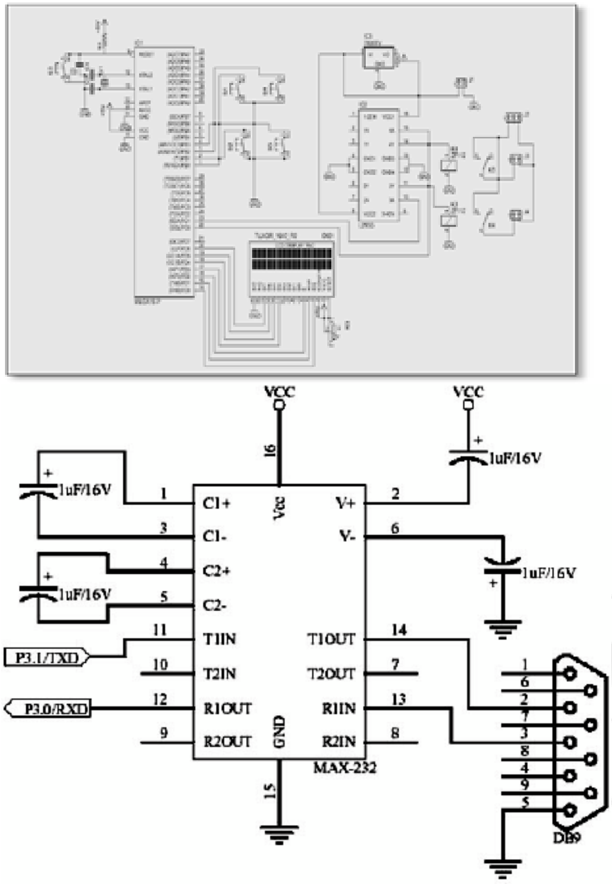


Figure 4: The (a) Microcontroller Design and (b) MAX232

2.3. Software Design

Software control system is programmed by C programming language as embedded system development tool for work flow with microcontroller AT-MEGA16. Here, we will describe control software according to comprehension of communication protocol and hardware access principles. The software communication module is controlled by register establishment, while USART controllers include RX Control Register, TX Control Register with Control Register. The software based initialization setting adopts the length of transmission character is 8-bit, Baud rate is 9600 bit, the circuit is free multi-machine protocol which can send, receive and interrupt enable [13]. Serial communication adopts interrupt mechanism; RXD and TXD also adopt interrupt mechanism. A microcontroller includes data acquisition system and control system programmed for the vibration measurement. The control system is to ensure data acquisition system works normally and give related instructions after analyzing and processing received data [13, 16, and 18].

3. Results and Discussion

3.1. Transducer Realization

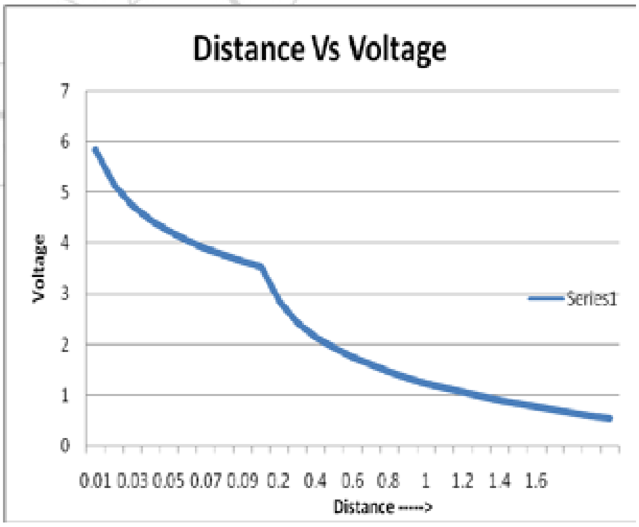
The design and analysis of vibration transducer shown in Fig. 2, has been realized as shown in Fig.3, the prototype consists of LED, phototransistor and cantilever arrangement. The casing of transducer as shown in Fig. 3 is placed on the loudspeaker for testing purpose [22]. The vibration transducer produces the voltage as distance changes between the LED and phototransistor. The LED serves as a light source and phototransistor placed on the cantilever tip of the blade. When the vibration transducer is installed on the mechanical vibration source, it will following the oscillation of the vibrations source. The oscillation magnitude of the cantilever vibration is proportional to the magnitude of the vibration source. The oscillation motion of the cantilever is calibrated with the distance variation between the LED and the phototransistor. The output voltage of phototransistor depends strongly on the amplitude of received light. The phototransistor respond to the LED light is given in table 1 with the distance. The signal of phototransistor has exponentially response to the distance variation of LED, that given by equation 1

$$y=0.257e^{-0.29x}, \qquad (1)$$

Where y is the signal output of phototransistor in Volt and x is the displacement of LED light.

Table 1: Voltage develop by phototransistor with displacement

Distance (mm)	*Voltage (V)*	*Natural frequency (Hz)*
0.01	5.844097	2.149245
0.02	5.150825	2.017742
0.03	4.745287	1.936683
0.1	3.541097	1.673001
0.2	2.847825	1.50032
0.8	1.461281	1.074717
0.9	1.343477	1.030487
1	1.238097	0.989247
1.1	1.14277	0.950401
1.8	0.650205	0.71689
1.9	0.596128	0.686431
2	0.544825	0.65623



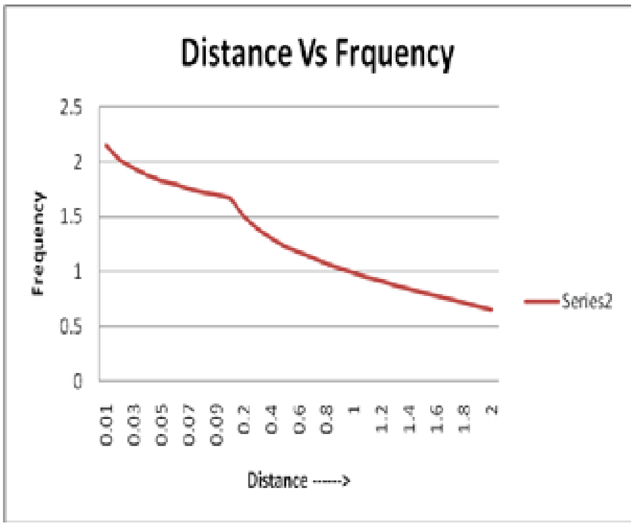


Figure 5: distance calibreted voltage and frequency

As the distance between LED and phototransistor changes, the output voltage of the transistor decreases. This is basic property to characterize the optics base device and also it places the limit of selection of white colored membrane wall with the accuracy point of sensor performance. The constraint of the membrane is solved using thick plastic black color glass. This distance variation between LED to the phototransistor gives the variation of light intensity values received by the phototransistor which gives voltage variation value. The more closely the LED to the phototransistor, the output voltage of the phototransistor increases. The maximum output voltage generated by phototransistor is 4.872 volts when there is no distance between the LED and phototransistor. The voltage output of phototransistor will be transferred serially to computer using ADC module available in ATmega-16 microcontroller[18] in association with Max232 circuits. The transferring process of analog signal to computer is controlled by microcontroller. The natural frequency of vibration transducer depends on its cantilever constant value as shown in Fig 5.

$$y = \frac{E * L * L * L}{3EI} \quad (2)$$

The value of cantilever constant

$$k=(3EI)/L^3 \quad (3)$$

The cantilever natural frequency is calculated using

$$f = i\frac{1}{2\pi}\sqrt{\frac{mp * g}{y(mp + \frac{mk}{4}}} \quad (4)$$

Where *mp* is the mass of ballast and *mk* is the cantilever mass, *y* is the deviation of the cantilever caused by placing the ballast on the end of cantilever, *F* is the force, *L* is the cantilever length, *E* is the Young constant of cantilever, *I* is inertia moment, and *k* is the spring constant.

3.2. Designed and Realized Software

The complete prototype design have two parts; the software embedded on microcontroller serves to control of hardware system and the interfacing software with the transducer as embedded nature as the acquisition systems to read from transducer and stored data with data processing in computer[19].

The software embedding on the microcontroller ATmega 16 realized on advance embedded "C" programming language mode by AVR Studio compiler, consists of several self-developed codes and data communication protocol for serial port of computer [19, 20]. In this prototype designing, the serial port used is in mode-1 with the baud rate9600 bps.

3.3. Measurement of Mechanical Vibration

The vibration measurement setup, we use the speaker (woofer) as vibration generating source actuated by the microcontroller with standard frequency generator. By changing the actuating frequency, the difference types of mechanical vibration are produce on speaker. At the 7Hz frequency the amplitude value of obtained signal decreases and gives the increasing of frequency value [11]. This condition indicates that the realized transducer is not able to respond the mechanical vibration with the frequency more than the natural frequency of transducer.

The calculation of frequency value according the signal, and the natural frequency value is 2.65 Hz, this obtained signal gives the frequency error value of 77.86%. This error value shows that the transducer will give the average results, if be operated on frequency below the natural frequency [11, 13, 16].

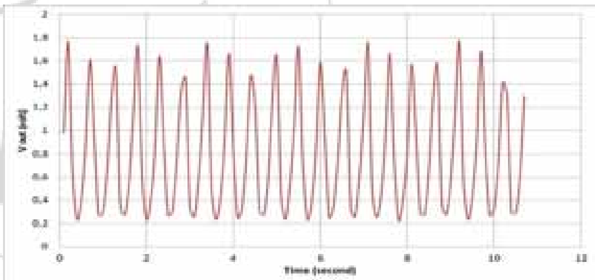


Figure 6: Theobtainedsignalfor7Hzofaudio generator frequency.

4. Conclusions

The new designed transducer with razor blade has the natural frequency is 2.18 Hz, this value gives the range of measurable mechanical vibration is 1–3Hz and with double folding structure it will till 6Hz.The resolution of realized transducer is 0.0041Hz . The utilization of microcontroller and the natural frequency value using speaker and audio generator is effectively found with the accuracy. The calculated frequency of obtained signals 1.90Hz for T1and1.97 Hz for T2.This frequency value agrees with the frequency source of audio generator signal, and the error value is 1.02% due to the microcontroller square clock pulse. By increasing the frequency value of audio generator, transducer can be modified by varying the characteristic of cantilever used.

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