



Establish Measurement System for Vibration Lab Unit Using Arduino

Haithem Elderrat¹, Nasseradeen Ashwear^{1*}, Omr Aweib¹ and Ali Elmahrouq¹

¹Mechanical Engineering Department, Faculty of Engineering, Misurata University, Misurata, Libya.

Authors' contributions

This work was carried out in collaboration among all authors. Authors HE and NA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HE and OA managed the analyses of the study. Authors NA and AE managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2020/V15i217143

Editor(s):

(1) Dr. Guang Yih Sheu, Chang-Jung Christian University, Taiwan.

Reviewers:

(1) Marcos Aurélio Ayres da Silva, Federal University of Piauí, Brazil.

(2) Odilon Linhares Carvalho Mendes, Instituto Tecnológico de Aeronáutica, Brazil.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/59516>

Received 24 May 2020

Accepted 31 July 2020

Published 07 August 2020

Original Research Article

ABSTRACT

As science and technology develop quickly, suitable measurement system is becoming more achievable. In dynamics of structures, measuring vibrations take a serious view during the process of design and construction to avoid resonance. The main objective of this study is to establish a vibration measurement system for a laboratory vibration unit by using a virtual instrumentation system. The Arduino microcontroller is used as the receiver of the electrical signals coming from the displacement sensor, which is connected to the vibration unit. The microcontroller then processes the electrical signals and send it to LabVIEW software on the computer for processing. The established measurement system is able to calculate the vibration of the moving body. Hence, the natural frequency of the system could be determined, and shock absorber for the unit could be designed. Results have been validated using calculated theoretical results of the unit. Thus, the unit is ready to conduct laboratory experiments on the concept of mechanical vibration.

Keywords: Mechanical vibrations; vibration measurements; structures dynamics.

*Corresponding author: Email: ashwear@mech.kth.se;

1. INTRODUCTION

A suitable measurement system is essential in the field of technology. It has an important effect for the engineering system, such as control systems in electrical plants, performance monitoring of machines, measurement of the roughness of vehicle roads, and monitoring nuclear plant [1-2]. There are a large number of previous studies in the metrology field and design measurement instrumentation, for instance; assessment of surface roughness using the Linear Variable Differential Transformer (LVDT) and an Arduino mega microcontroller as a receiver for data transmission to the computer was introduced [3]; Such system was developed an efficient and cost-effective approach to measuring surface roughness. Muhammad et al. [4] published a study on liquid level detection techniques. The study included the creation of a small range by LVDT, which is used in detecting water, petroleum and gasoline levels, through the sensitivity of the differential converter resulting from the linear displacement works with good precision. Joshi et al. [5] studied the measurement system in civil application such as the extensive use of the rail to measure dynamic displacement and detect vibrations in structures. Masi et al. [6] studied the effect of magnetic fields and they argue that fixed or variable magnetic fields could affect the performance of the measurement system.

In the automotive and dynamic systems, researchers paid significant attention to measure the vibrations of moving bodies on roughness surface [7]. Elderrat have used the compression load cells sensors and displacement transducer connected with MTS software and MTS Flex Test controller for continuous data acquisition to measuring the vibrating parameters in FFFfluid vibration isolators [8]; while Al-Zughaibi et al. [9] have used accelerometer sensor with MATLAB software as the measurement system to study the effects of bearing's body friction in diminishing or removing the fluctuation of the body for quarter car test rig in cooperated with suspension system units. Both measurement systems in these studies have a possibility to record the input displacement against the output force of the test rig. Subsequently, the displacement vs force diagram could be obtained for both static and dynamic load. They have achieved acceptable results in the experimental test.

Misurata University is concerned in the equipment of experimental labs, different

hardware equipment and some software programs are available in the university. Lab's vibration unit is one of the equipment. However, the measurement system of this unit is not available; such missing makes the unit useless. Therefore, this article aims to establish a measurement system for the vibration unit lab at the university by using an Arduino microcontroller and LabVIEW software. This paper is consisted of presenting the importance of measurement system with paying more attention to vibration measurement system by virtual instrumentation. Then, presenting establish measurement system for the lab vibration unit by using Arduino. Finally, the theoretical calculations and experimental results are presented and compared.

2. MEASUREMENT OF VIBRATION

Vibration means the state of an object moving repetitively back/forward, right/ left or up/down and is generally expressed by Frequency (Hz), Displacement (μm , mm), Velocity (mm/s, cm/s), and Acceleration (m/s^2 , g).

Measurement of vibration is an important topic in applications and equipment. An important reason is to avoid resonant conditions such as those that destroyed the Tacoma Narrows Bridge in 1940, three months after its construction. In addition, measurement of input and output vibrations of any system enables engineers to determine the model parameters (mass, stiffness, and damping) of a system, and with these parameters determine the natural frequency of the system. Vibration measurement is used not only when the problem occurs but also when the daily maintenance is performed. The production system is kept in operation by detecting the deterioration or possible failure of a part through adverse vibration patterns.

Measuring the condition of things was first performed by human sense, then simple devices such as rulers were used, but nowadays measuring the parameters of a machine need complex and huge applications and consists of different components. All measurement application can be divided into three main tasks; data acquisition, data processing, and data distribution [10]. These processes are shown in Fig. 1. The term 'data acquisition' is used for elements which obtain information or signals relating to the quantity of a parameter being measured. The term 'data processing' is used for elements that amplify or reduce data and then digitalize making it ready to be accepted by a

computer. 'Data distribution' is where the data is displayed, recorded or transmitted to some control system.

As with any modern science, instrumentation systems improved quickly during the last century. The development period had been divided into four phases [11]. The first period uses analog measurement devices. It is represented by pure analogue system devices, for example, oscilloscopes, which consist of power supply, sensors, translators, and screen displays. This system was completely closed, so they needed a manual setting. Data acquisition and processing devices are part of the second phase. In this phase, the measurement system was incorporated with a control system such as an array or Proportional–integral–derivative (PID) controller. The third phase is digital processing, where the measurement system becomes computer based and needed to digitalize the signal to convey to a computer. This stage also begins using interfaces to communicate between instruments and computers and includes the rapid development of measurement methods and tools, especially of those that are computer-based or assisted. The last phase is the distributed virtual instrumentation. It is the most

modern phase, where the hardware and software are integrated into the measurement system. A virtual instrument is defined as a layer of software and hardware added to a general-purpose computer that users can interact with the computer as though it were their own custom-designed traditional electronic instrument [11]. This phase is considered much convenience one in the structures dynamic systems and it is used in highly technical areas, such as biomedical [11]. Hence, such instrumentation is used in this study.

3. DESIGN OF THE MEASUREMENT INSTRUMENTATION

The lab vibration unit consists of a cantilever beam fixed at one end and a suspended with a spring at the other end. An exciter (vibrating force) is placed at the middle of the beam, as shown in Fig. 2-a. The unit has been designed to add shock absorbers and remove them as needed, as shown in Fig. 2-b. To carry out experimental dynamic investigations, it is important to measure the amplitudes of the vibrating beams and to establish virtual instrumentation for such unit.

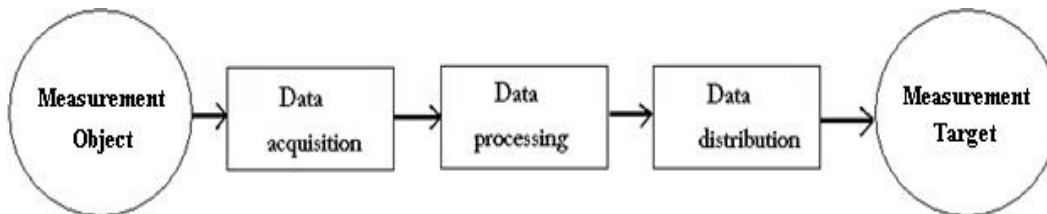


Fig. 1. Elements of the measurement system

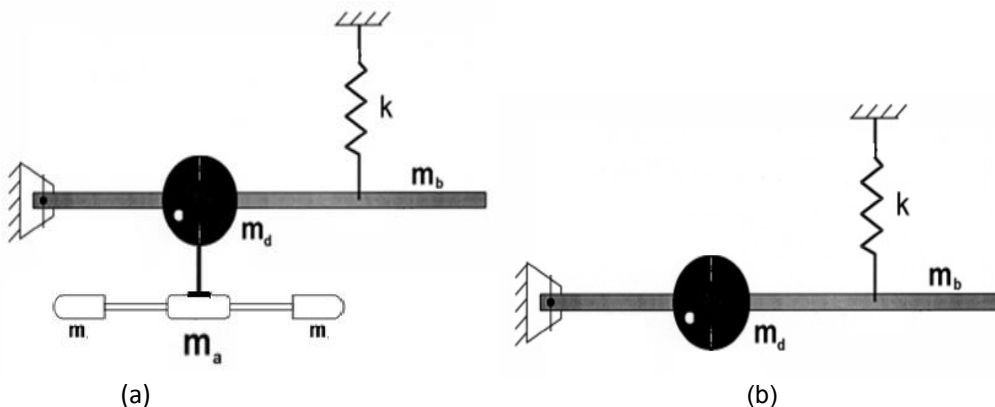


Fig. 2. Vibration unit lab: (a) Single beam, (b) Beam with shock absorber

The idea of the measurement system is to use the Linear Variable Differential Transformer (LVDT) sensor which is essentially a differential inductive sensor. The magnetic core moves through the energized windings, producing both a voltage and a phase. In other words, this sensor can sense the amplitude and convert it to electrical signal [12]. Then, the Arduino was used as a receiver for the data received by LVDT to be digitalized. After that, this data is sent to a computer to be processed by using the Arduino IDE program and viewed by using the LABVIEW program. Fig. 3 shows the network connecting the parts of the measurement system.

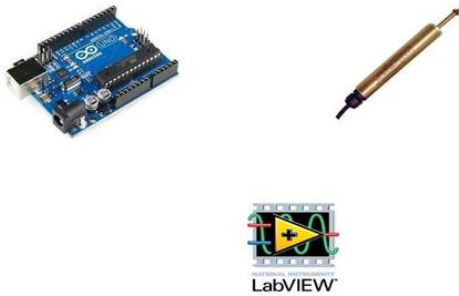


Fig. 3. Elements connection of the measurement system

After connecting the elements of the measurement system, the calibration process is an essential activity. Therefore, LVDT is calibrated to ensure that it sends signals with the same amount of the changes in displacement and has zero displacement (from stable position) at zero voltage. Fig. 4 shows the relationship between the output signal of LVDT and the changes of displacement. The third-order

mathematical equation, which describes the calibration curve, is also found. This equation used the data (the electrical signal) coming from the sensor.

Fig. 5 shows the code written on the Arduino IDE program for reading the signal of LVDT and displaying the results on the screen, taking into consideration the writing of the calibration equation to obtain reliable results. In addition, LABVIEW is used to display the measurement results. Hence, the program of LABVIEW is designed for results demonstration. The instrumentation system connected with the vibration unit lab is showing in Fig. 6.

4. THEORETICAL CALCULATIONS

By establishing the measurement system and connecting it with the vibration unit lab, it is important to validate its results. This unit aims to find the natural frequency of the system and to determine the mass added to a shock absorber that minimizes the amplitude of vibration beam experimentally. Therefore, it is vital to calculate these parameters theoretically to compare between the experimental and theoretical results.

To calculate the natural frequency of the unit that was previously shown in Fig. 2-a, it is important to find the equivalent mass and stiffness element of the system. The beam is made from steel, with young's modulus $E = 210 \text{ kN/mm}^2$ and has a width $b = 25 \text{ mm}$, height $h = 12 \text{ mm}$, and length $L = 838 \text{ mm}$. The stiffness of the cantilever beam is can be calculated as in [10]:

$$k_b = \frac{3EI}{L^3} = \frac{3 \cdot 210 \cdot 3600}{(838)^3} = 3.85 \text{ N/mm} \quad (1)$$

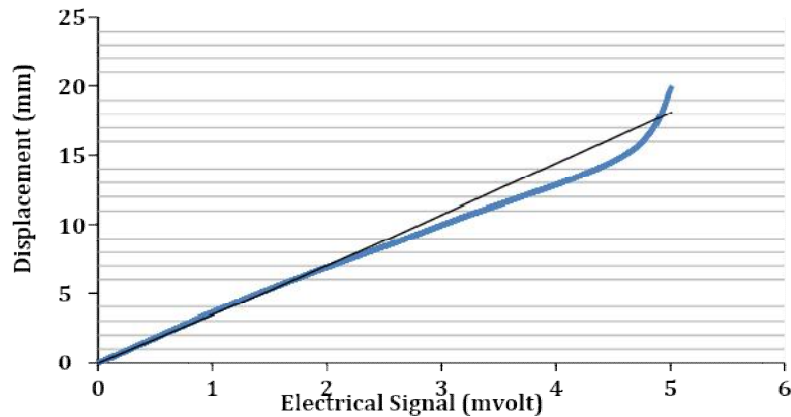


Fig. 4. Calibration of LVDT

```

AnalogReadSerial

Reads an analog input on pin 0, prints the result to the Serial Monitor.
Graphical representation is available using Serial Plotter (Tools > Serial Plotter).
Attach the center pin of a potentiometer to pin A0, and the outside pins to ground and 5V.

This example code is in the public domain.

http://www.arduino.cc/en/Tutorial/AnalogReadSerial
*/

// the setup routine runs once when you press reset:
void setup() {
  Serial.begin(9600);
}

void loop() {
  float x = analogRead(A0);
  float y;
  y=0.02486*x*x - 1.626*x + 5.7645*x - 0.1193;
  Serial.println(y);
  delay(1);
}
    
```

Fig. 5. Code of arduino IDE

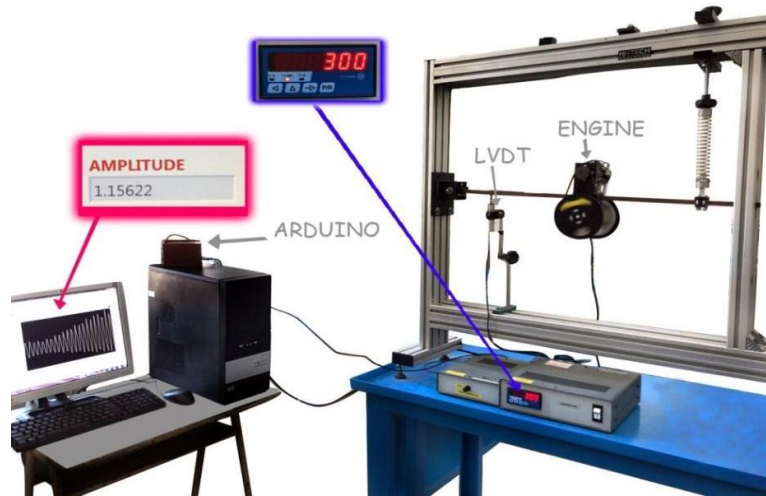


Fig. 6. Instrumentation system connected with the vibration unit lab

This beam is connected in parallel with the spring. Therefore, equivalent stiffness of all system is $k_{eq} = 6.56 \text{ N/mm}$. The mass of exciter (vibrator) is $m_d = 4.607 \text{ kg}$, while the mass of the beam is $m_b = 2.097 \text{ kg}$. So, the total equivalent mass at the middle system is $m_{eq} = 6.704 \text{ kg}$. Hence, the natural frequency of the system is:

$$\omega_n = \sqrt{\frac{k_{eq}}{m_{eq}}} = \sqrt{\frac{6563.99 \text{ N/m}}{7.202 \text{ kg}}} = 31.29 \text{ (rad/s)} = 298.8 \text{ rpm} \quad (2)$$

5. EXPERIMENTAL RESULTS

The working mechanism of the measurement system and its connection with the vibration device located in the laboratory, is showing in Fig. 6. The procedures of the test were as the following: the vibration force with frequency of 100 rpm was applied to the beam; then the amplitude was recorded. Subsequently, this procedure is repeated several times with increasing the frequency by 20 rpm at each time.

Thus, the relationship between frequency and amplitude is plotted. After that, the shock absorber was installed and repeating the previous procedures.

To find the natural frequency experimentally, Fig. 7 shows the relationship between the frequency and amplitude. The maximum amplitude of the beam occurs when the frequency of force is equal to the natural frequency of the beam [13]. Hence, from Fig. 8, the natural frequency of the system is 300 rpm, which is close to the theoretical results 298.8 rpm (Equation 2).

The test device has been designed to add shock absorbers if needed, to design the shock absorber properly as shown in Fig. 2-b. The natural frequency of the system with shock absorber should be equal or close to the natural frequency of the system without the shock absorber (Fig. 2-b,a).

The absorber has the following specification: $E = 210 \text{ kN/mm}^2$ and the width $b = 25 \text{ mm}$, the length $L = 590 \text{ mm}$ and height $h = 3.4 \text{ mm}$. The beam is fixed at the middle; hence it acts as dual cantilever. Therefore, the stiffness constant of single one is:

$$k_1 = \frac{3EI}{L^3} = \frac{3 \cdot 210 \cdot 81.8}{(590/2)^3} = 2.009 \text{ N/mm} \quad (3)$$

The total stiffness of the shock absorber is $k_{eq} = 2 \cdot [2.009 \text{ N/mm}] = 4.018 \text{ N/mm} =$

4018.83 N/m . The natural frequency from Fig. 7 $\omega_n = 298.8 \text{ RPM}$. Therefore, to find the attached mass to the shock absorber, it's should be:

$$m = \frac{k}{\omega_n^2} = \frac{4018.83 \text{ N/m}}{(29.88)^2 \text{ (rad/s)}} = 4.5 \text{ kg} \quad (4)$$

To check the calculated mass of the shock absorber in Equation 4, the minimum amplitude should have occurred at the natural frequency of the system when the shock absorber is installed. Fig. 8 shows the relationship between the frequency and amplitude of the system with shock absorber. From this figure, it is clear that the amplitude has minimum value in the frequency range between 280 and 320 rpm. Therefore, the mass 4.5kg is an appropriate mass for designing the correct shock absorber.

For validation, the experiment was repeated by using different types of beams, and the results of the experimental data matched with the theoretical calculations. Fig. 9 shows the result of the experimental procedure of one of these beams. The natural frequency of such beam is 185 rpm. This beam has the following specification: Young's modulus: $E = 210 \text{ kN/mm}^2$, Width $b = 12.5 \text{ mm}$, height $h = 6 \text{ mm}$, length $L = 1048 \text{ mm}$. Thus, its natural frequency from the theoretical calculations is 200 rpm. Therefore, such instrumentation has a trustworthy result and it could be used for further experiments.

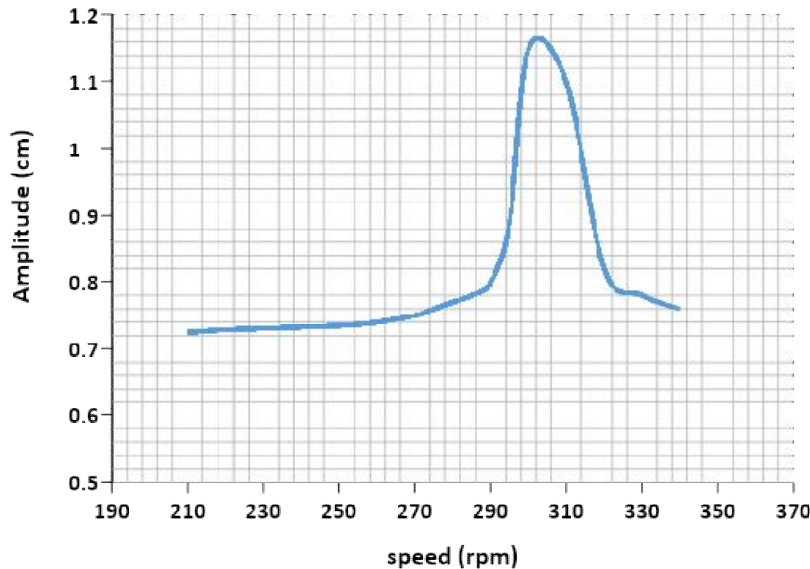


Fig. 7. Speed vs amplitude for single beam

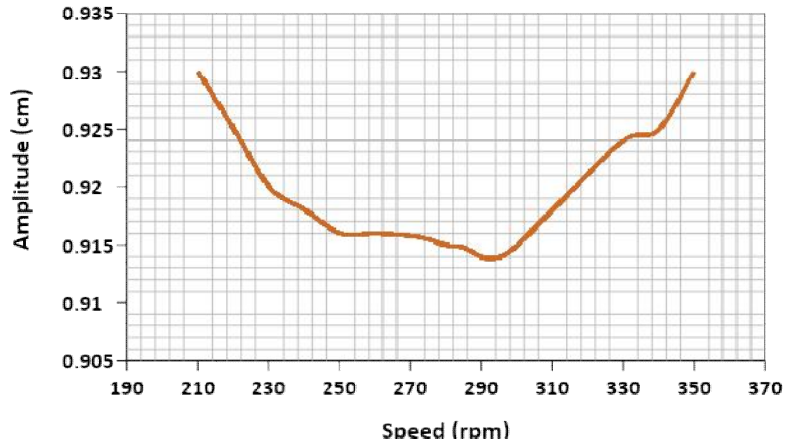


Fig. 8. Speed vs amplitude for a beam with shock absorber

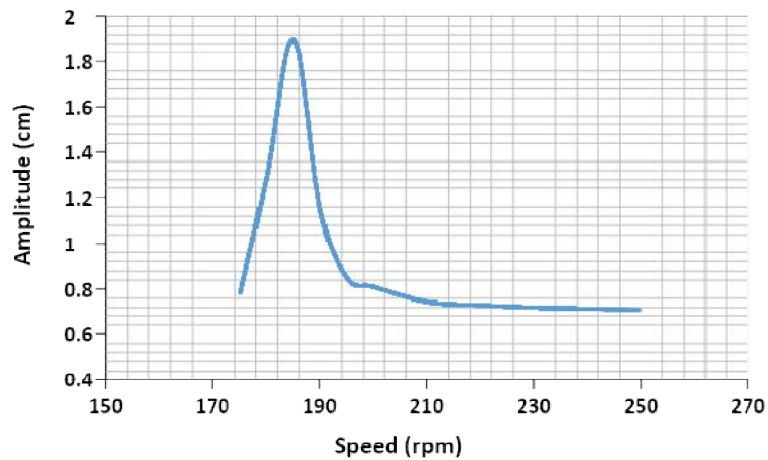


Fig. 9. The result of the new beam

6. CONCLUSION

The measurement system is an essential activity in the vibrating and structures dynamics to avoid failure of breakdown. In this study, the main objective was to establish a vibration measurement system for laboratory vibration unit. The vibration measurement was successively achieved by using virtual instrumentation system. Such system consists of: LVDT sensor, Arduino microcontroller, Arduino IDE program and LabVIEW software. The established measurement system is able to precisely calculate the amplitude of the vibrating beam, so the natural frequency of the system could be determined. Also shock absorber could

be designed. The recorded results from the established system have proved and validated with the calculated theoretical results. Thus, the unit is ready to conduct laboratory experiments on the concept of mechanical vibration.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Collacott R. Mechanical fault diagnosis and condition monitoring springer science & business media; 2012.

2. Childs PRN. Advances in temperature measurement Advances in heat transfer, Elsevier. 2003;36:111-81.
3. Sanjida N, Rokunuzzaman Md, Samarjith B. Assessment of surface roughness using LVDT Int. Conf. on mechanical, industrial and materials eng. 2017;391:1-6.
4. Muhammad UK, Umar S. Sensitivity determination of Linear variable differential transducer (LVDT) in fluid level detection techniques. International Journal of Modern Engineering Sciences, 2013;2(2): 73-83.
5. Joshi S, Harle SM. Linear variable differential transducer (lvdt) & its applications in civil engineering. International Journal of Transportation Engineering and Technology, 2017;3(4): 62-66.
6. Masi A, Danisi A, Losito R, Martino M, Spiezia G. Study of magnetic interference on an LVDT: FEM modeling and experimental measurements. Journal of Sensors. 2011;9.
7. Xu YL, Guo WH, Effects of bridge motion and crosswind on ride comfort of road vehicles. Journal of Wind Engineering and Industrial Aerodynamics, 2004;92(7-8): 641-62.
8. Elderrat Haithem. Study of a novel material solution for vibration isolation. PhD thesis, Cardiff University; 2016.
9. Alzughairi A, Xue Y, Grosvenor R. A new insight into modelling passive suspension real test rig system with consideration of nonlinear friction forces Proceedings of the Institution of Mechanical Engineers, Part D. Journal of Automobile Engineering, 2018;09544070-18764942.
10. Bolton W. instrumentation and control systems (newnes) elsevier; 2015.
11. Sumathi S, Surekha P, LabVIEW Based advanced instrumentation system. Springer, Berlin. 2007;723.
12. Boyes W. ed. Instrumentation reference book (Butterworth-Heinemann); 2009.
13. Rao SS, Yap FF, mechanical vibrations pearson education, inc. Publishing as Prentice Hall, USA. 2011:4.

© 2020 Elderrat et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
<http://www.sdiarticle4.com/review-history/59516>