

Experimental Study of Vibration Training System Test Equipment TM 150: Comparative Analysis of Beam Oscillation, Damped Oscillation, and Spring-Mass System Tests

¹Djoeli Satrijo, ^{2*}Toni Prahasto, ³Ojo Kurdi, ⁴Mikhael Dixon Darmawan

^{1,2,3,4}Mechanical Engineering, Diponegoro University, Semarang, Central Java, Indonesia

*Corresponding Author's E-mail: toniprahasto@lecturer.undip.ac.id

Abstract - Vibration can occur for a variety of reasons, such as machine operation, environmental factors, human activities, and others. Therefore, the ability to accurately measure and analyze vibration is essential to optimize the design and performance of a mechanical system. This research paper presents an experimental study of the GUNT TM 150 Vibration Training System Test Equipment. The purpose of this study is to conduct a comparative analysis of the performance of the test equipment through three types of mechanical vibration tests: beam oscillation, damped oscillation, and spring-mass oscillation. This study evaluates the effectiveness of each type of test in simulating different types of mechanical vibration and analyzes the results obtained. The analysis is done by comparing the experimental results with theoretical calculations. The findings of this study are expected to contribute to the improvement of vibration testing methods and techniques in various fields, especially mechanical engineering.

Keywords: beam oscillation, damped oscillation, GUNT TM 150, mechanical vibration, spring-mass oscillation.

I. INTRODUCTION

Vibration analysis is an important aspect of mechanical engineering and is used to evaluate the performance, stability, and durability of various structures and machines. Although the study of oscillatory motion dates back four centuries, research on this subject is still actively conducted today [1]. Vibration can occur for a variety of reasons, such as machine operation, environmental factors, human activities, and others. Therefore, the ability to accurately measure and analyze vibration is essential to optimize the design and performance of a mechanical system. Early studies conducted on vibration focused on understanding natural phenomena and developing mathematical theories that describe vibrations in a physical system [2]. Recent investigations reveal that most vibration problems are caused by imbalances in the engine of a machine/equipment. Unbalance can be caused by errors in

design, or poor manufacturing. Vibration can cause spectacular mechanical damage [3].

A study was conducted by Wildan, M. [4], on a bus chassis, and it was found that external forces such as road roughness, passenger weight, and engine vibration can cause failure of the chassis, if the external excitation frequency is equal to the natural frequency of the chassis, this phenomenon is called resonance. Vibration can also cause engine parts such as bearings and gears to wear faster and also cause excessive noise. Feng, C. [5] conducted research on mechanical vibrations in a vehicle by changing the four-degree-of-freedom model to a single-degree-of-freedom, then using MATLAB software to solve the mathematical model. He said that mechanical vibration greatly affects engine performance. It can disrupt engine performance, make engine components quickly damaged, affect engine balance, and cause annoying sounds. To study the mechanism of various vibration phenomena and understand the basic principles of vibration, knowledge of mechanics is needed to create a mathematical model, which must then be analyzed and solved. This process involves mathematical derivatives and solving differential equations that are very complex, time-consuming, and error-prone if done manually. Therefore, the use of software is proposed to help solve the existing equations.

The important role of vibration in the world of machinery creates a need for engineers, researchers, and even students to deepen the science of vibration. Theoretical calculations accompanied by validation through experiments is one way that can be done to achieve this goal. One of the main objectives of this research is to get a "complete vision of the subject" or a full understanding of the topic discussed, from theory to practice. Research conducted by Urizar, M. [6], on vibration theory through experimental analysis, as well as virtual simulation, and in conclusion it is said that mechanical vibration theory, when accompanied by experimental analysis can improve our insight and view of important concepts in mechanical vibration theory such as resonance, damping effects, vibration modes, and so on.

Vibration experiments can be done in several ways, one of which is by using a training system, which is specifically designed to conduct experiments related to vibration. The TM 150 Vibration Training System is a device produced by the GUNT company from Germany. This device is designed to study and research various topics from the field of vibration theory through experimentation. However, studies on the comparative effectiveness of the TM 150 Vibration Training System Tester and other vibration testers are limited. Therefore, this study aims to validate the results of theoretical calculations, as well as test the performance of the TM 150 Vibration Training System test device, to ensure that the training device is still in good condition or not damaged so that it can be used for data collection in future practicums. Tests were conducted on the device using three different tests, namely beam oscillation, damped oscillation, and spring-mass system. The three tests were then compared with the results of theoretical calculations accompanied by free body diagrams of each experiment. The experimental data and theoretical calculations are then converted into graphs, to show the comparison between the two.

The hypothesis for this study is that the TM 150 Vibration Training System is expected to produce results similar to those of the theoretical calculations. This hypothesis is based on the assumption that the training system is free of significant defects or damage. This research contributes to the knowledge base on the use of the TM 150 Vibration Training System Tester and its potential usefulness in the field of mechanical engineering.

II. FREE BODY DIAGRAM

A) Beam Oscillation

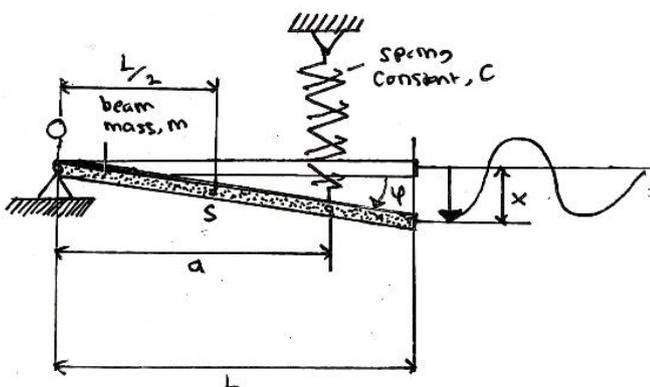


Figure 1: Free Body Diagram of Beam Oscillation

$$\sum M_o = J_o \ddot{\phi} = -F_c a$$

$$F_c = c x = c \phi a$$

$$J_o = \frac{m L^2}{3}$$

$$\ddot{\phi} + \frac{3 c a^2}{m L^2} \phi = 0$$

$$\omega_o^2 = \sqrt{\frac{3 c a^2}{m L^2}}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{3 c a^2}{m L^2}} \quad (1)$$

B) Damped Oscillation

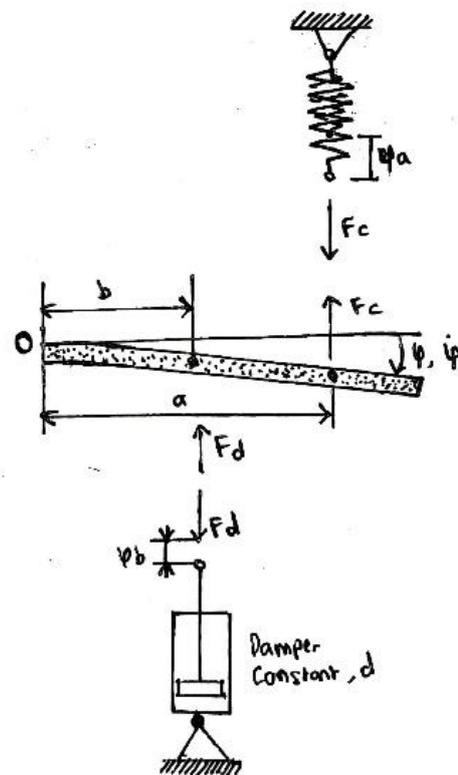


Figure 2: Free Body Diagram of Damped Oscillation

$$\sum M_o = J_o \ddot{\phi} = -F_c a - F_d b$$

$$F_d = d \dot{x} = d \dot{\phi} b$$

$$\ddot{\phi} + \frac{d b^2}{J_o} \dot{\phi} + \frac{c a^2}{J_o} \phi = 0$$

$$\phi(t) = \frac{\omega_o}{\omega_d} \hat{\phi} e^{-D \omega_o t} \sin(\omega_d t + \psi)$$

$$\omega_d = \omega_o \sqrt{1 - D}$$

$$\omega_0^2 = \frac{c a^2}{J_0}$$

$$D = \frac{b}{2 J_0 \omega_0} \quad (2)$$

C) Spring-Mass System

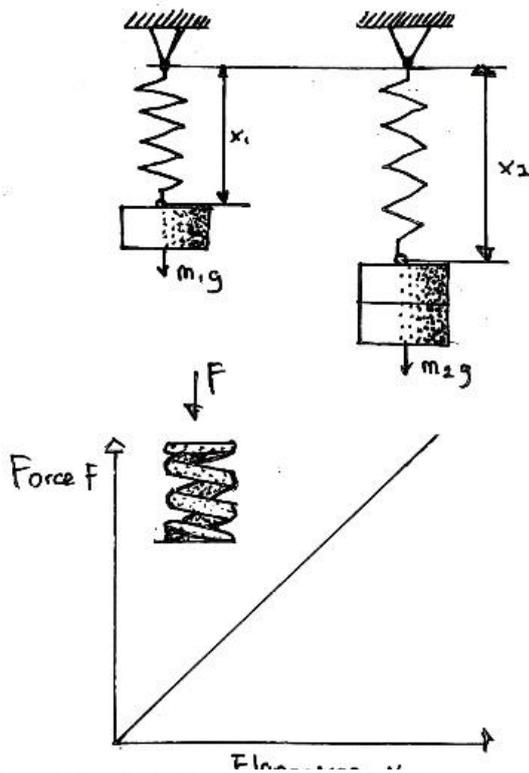


Figure 3: Free Body Diagram of Spring-Mass System

$$F = c \cdot x$$

$$c = \frac{(m_2 - m_1)g}{x_2 - x_1} \quad (3)$$

III. EXPERIMENT

A) Beam Oscillation

This experiment was designed to compare the theoretically calculated natural frequencies with variations in the constant and lever arm.

$$m = 1.680 \text{ kg}$$

$$L = 732 \text{ mm}$$

By entering the two values above, as well as the constant value of the spring and also the variation of the lever arm a into equation (1), the natural frequency value of the system is obtained, which can be seen in table 1 below.

Table 1: Theoretical System Natural Frequency

Influence of spring constant Calculated frequencies			
Experiment	Spring No., constant C in N/mm	Lever arm a in mm	Natural frequency f in Hz
1	1, 0.75	350	2.78
2	1, 0.75	650	5.17
3	2, 1.50	350	3.94
4	2, 1.50	650	7.31
5	3, 3.00	350	5.57
6	3, 3.00	650	10.34

Natural non-damped oscillation experiments were conducted on the beam, by applying an initial deviation to the beam by hand, and letting it oscillate to generate plots for analysis. The oscillation process is indicated in the following plots:

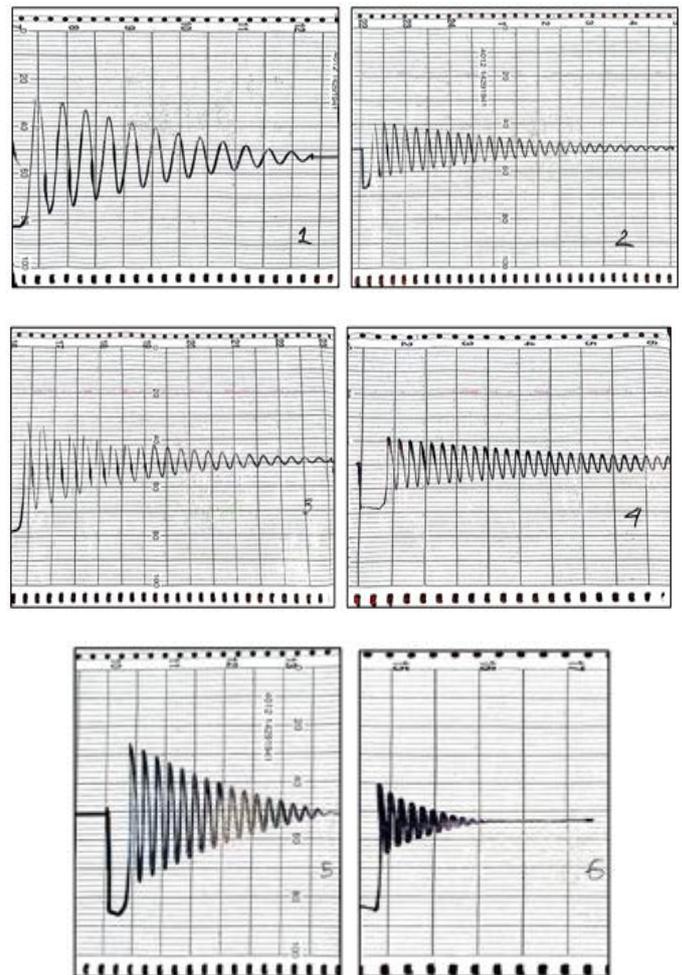


Figure 4: plot results of beam oscillation experiment

The experimental results above are then compared with the theoretical results; the comparison can be seen in table 2.

Table 2: Experimental results of beam oscillation

Frequencies of non-damped oscillation			
Experiment No.	Experiment		Theoretical frequency in Hz
	Periodic time in s	Frequency in Hz	
1	0.410	2.44	2.78
2	0.230	4.35	5.17
3	0.305	3.28	3.94
4	0.165	6.06	7.31
5	0.205	4.88	5.57
6	0.110	9.09	10.34

B) Damped Oscillation

This experiment is designed to show the effect of damping on the oscillation behavior with variations in the needle valve and lever arm.

$$C = 0.75 \text{ N/mm}$$

$$a = 650 \text{ mm}$$

Table 3: Combination of damping experiments

Influence of Damping		
Experiment	Needle valve position	Lever arm b in mm
1	open	150
2	close	150
3	open	600
4	close	600

Experiments were conducted on a damped beam and plots were obtained that illustrate the effect of a damper on oscillations.

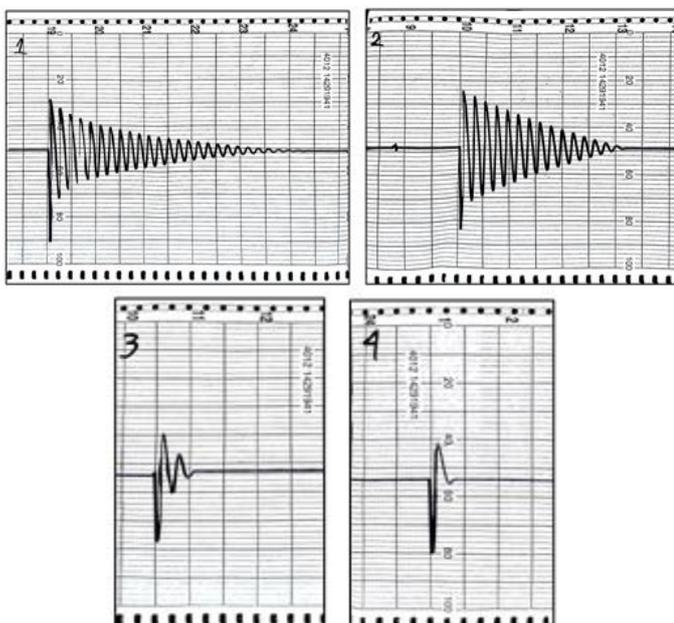


Figure 5: plot results of damped oscillation experiment

C) Spring-Mass System

The spring constant is a characteristic variable of a spring that reflects the relationship between spring force and spring deflection. The experiment starts with the spring loaded by adding weight m and then the elongation x is measured. As a linearity check, the measured values can also be plotted in a force-elongation graph.

Table 4: Experimental results of spring-mass system

Determination of spring constants				
	Mass in kg	Force in N	Deflection in mm	Elongation in mm
Spring type 1	0	0	100.0	0
	1	9.81	112.0	12.0
	2	19.62	124.0	24.0
	3	29.43	135.0	35.0
Spring type 2	0	0	100.0	0
	2	19.62	112.0	12.0
	4	39.24	125.0	25.0
	5	49.05	132.0	32.0
Spring type 3	0	0	100.0	0
	2	19.62	106.0	6.0
	4	39.24	112.0	12.0
	6	58.86	119.0	19.0

Here are the constant results for the spring referred to the maximum force (theoretical stiffness in parentheses).

$$C_1 = \frac{29.43}{35.0} = 0.84 \text{ N/mm (0.75 N/mm)}$$

$$C_2 = \frac{49.05}{32.0} = 1.53 \text{ N/mm (1.50 N/mm)}$$

$$C_3 = \frac{58.86}{19.0} = 3.09 \text{ N/mm (3.00 N/mm)}$$

IV. RESULTS & DISCUSSION

A) Beam Oscillation

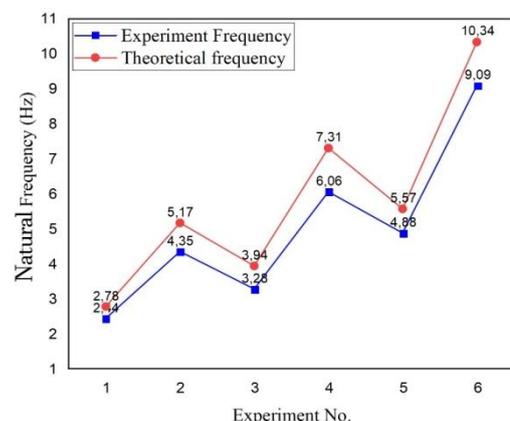
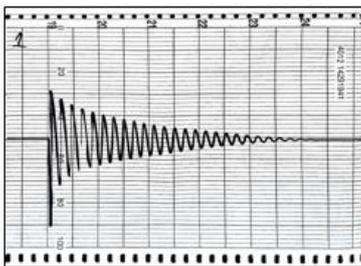
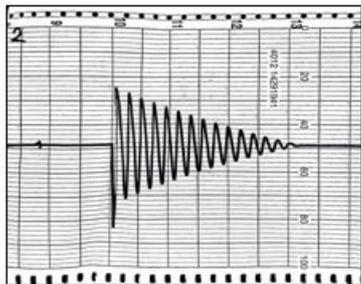


Figure 6: Comparison between Experiment and Theoretical Frequency of Beam Oscillation

Comparison of experimental results and theoretical calculations for beam oscillation testing can be seen in the graph above. It can be seen that there is a similarity in the shape of the plot obtained from the experiment when compared to the theoretical plot. The difference in values found in the experimental results is understandable, given that the results of theoretical calculations use the assumption that there are absolutely no external factors affecting the system during oscillation. Theoretical values often depend on ideal conditions that may not be fully achievable in practice. Real-world experiments can be affected by factors that are difficult to control or fully account for, such as variations in temperature, pressure, or the presence of external disturbances. An example can be seen in experiment number 3, where the theoretical value of the calculated natural frequency is 3.94 Hz, and the experimental value of the natural frequency obtained is 3.28 Hz. There is a difference in value of 0.66 Hz caused by external factors that are not considered or ignored in the theoretical calculation.



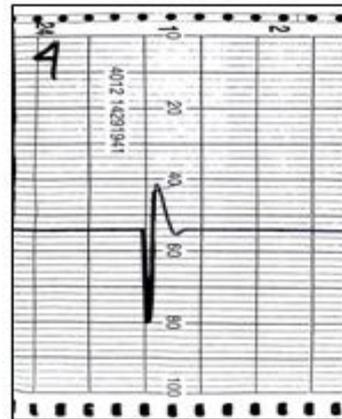
- The system is slightly damped in the 1st figure. It oscillates 24 times before it comes to rest. The stylus friction gives the impression of additional damping.



- 2nd figure shows moderate damping corresponding to a degree of damping of roughly $D = 0.1$.



- In the 3rd figure the system is subject to relatively high damping. Oscillation has decayed after 3 periods. The degree of damping is $D = 0.25$.



- The system is subject to aperiodic damping in the 4th figure. There are no oscillation to be seen, merely once-only over swing. The degree of damping is $D = 1$.

C) Spring-Mass System

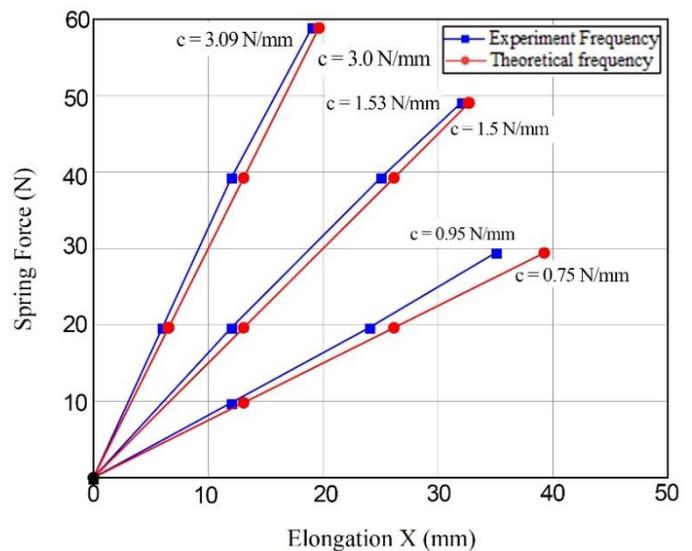


Figure 7: Comparison between Experiment and Theoretical Frequency of Spring-Mass System

The experimental results of the spring-mass system can be seen in the graph above. Hooke's law says that if the tensile force exerted on a spring does not exceed the elastic limit of the spring, then the increase in spring length is directly proportional or proportional to the tensile force, therefore the presentation of the graph above aims to show the linearity of the experimental results. It can be seen that the results of elongation measurements made on 3 springs that have different constants, coincide quite well with the theoretical constant value. The experimental results show that a value of 0.84 N/mm was obtained for spring type 1, where the theoretical value is 0.75 N/mm, a value of 1.53 N/mm for spring type 2, where the theoretical value is 1.50 N/mm, and a value of 3.09 N/mm for spring type 3, where the theoretical value is 3.00 N/mm.

V. CONCLUSION

In summary, our investigation comparing theoretical predictions with experimental results has confirmed the reliability and accuracy of the theoretical framework. By conducting careful experiments and utilizing sophisticated measurement methods, we have obtained convincing data that strongly support the theoretical model. The observed coherence between theory and experiment strengthens our confidence in the theoretical framework, enriches our understanding of the phenomenon, and paves the way for future research and practical applications in various disciplines.

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