# A PROPOSED METHOD TO FIND EXCITER'S MAXIMUM ACCELERATION MAGNITUDE ON VIBRATION METER CALIBRATION SYSTEM

## *METODE YANG DIUSULKAN UNTUK MENGETAHUI PERCEPATAN GETARAN MAKSIMUM EXCITER PADA SISTEM KALIBRASI VIBRATION METER*

**Ninuk Ragil Prasasti, Denny Hermawanto**
Center for Research and Human Resources Development, National Standardization Agency of Indonesia
PUSPIPTEK area, Building 420, Setu, South Tangerang, Banten, Indonesia, 15314
*e-mail: ninuk@bsn.go.id*

**ABSTRACT**

National Measurement Standards-National Standardization Agency of Indonesia (SNSU-BSN) has implemented calibration method for vibration meters according to ISO 16063-21:2003. In this calibration system, an electrical signal at a particular frequency and magnitude is generated by the signal generator. Then it is amplified before converted into a mechanical vibration by the exciter. A vibration acceleration produced by the exciter is measured by the reference accelerometer as well as the vibration meter under test simultaneously. However, the maximum acceleration generated in the calibration system is affected and limited by several factors such as a total mass load of accelerometer, data acquisition system, displacement and velocity limits of an exciter. This paper presents the analysis of maximum acceleration produced by the exciter in the vibration meter calibration system considering the effect of those factors within a frequency range from 10 Hz to 5 kHz.

**Keywords**: exciter, accelerometer, calibration, vibration meter.

***ABSTRAK***

*Standar Nasional Satuan Ukuran-Badan Standardisasi Nasional (SNSU-BSN) telah mengimplementasikan metode kalibrasi untuk vibration meter sesuai dengan ISO 16063-21: 2003. Pada sistem kalibrasi tersebut, sebuah sinyal listrik pada frekuensi dan besaran tertentu dibangkitkan oleh sebuah generator sinyal. Kemudian sinyal tersebut dikuatkan sebelum dikonversi menjadi sebuah getaran mekanik oleh exciter. Percepatan getaran yang dihasilkan oleh exciter diukur oleh reference accelerometer dan alat ukur getaran yang dikalibrasi secara simultan. Akan tetapi, percepatan getaran maksimum yang dihasilkan pada sistem kalibrasi alat ukur getaran dipengaruhi oleh beberapa faktor seperti total massa beban accelerometer, sistem akuisisi data, batas persimpangan getaran dan kecepatan getaran dari exciter. Tulisan ini menampilkan analisis percepatan getaran maksimum yang dihasilkan oleh exciter pada*

*sistem kalibrasi alat ukur getaran dengan mempertimbangkan pengaruh dari faktor tersebut di atas pada rentang frekuensi mulai dari 10 Hz sampai dengan 5 kHz.*
***Kata kunci**: exciter, accelerometer, kalibrasi, pengukur getaran.*

## 1. INTRODUCTION

Vibration analysis is used by industries for many purposes, especially machine health monitoring. Information obtained from this activity can be used to detect problems in the machine much earlier to prevent more serious effect that may occur in the future (Bengherbia, et al, 2017; Xiao, et al, 2017). Unexpected failures of the machine in the process will affect whole production loss. Furthermore, the production loss may result in economic losses (Shen, et al, 2013). In 2015, a tea company lost around USD 70,000 in term of production loss due to the lack of machine maintenance (Mathew & Mathew, 2015). In Indonesia, influence of the cost of machine maintenance to operating profit was around 60% to 80% (Kusuma, 2015; Sukendra, 2009). However, preventive maintenance incorporating vibration analysis might avoid the consequences of such problems (Nahas, 2017; Várkonyi-Kóczy, et al, 2012). Instrument used for vibration analysis is vibration meters having data logger capability and some of them having spectrum analysis feature. A transducer used by vibration meters to convert mechanical acceleration to electrical signal is an accelerometer. It is connected to a charge amplifier to make it works and yields output voltage for further processes. Since the vibration meters can be used for many different applications then the accelerometer may have different characteristics to suit specific application. For general purposes, the accelerometer has sensitivity in the range of 1 mV to 10 mV or pC per m/s² and weighs about 10 g to 50 g. Meanwhile for high level or high frequency measurements, the sensitivity and weight are in the range of 0.05 mV to 0.3 mV or pC per m/s² and only 0.5 g to 2 g, subsequently. Whereas for special purposes such as very low vibration levels, high level shocks, and permanent monitoring on industrial machines, the accelerometer weighs up to 2 kg (B&K, 1982, 2015). In all cases, their frequency response is an important parameter to be considered when selecting the correct accelerometer for a measurement (Lent, 2009).

These vibration meters need to be calibrated regularly to ensure their accuracy and traceability.

SNSU-BSN has implemented "comparison to a reference transducer method“ to provide calibration for vibration meters according to ISO 16063-21 (ISO 16063-21, 2003). However, the maximum acceleration generated in the calibration system is affected and limited by several factors, such as total mass load of accelerometer, data acquisition system, displacement, and velocity limits of an exciter (Bartoli, 2014). Therefore, we need to formulate maximum acceleration for different accelerometer weight to avoid the exciter in the calibration system broken. In addition, the maximum acceleration is essential to determine the safety and measurement capabilities of the system.

The aim of this study is to find the maximum acceleration produced by the exciter in the SNSU-BSN’s vibration meter calibration system by considering the effect of total mass load, data acquisition system, displacement, and velocity limits of the exciter within frequency range from 10 Hz to 5 kHz. The calculation of exciter’s maximum acceleration is implemented on the Microsoft Excel according to the instrument specification and actual measurement. This calculation will be used as the reference for setting the maximum acceleration value for the exciter in the vibration meters calibration process for different accelerometer weight loads.

## 2. BASIC THEORY

Transducer mass loading effect in a shaker or an exciter testing has been analyzed (Karle, et al, 2014). The addition of accelerometer mass to the mass of the vibrating structure changes the resonant frequency of the vibrating systems. The resonant frequency of vibrating systems depends on the frequency, stiffness (K), and mass of the structure (M), and also mass of the accelerometer ($m_a$) as shown in Figure 1.

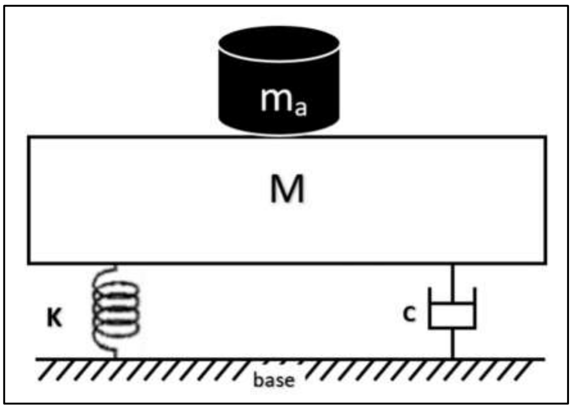


**Figure 1.** Transducer mass loading effect in a shaker.

The system can be formulated as follows:

$$f_m = f_s\sqrt{\frac{K}{(M+m_a}} \quad (1)$$

where:

K = stiffness of the structure

M = mass of the structure

$m_a$ = accelerometer mass

$f_m$ = frequency of the structure with the influence of the accelerometer mass

$f_s$ = frequency of the structure without the influence of the accelerometer mass

Further, the maximum acceleration produced by the exciter is determined by taking the effect of total mass load, data acquisition system, displacement limits, and velocity limits into account.

**A. Effect of Total Mass Load**

The force required to vibrate a mass with acceleration is given by the equation of Newton's second law. By rearranging and including the effective mass of the exciter's moving element, the maximum acceleration due to total mass load can be calculated as follows:

$$a = \frac{F}{m + m_e} \qquad (2)$$

where:

$a$ = maximum acceleration

$F$ = maximum force

$m$ = total mass load

$m_e$ = mass of moving element

**B. Effect of Data Acquisition System**

According to the data acquisition system, the maximum acceleration can be defined as follows:

$$a = \pi\, f\, f_{sa}\, \lambda \qquad (3)$$

where,

$a$ = maximum acceleration

$\pi$ = constants

$f$ = vibration frequency

$f_{sa}$ = sampling frequency of the data acquisition system

$\lambda$ = wavelength limit of the data acquisition system

**C. Effect of Displacement Limits**

The maximum acceleration due to displacement limits can be formulated as follows:

$$a = -d\,(2\,\pi\, f)^2 \qquad (4)$$

where,

$a$ = maximum acceleration

$d$ = maximum displacement of exciter

$\pi$ = 3.14

$f$ = vibration frequency

**D. Effect of Velocity Limits**

The maximum acceleration due to velocity limits depends on the voltage available from the power amplifier used to drive the exciter (B&K, 2015). Typically, 5 volt of voltage is equivalent to 150 $m/s^2$ of acceleration.

## 3. METHOD

The set-up instruments of vibration meters calibration system are shown in Figure 2. The instruments used for this system are as follows:

- PULSE Signal generator B&K 3110
- Power amplifier B&K 2719
- Vibration exciter B&K 4808

- Reference accelerometer B&K 8305
- Conditioning amplifier B&K 2692
- Vibration meter
- PULSE Voltmeter B&K 3110
- PULSE Analyzer B&K 3110
- Personal Computer

An electrical signal at a particular frequency and magnitude is generated by the signal generator, and then it is amplified before converted into a mechanical vibration by the exciter. A vibration acceleration produced by the exciter is measured by the reference accelerometer as well as the vibration meter under test simultaneously. Both of them are positioned inline and mounted on the top side of the exciter (back to back position).

Output of the reference accelerometer was connected to the conditioning amplifier before it is connected to the PULSE Analyzer to process the output signal and the result was displayed on the personal computer. Meanwhile, output of the vibration meter was displayed on its screen. Value difference between those indicated by the reference accelerometer and by the vibration meter under test is called correction.

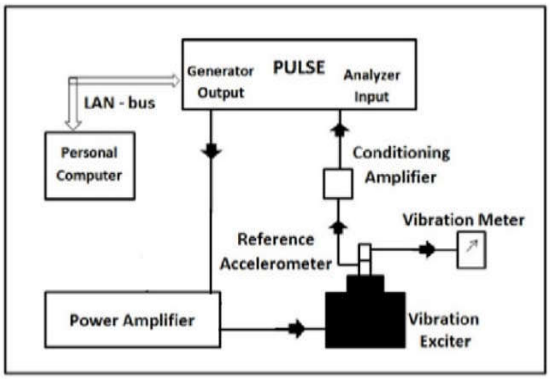


**Figure 2.** Set up of the vibration meter calibration system using comparison method.

The maximum acceleration yield by the exciter in the vibration meters calibration system described previously can be determined by taking some factors, namely, total mass loads, data acquisition system, displacement and velocity limits of the exciter into account.

The first factor, the total mass loads, consists of the mass of moving element, the reference accelerometer and the vibration meter's accelerometer under test. According to the specification (B&K, 2015), the mass of moving element was 0.16 kg. While the reference accelerometer was 0.04 kg. In this study, the vibration meter's accelerometer under test was evaluated for some mass loads which are 0.1 kg, 0.5 kg, 0.6 kg, 0.7 kg, 0.8 kg, 0.9 kg, 1.0 kg, 1.5 kg, and 2.0 kg. The maximum acceleration due to the total mass loads was calculated by formula (2).

The second one was the performance of the analog to digital converter in the PULSE analyzer system that depends on its sampling frequency and wavelength limits. According to the PULSE analyzer documentation (B&K, 2006), there are three options of sampling frequency, i.e. 65.536 kHz, 262.144 kHz, and 524.288 kHz. In this study, it was setting to 262.144 kHz while the wavelength limit was 632 nm. The sampling frequency and wavelength limit of the PULSE Analyzer influences the acceleration as formulated in (3).

Further, the third factor was the effect of the displacement limit of the exciter. According to the specification, the exciter maximum acceleration performance is limited by the maximum displacement, which was 12.7 mm, and it can be calculated as in (4).

The last one was the effect of velocity limits of the exciter which depends on the voltage available from the power amplifier used to drive the exciter. For this study, the maximum voltage was 5 volt which is equivalent to 150 $m/s^2$ of acceleration.

Finally, the maximum acceleration of the exciter is determined by selecting minimum value between those factors for each frequency.

## 4. RESULT AND DISCUSSION

The exciter's maximum acceleration value within the frequency range from 10 Hz to 5 kHz obtained from analysis can be seen in Table 1. The mass loads of 0.1 kg, 0.5 kg and 0.6 kg have the same maximum acceleration for all frequencies. At frequency 10 Hz to 250 Hz the maximum acceleration was increasing from 5 $m/s^2$ to 130 $m/s^2$. Whereas, from frequency 315 Hz to 5 kHz, the maximum acceleration was 150 $m/s^2$ for all these frequencies. The mass loads of 0.7 kg, 0.8 kg, and 0.9 kg have the same maximum acceleration at frequency 10 Hz to 200 Hz which was rising from 5 $m/s^2$ to 104 $m/s^2$. While at frequency 250 Hz to 5 kHz the maximum acceleration 130 $m/s^2$, 117 $m/s^2$, and 106 $m/s^2$ are obtained.

With the mass loads of 1 kg and 1.5 kg, the exciter produced the same maximum acceleration at frequency 10 Hz to 125 Hz that was increasing from 5 $m/s^2$ to 65 $m/s^2$. Meanwhile, at frequency 200 Hz to 5 kHz, the maximum acceleration for the loads of 1 kg, 1.5 kg and 2 kg was 97 $m/s^2$, 67 $m/s^2$, and 52 $m/s^2$, respectively.

**Table 1.** Maximum acceleration of the exciter, by loads, as a function of the frequencies.

| | Maximum Acceleration (m/s²) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **f (Hz)** | **0.1** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** | **1.0** | **1.5** | **2.0** |
| | **Mass loads (kg)** | | | | | | | | |
| 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 31.5 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| 40 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| 63 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 |
| 80 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 |
| 100 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| 125 | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 52 |
| 160 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 67 | 52 |
| 200 | 104 | 104 | 104 | 104 | 104 | 104 | 97 | 67 | 52 |
| 250 | 130 | 130 | 130 | 130 | 117 | 106 | 97 | 67 | 52 |
| 315 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 500 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 630 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 800 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 1000 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 1250 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 1600 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 2000 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 2500 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 3150 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 4000 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |
| 5000 | 150 | 150 | 150 | 130 | 117 | 106 | 97 | 67 | 52 |

Figure 3 shows the relation of the maximum acceleration with different mass load as function of frequency. It can be seen that the maximum acceleration for all loads has the same trend that was rising as the frequency increase. However, the maximum acceleration of each loads became constant at a particular frequency.

At frequency 10 Hz to 100 Hz, the maximum acceleration for all mass loads was the same, which was increasing from 5 $m/s^2$ to 52 $m/s^2$. The results showed that the factors described previously affecting the maximum acceleration produced by the exciter.

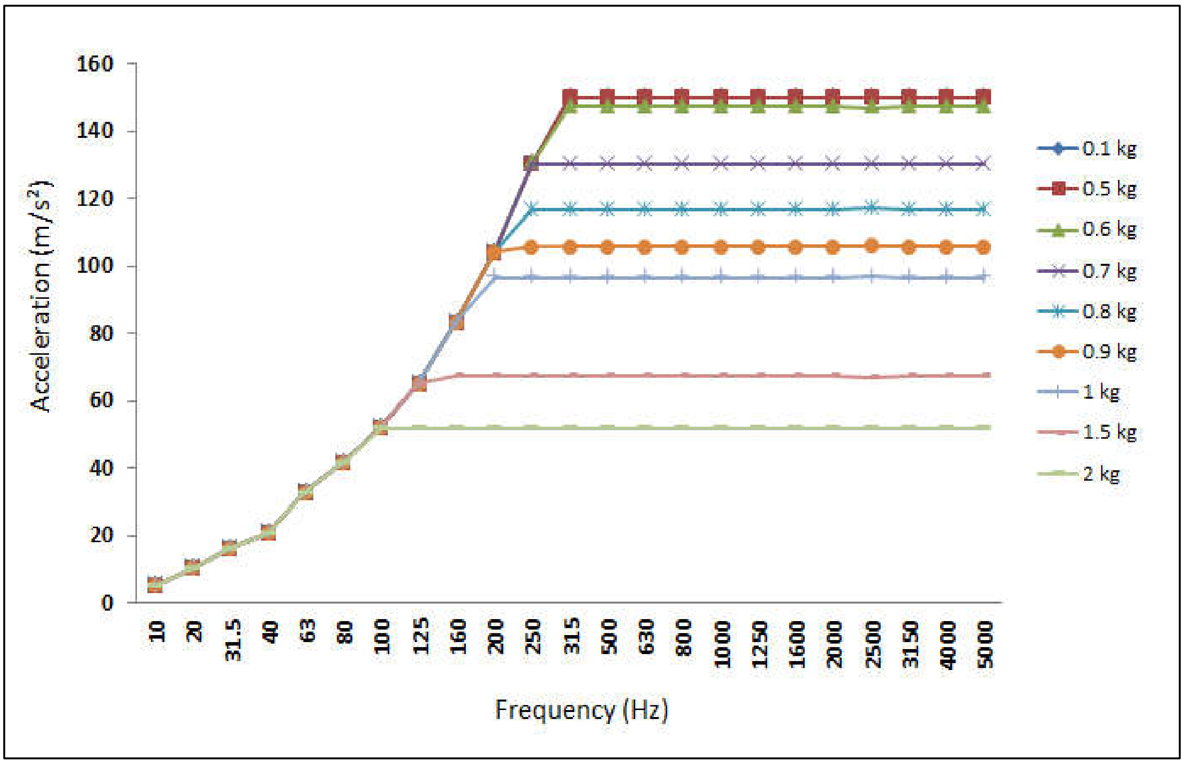


**Figure 3.** Maximum acceleration of the exciter for various loads.

## 5. CONCLUSION

The maximum amplitude of acceleration generated by the exciter was increasing with the increase of frequency and had a flat response after a certain critical frequency point. This critical frequency is

determined by mass loads attached to the exciter. The heavier mass loads yield a lower critical frequency point. Other factors that limit the maximum amplitude generated by the exciter are sampling rate and wavelength limit setting in the data acquisition system, and the displacement and velocity limit of the used exciter. This analysis can be implemented to determine the maximum acceleration for such vibration meter calibration, which is essential to keep the exciter working safely.


## ACKNOWLEDGMENT

The authors would like to thank all the staffs of the laboratory of SNSU for Acoustics and Vibration BSN for the valuable discussion about this work. We would also thank to Prof. Jimmy Pusaka who provided insight and advise that greatly improved the manuscript.


## REFERENCES


B&K. (1982). *Measuring Vibration*. Naerum Denmark: Bruel & Kjaer.

B&K. (2015). Technical Documentation for Vibration Exciter Type 4808. Naerum Denmark: Bruel & Kjaer.

B&K. (2006). System Data IDAe Hardware Configurationsfor PULSE Version

6.1. Naerum Denmark: Bruel & Kjaer.

Bartoli, C. (2014). Training for calibration of accelerometers by primary and secondary methods. LNE: Paris.

Bengherbia, B., Ouldzmirli, M., Toubal, A., & Guessoum, A. (2017). FPGA-based Wireless Sensor Nodes for Vibration Monitoring System and Fault Diagnosis. *Measurement*, 101, 81-92.

ISO 16063-21. (2003). Methods for the Calibration of Vibration and Shock Transducer Part 21-Vibration Calibration by Comparison to a Reference Transducer.

Karle, A. D., Bhoite, S. K., & Amale, A. B. (2014). An Analysis of Transducer Mass Loading Effect Inshaker Testing. *Journal of Engineering Research and Applications*, *4*(6), 207–212.

Kusuma, W. P. (2015). *Pengaruh Biaya Pemeliharaan Mesin Terhadap Laba Bersih Yang Diperoleh Pt. Karya Sawit Lestari Palembang*. Tugas akhir, Universitas Bina Darma, Palembang.

Lent, B. (2009). Simple steps to selecting the right accelerometer. *Sensors (Peterborough, NH)*, *26*(3).

Mathew, J., & Mathew, S. G. (2015). Analysis of Failure Modes and Selection of Maintenance Strategy for Vital Machines in a Tea Industry. *International Journal of Science Technology & Engineering*, *2*(05), 121–125.

Nahas, N. (2017). Buffer allocation and preventive maintenance optimization in unreliable production lines. *Journal of Intelligent Manufacturing*, *28*(1), 85–93.

Shen, C., Wang, D., Kong, F., & Tse, P. W. (2013). Fault diagnosis of rotating machinery based on the statistical parameters of wavelet packet paving and a generic support vector regressive classifier. *Measurement: Journal of the International Measurement Confederation*, *46*(4), 1551–1564.

Sukendra, I. R. (2009). *Pengaruh Biaya Pemeliharaan Mesin Terhadap Laba Operasional Pada Perusahaan Daerah Air Minum (Pdam) Bandung*. Tugas akhir, Universitas Komputer Indonesia, Bandung.

Várkonyi-Kóczy, A. R., Szabó, J. Z., Nagy, I., & Rudas, I. J. (2012). Maintanance Analysis of Rotating and Moving Machines Using 3D Vibration Animation. *IFAC Proceedings Volumes*, *45*(22), 584–589.

Xiao, X., Tang, B., & Deng, L. (2017). High accuracy synchronous acquisition algorithm of multi-hop sensor networks for machine vibration monitoring. *Measurement*, *102*, 10–19.

## CONTRIBUTION STATEMENT

The authors of this paper stated that all authors are the main contributors to the writing of this paper.