

Resonance Frequency Detection Using Accelerometer of a Test Bridge

Ali Akbar Shah¹, Bhawani Shankar Chowdhry¹, Anjum Khalique Bhatti²

¹ Mehran University of Engineering and Technology, Jamshoro, Pakistan

² SZABIST Hyderabad, Pakistan

Abstract: This research proposes a device that can be used for detecting whether or not the bridge has reached its resonance frequency. For this, a prototype test bridge had been used and the forced vibration had been created by using excitation motor. The forced vibration is measured in terms of frequency response using accelerometer and the data is processed into Arduino UNO microcontroller, which with the help of condition statement detects the resonance frequency and turns on LED light as an indicator. This device has applications in smart bridges that are the part of smart cities.

Keywords: Resonance frequency, prototype test bridge, forced vibration, excitation motor, frequency response, accelerometer, smart bridges, smart cities

I. INTRODUCTION

The bridges are an essential part of transportation therefore long span bridges like Chaotianmen bridge (China) and Akashi Kaikyo bridge (Japan) are constructed for the ease of transportation [1][2]. While these bridges that are already in service are prone to collapse due to the lack of structural health monitoring because over the years these structures had undergone through various weather conditions, natural disasters and accidents [3][4]. Structural health monitoring in the past of the structures had been done using modal testing [5][6][7][8][9], finite element analysis [10][11], AI [12], DSP[13], etc. In all these, the most fundamental part of knowing whether the bridge has reached its resonance frequency or not lies with the frequency analysis.

Accelerometer is used in order to measure frequency response of the structure usually applying forced vibration because of its robust results and easy usage [14][15]. In order to measure, the frequency response of the prototype test bridge structure, forced vibrations are produced using excitation motor because the forced vibration in the recent years had produced successful results in analyzing the structural damage [16][17][18].

The resonance frequency is used in order to analyze whether or not the bridge had reach its maximum amplitude of excitation frequency before getting destroyed. The excitation frequency in this research is created using forced vibration and when this excitation frequency reaches the natural frequency of the structure then resonance frequency is formed. The resonance frequency is sufficient enough for destroying any structure. Therefore, in order to avoid this, this research proposes a resonance frequency detector so that the resonance frequency could be avoided.

II. MATHEMATICAL REPRESENTATION

The mathematical representation in terms of frequency response can be represented in the equation below:

$$G_{yy}(j\omega) = \dot{H}(j\omega)G_{xx}(j\omega)H(j\omega)^T \quad (1)$$

Where, the Power Spectral Density of input and output is $[G_{yy}(j\omega) \text{ and } G_{xx}(j\omega)]$ in terms of the frequency response $H(j\omega)$.

III. METHODOLOGY

The methodology of the proposed research comprises of the following steps:

A) CONSTRUCTION OF TEST BRIDGE SYSTEM

A prototype test bridge system is created in order to analyze its frequency response when it reaches its resonance frequency. The test bridge is of 0.8m length, 15cm width, 2mm thickness and is constructed using stainless steel. In order to simplify our analysis, the test bridge is divided into four equal sections each of 0.2m in length and are named as Mode 1, Mode 2, Mode 3 and Mode 4. The frequency response of each of the mode is analyzed by placing an accelerometer ADXL320 at the middle of each and every mode.



Fig.1. Prototype Test Bridge

B) FORCED VIBRATION

Forced vibration is produced on the test bridge in order to analyze its frequency response. The forced vibration is produced by attaching an uneven mass of 20g on the rotor of the 5V DC motor.



Fig.2. Excitation Motor

Various speeds of the rotor of the excitation motor were measured using photo-tachometer.



Fig.3. Measuring RPM of Excitation Motor

C) RESONANCE FREQUENCY

In order to analyze the resonance frequency, the forced vibration was applied on the test bridge using excitation motor under various voltage ratings and the frequency response was measured using accelerometer (ADXL320) that is attached to each and every mode. Thus the readings calculated were:

Voltage (V)	Speed (RPM)	Frequency (Hz)
4	812	284
5	1109	801
6	1548	796
7	1754	772

According to the mentioned above table the highest frequency was noted to be 801 Hz, which was produced by the help of excitation motor rotating at an rpm of 1109.

D) RESONANCE FREQUENCY DETECTOR

This device is built by attaching accelerometers that are embedded on each of the four modes to the analog pins of the Arduino UNO that are connected to the OR logical operator and then if condition statement is been used. Such that if any of the Mode surpasses 800 Hz of frequency response then the red LED light attached to the pin 13 of the Arduino UNO.

The functionality of the OR logical gate included that, if any of the Mode is high (Surpasses 800 Hz) then LED 13 will turn on otherwise it will remain off.

IV. RESULTS AND CONCLUSION

The excitation motor was placed on each of the four modes and then was supplied with the power of 5V. Whenever any of the modes reached 800Hz, LED attached to the digital pin 13 turned on. Thus validating, the application of this device.

Hence, this device can be vital part of the construction of the smart bridges that are the essential part of the smart cities for the detection of resonance frequency so that any catastrophic event could be avoided.

V. ACKNOWLEDGEMENTS

We thank our supervisor Dr. Bhawani Shankar Chowdhry for the support throughout the experiments and the support of friends and family in the commissioning of this work.

REFERENCES

- [1] M. CHAN, W. K. POON, Y. W. LEUNG, D. Sai Ho CHAN, V. PREMAUD, and Y. RIALLAND, "Challenges in Hong Kong–Zhuhai–Macao Bridge (Hzmb) Hong Kong Link Road Project," in *IABSE Symposium Report*, 2016, vol. 106, no. 4, pp. 797–804.
- [2] J. Liu, X. Li, Z. Wang, and Y. Zhang, "Modelling and Experimental Study on Active Energy-Regenerative Suspension Structure with Variable Universe Fuzzy PD Control," *Shock Vib.*, vol. 2016, 2016.
- [3] H. Sousa, B. J. A. Costa, A. A. Henriques, J. Bento, and J. A. Figueiras, "Assessment of traffic load events and structural effects on road bridges based on strain measurements," *J. Civ. Eng. Manag.*, vol. 22, no. 4, pp. 457–469, 2016.
- [4] H. Sousa, F. Cavadas, A. Henriques, J. Figueiras, and J. Bento, "Bridge deflection evaluation using strain and rotation measurements," *Smart Struct. Syst.*, vol. 11, no. 4, pp. 365–386, 2013.
- [5] S. W. Doebling, C. R. Farrar, and M. B. Prime, "A summary review of vibration-based damage identification methods," *Shock Vib. Dig.*, vol. 30, no. 2, pp. 91–105, 1998.
- [6] J. J. Moughty and J. R. Casas, "Vibration based damage detection techniques for small to medium span bridges: A review and case study," in *Proceedings of the 8th European Workshop on Structural Health Monitoring (EWSHM 2016), Bilbao, Spain*, 2016, pp. 5–8.
- [7] S. Das, P. Saha, and S. K. Patro, "Vibration-based damage detection techniques used for health monitoring of structures: a review," *J. Civ. Struct. Heal. Monit.*, vol. 6, no. 3, pp. 477–507, 2016.
- [8] A. Cabboi, F. Magalhães, C. Gentile, and Á. Cunha, "Automated modal identification and tracking: Application to an iron arch bridge," *Struct. Control Heal. Monit.*, vol. 24, no. 1, 2017.
- [9] V. Zabel, F. Magalhães, and C. Bucher, "The influence of parameter choice in operational modal analysis: a case study," in *Topics in Modal Analysis & Testing, Volume 10*, Springer, 2016, pp. 179–190.
- [10] L. K. L. A. W. Tutorial, "Structural & Thermal Analysis Using the ANSYS Workbench Release 13," *Enviroment. Schroff Dev. Corp.*, 2011.
- [11] M. Batista, "On the stress concentration around a hole in an infinite plate subject to a uniform load at infinity," *Int. J. Mech. Sci.*, vol. 53, no. 4, pp. 254–261, 2011.
- [12] A. K. Yadav and P. Gaur, "AI-based adaptive control and design of autopilot system for nonlinear UAV," *Sadhana*, vol. 39, no. 4, pp. 765–783, 2014.
- [13] Z.-S. Chen, C. Zhang, X. Wang, and C.-M. Ma, "Wind tunnel measurements for flutter of a long-afterbody bridge deck," *Sensors*, vol. 17, no. 2, p. 335, 2017.
- [14] A. Santos, E. Figueiredo, and J. Costa, "Clustering studies for damage detection in bridges: A comparison study," *Struct. Heal. Monit.* 2015, 2015.
- [15] R. C. Sharma, R. Tateishi, K. Hara, H. T. Nguyen, S. Gharechelou, and L. V. Nguyen, "Earthquake damage visualization (edv) technique for the rapid detection of earthquake-induced damages using sar data," *Sensors*, vol. 17, no. 2, p. 235, 2017.
- [16] M. Chang and S. N. Pakzad, "Modified natural excitation technique for stochastic modal identification," *J. Struct. Eng.*, vol. 139, no. 10, pp. 1753–1762, 2012.
- [17] J. P. Lynch, C. R. Farrar, and J. E. Michaels, "Structural health monitoring: technological advances to practical implementations [scanning the issue]," *Proc. IEEE*, vol. 104, no. 8, pp. 1508–1512, 2016.
- [18] Y. Ikeda, "Verification of system identification utilizing shaking table tests of a full- scale 4- story steel building," *Earthq. Eng. Struct. Dyn.*, vol. 45, no. 4, pp. 543–562, 2016.