
The Study of Vibration Transmission Using Virtual Instruments

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Abstract: - In present, learning through experiments is the preferred studying method for students. Theoretical notions by experimental example offer a high level of understanding on phenomena. Virtual labs represent a method that ensures achieving high performance in designing tool machine. After familiarizing students with theoretical aspects, using Java applets they have carried out a series of experiments which gave them the possibility of a full understanding of the phenomena concerned. The experimental part consisted of successive virtual simulations based on the modification of some functional parameters.

Keywords: - harmonic excitation, transmission of vibrations, frequency, simulation, virtual instruments.

1. INTRODUCTION

Future engineers increasingly use virtual tools in the learning process. Some examples of using virtual instruments (VI) in various fields of science like chemistry, physics, biology or biotechnology are exemplified in [1-5].

Developing students' analytical skills in data synthesis and analysis is crucial in the formation of the future specialist. The real challenge for engineers is the ability to translate into practice the theoretical notions accumulated during the training period as students. To help them achieve this goal, the higher education system applies an appropriate curriculum that supports active learning through experience. Each specialized discipline is also provided with some practical applications during the laboratory hours. The results of the active learning journey are presented in [6] through the implementation of a virtual study method in a fluid mechanics laboratory.

The use of virtual tools has led to the development of practical skills in the use of mathematical tools, through dedicated software, to solve specific situations [7]. Specifically, in this paper, the virtual instrument used was Java, Java applets being used to

understand specific phenomena as a tool for alternative learning [7-8].

The theoretical part of the paper contains a brief description of the phenomenon of transmission of vibrations in the mechanical structures and is the basis for justifying the necessity of applying some solutions to prevent and combat this phenomenon. A virtual instrument is created with the help of Java applications in order to learn how to minimize the transmission of vibrations. This tool allows students to deeper understand the phenomenon.

2. TRANSMISSIBILITY OF VIBRATIONS

The operation under normal or crash conditions of dynamic mechanical systems, such as machine tools, implies the occurrence of vibrations. These vibrations, depending on the machine's working regime, can produce varying effects. Irrespective of the source of the vibrations, resulting either directly from the machine's operation or indirectly from collateral sources, it is necessary to perform isolation to prevent their development and/or propagation. Figure 1 presents a lathe as a source of vibration during operation.

To prevent the vibration transmission to the foundation or to avoid overloading the lathe with vibrations from possible external sources, it is necessary to isolate it from the foundation [9].



Figure 1. The support base of the lathe

In the first case, shown in Figure 2.a, the vibration source is the mechanical system during the operation itself. The vibrations are produced by an unbalanced component that gives a sinusoidal variation law. If mass m , which is part of the machine, has the eccentricity e and is rotating with the angular frequency ω , it is responsible for producing an excitation force $F(t) = F_0 \sin \omega t$ that varies in time t and has the amplitude F_0 . This will generate vibrations, which have to be isolated with the spring-damper system placed between the mass and the foundation.

In the second case, illustrated in Figure 2.b, the vibration source is external and is given by the displacement of the foundation, described by an equation of form $y(t)$. In that case, the external vibrations will be transmitted to the machine and hence the need to protect the machine from these vibrations is again necessary.

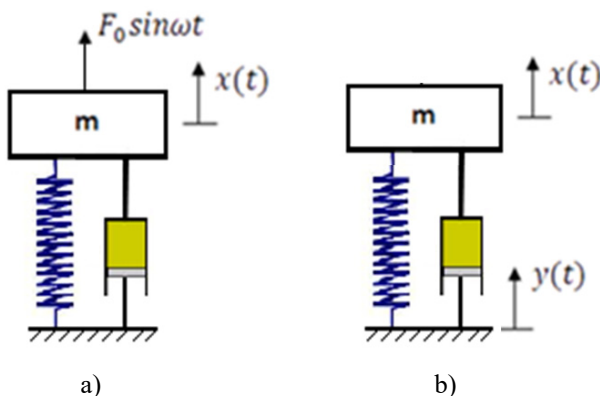


Figure 2. Vibratory system of the machine with:
a) internal vibration source; and b) external vibration source

In case of the vibratory system with internal vibration source, the required insulation system can be described by using the Kelvin-Voigt model [10] shown in Figure 3.

The equation that describes the forced vibration is given in [11]. It is:

$$m\ddot{x} + c\dot{x} + kx = F_0 \sin \omega t \quad (1)$$

where x is the displacement of the machine due the vibration, c is the damping coefficient and k is the rigidity of the support.

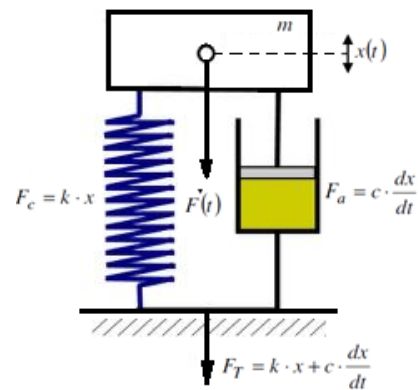


Figure 3. The Kelvin-Voigt model for the machine vibratory system

Considering the damping factor and the angular frequency being $2n = \frac{c}{m}$ respectively $\omega_0 = \sqrt{\frac{k}{m}}$ for the considered elastic system, equation (1) becomes:

$$\ddot{x} + 2n\dot{x} + \omega_0^2 x = \frac{F_0}{m} \sin \omega t \quad (2)$$

The solution of equation (2) is of the form:

$$x = A \sin(\omega t - \varphi) \quad (3)$$

where A is the vibration amplitude, φ the angle between the displacement x direction and the disturbing force F direction.

The vibration amplitude is given by a relation of form $A = \frac{F_0}{k} A_0$ where A_0 is the amplification factor given by the formula:

$$A_0 = \left[\sqrt{(1 - \delta^2)^2 + 4\zeta^2 \delta^2} \right]^{-1} \quad (4)$$

where $\delta = \frac{\omega}{\omega_0}$ and $\zeta = \frac{n}{\omega_0}$.

If $\omega \ll \omega_0$, independent of the system damping, the amplification factor tends to become equal to the unit $A_0 = 1$.

In contrary, the amplification factor tends to become null if $\omega \gg \omega_0$. In this way the amplitude of the forced vibrations is not influenced by the damping in the system. The only unwanted situation occurs when $\omega = \omega_0$ which causes an increase in vibration amplitude, amplitude which this time is influenced by the system damping. The occurrence of the resonance phenomenon is directly conditioned by the fulfillment of this condition.

The force generated by mass m of the machine component, and dissipated in the system by means of the elastic spring-damper system is given by formula:

$$F_T = F_e + F_a = kx + c\dot{x} \quad (5)$$

The transmissibility T of vibrations is defined in [11] as the ratio between the dissipated force in the system F_T and the amplitude of the disturbing force F_0 , that is:

$$T = \frac{F_T}{F_0} = \frac{(1 + 4\zeta^2\delta^2)^{1/2}}{[(1 - \delta^2)^2 + 4\zeta^2\delta^2]^{1/2}} \quad (6)$$

Based on equation (6), the chart in Figure 4 can be plotted [12] for different values of ζ .

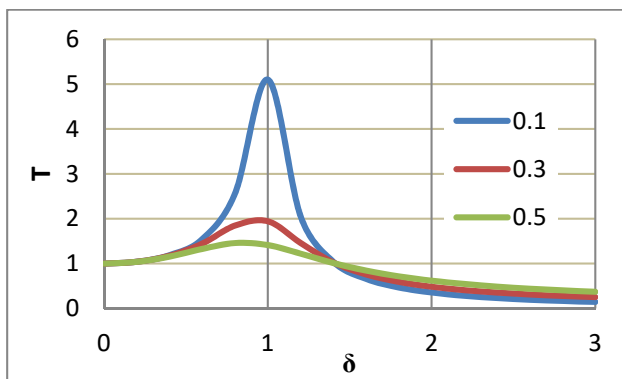


Figure 4. The variance of transmissibility for different values of ζ (0,1; 0,3 and 0,5)

From this figure one can see that, for $\delta = \sqrt{2}$, $T = 1$ regardless of the value of ζ . Also, clearly results that, for $\delta > \sqrt{2}$, independent of system damping, the lower the damping factor ζ , the better the isolation is. Finally, it is noticed that in the resonance range $\delta \in [0.5; 1.5]$ the higher the damping factor ζ is, the vibration isolation is more efficient.

3. APPLET FOR SIMULATIONS IN THE VIRTUAL LABORATORY

Learning how to protect mechanical systems from vibration effects is one of the purposes of the Vibration of Machines and Equipment course. To achieve this goal, in the vibration laboratory, the students have at their disposal an experimental stand whereby the understanding of the transmission of vibration phenomenon becomes more inclusive.

During the laboratory hours, students using a virtual instrument can perform different simulated measurements in order to identify and quantify the dependence between different parameters describing the phenomenon of vibration transmission.

Software used for the practical application named Java Applets for Physics by Walter Fend has the following modules of practical value for the course of vibration: Mechanics, Oscillations and Waves. Module used for the application in this paper is the second one.

In order to use the mentioned virtual instrument, students must first know how spring pendulum work. Subsequent, the students can use the Forced oscillation application from Oscillation module. This virtual tool provides information on the variation of elongation, on the amplitude and phase difference of forced oscillations [13]. Figure 5 shows a spring pendulum analysis sequence subjected to forced oscillations.

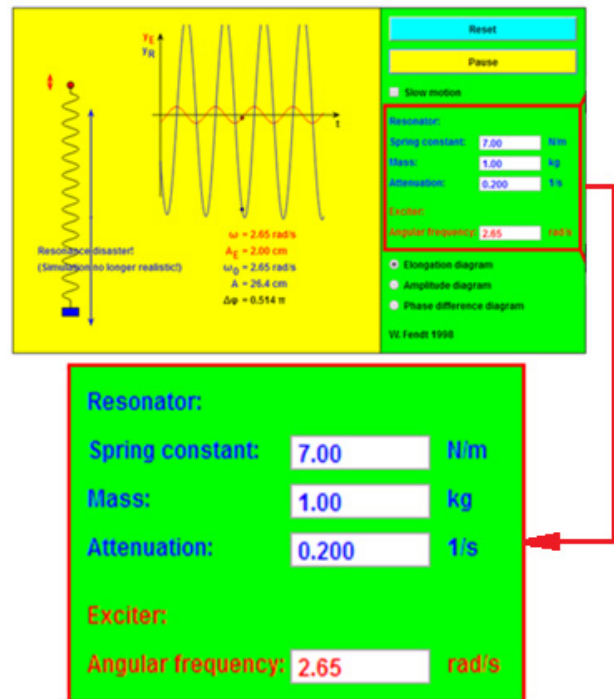


Figure 5. The Java Applets interface with marking the parameter setting area of the analysis

On the right side of the VI interface, above the area to set the analysis parameters, the “Reset” and “Pause” buttons are placed. The “Reset” button can return to the initial values of the spring pendulum start position. The “Pause” button is destined to interrupt the simulation process aiming to reveal the characteristics of the system at a given moment.

Within the application the students have the possibility to modify the input parameters with respect to certain limits, as follows:

- The spring constant can vary between 5 to 50 N/m;
- The mass can vary between 1 to 10 kg;
- The attenuation constant can vary between 0 to 100 1/s;
- The angular frequency can vary between 0 to 10 rad/s.

In other words, the input parameters represent the variables of the considered mechanical system.

Changing any of the four input parameters, successively or simultaneously, leads to different results, allowing the analysis of vibration resonance phenomenon in all its complexity.

The first test was made for an excitation with the angular frequency $\omega = 2.24 \text{ rad/s}$ and the amplitude was set $A_E = 2 \text{ cm}$ automatically by the applet. The mass m , stiffness k and damping coefficient c can be set by the student. The values $m = 1 \text{ kg}$ and $k = 5 \text{ N/m}$ were chosen, while the damping was inexistent. By performing simulations, it is observed that for $\omega = \omega_0$ the phenomenon of resonance appears, and the amplitude of the system becomes infinite (see the blue square in Figure 6).

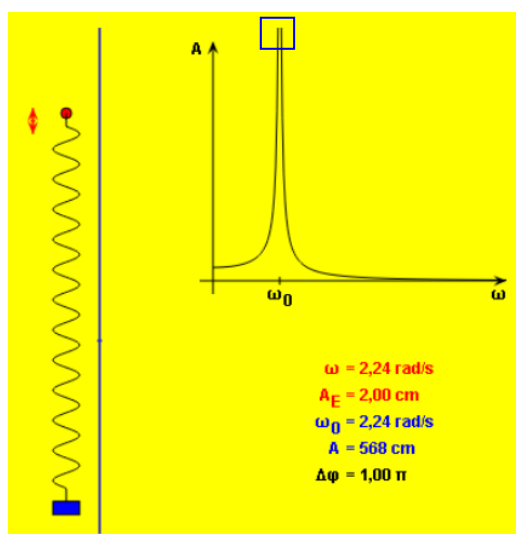


Figure 6. The amplitude diagram highlighting the resonance achieved for obtained $\omega = \omega_0$

Setting the damping coefficient $c = 0.2$, the amplitude decreases. This is shown in Figure 7, where the calculated amplitude $A = 22.3 \text{ cm}$ is marked with a blue point. The frequency remains unchanged.

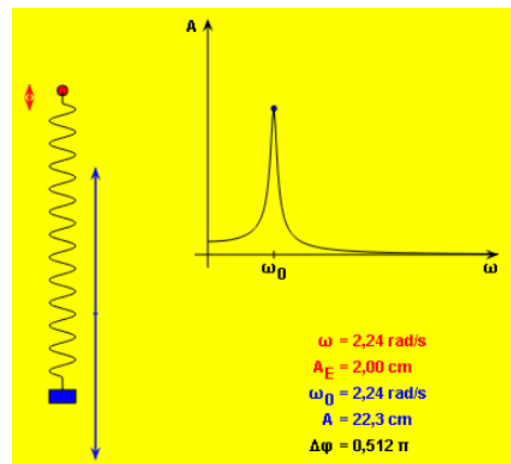


Figure 7. The amplitude diagram obtained by assigning a damping coefficient

By increasing the spring stiffness to $k = 10 \text{ N/m}$ and maintaining the other parameters, the angular frequency of the system increases and the system is removed from the resonance domain. Due to the natural frequency increase of the mass-spring system, the frequency ratio decreases and the system achieves a lower amplitude $A = 3 \text{ cm}$, as shown in Figure 8. Increasing the rigidity to infinite leads to a response amplitude similar with that of the excitation, hence 2 cm.

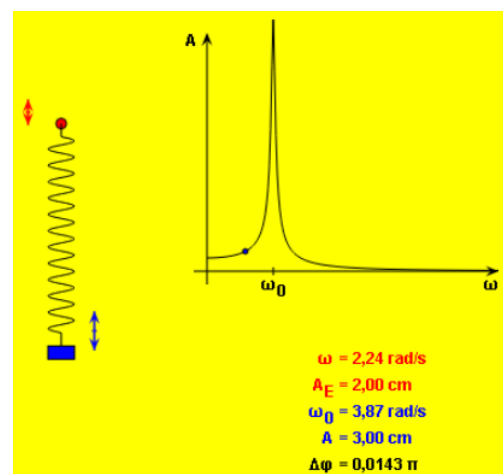


Figure 8. The amplitude diagram achieved for a rigid support (big elastic coefficient)

To demonstrate the effect of decreasing k , new parameters are set for the system. This is necessary because of the applet’s capacity to process information.

For the structural parameter values $m=1\text{kg}$, $k=5\text{N/m}$ and $c=0.2$, the natural frequency of the system is $\omega=2.24\text{rad/s}$. If increasing the excitation frequency, for instance taking it $\omega=3\text{rad/s}$, the frequency ratio increases and the amplitude decreases in consequence, see the red point in the Figure 9. Thus, if ensuring a weak support, i.e. a low k and consequently ω_0 , the amplitude of the response decreases. The weaker the spring stiffness k , the lower the response amplitude A is. Extremely decreasing the stiffness, the amplitude of the response becomes null.

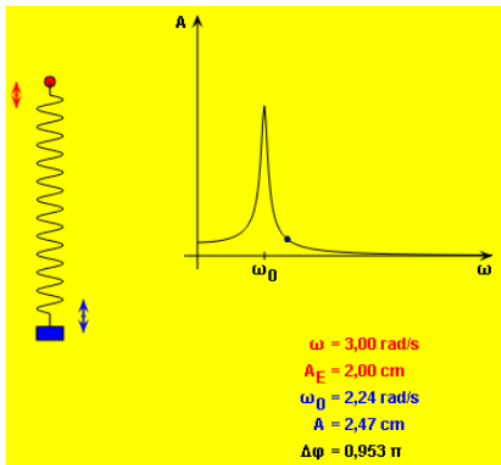


Figure 9. The amplitude diagram achieved for a weak support (low elastic coefficient)

Keeping the other parameters constant and varying only the damping factor, is found to be inversely proportional to the amplitude. This can be observed if comparing the response amplitude $A=22.3\text{cm}$ obtained for damping $c=0.2$ (see Figure 7) with the amplitude $A=14.9\text{cm}$ obtained for the damping $c=0.3$ (see Figure 10).

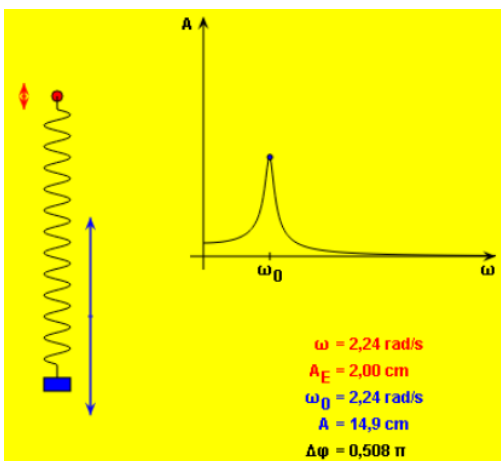


Figure 10. The amplitude diagram achieved for significant damping

On the interface of the virtual instrument shown in Figure 5, in the area for the analysis options, beside the amplitude, students can select also other characteristics to be represented and analyzed. These are the elongation of the excitation and response signals (Figure 11) and the phase difference (Figure 12). In the graphical section of the interface also the values of the output parameters are displayed and, if necessary, a series of messages generated from the analysis, regarding the impact of the simulated situation in real conditions.

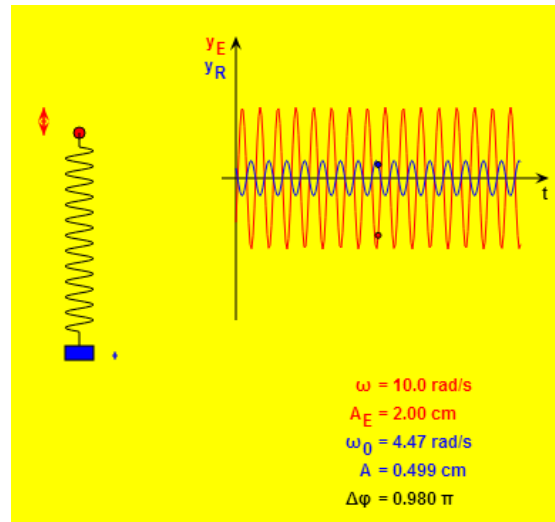


Figure 11. Elongation diagram of the excitation and response signals

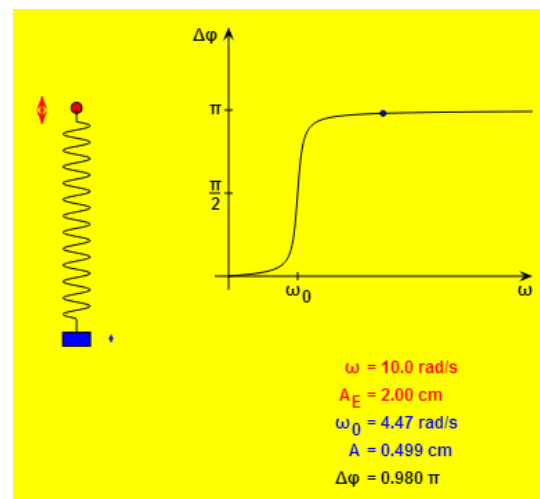


Figure 12. Phase difference diagram

Applying different values for the input parameters, the students can observe the impact on the transmissibility. Simulations are easily performed and request no computational or time resources. However, these simulations cannot totally replace the real experiments, as shown in [14].

How these aspects apply to the functioning of real systems, in concrete conditions, is presented for heavy machines in [15] and [16].

4. CONCLUSIONS

The use of virtual laboratories, in contrast to classical laboratories, provides a number of advantages such as the use of simple and less expensive equipment. At the same time, the use of virtual instrumentation to simulate real phenomena can be accomplished in a much shorter time by students, while simultaneously participating actively in performing the experiments.

Access to Java applets in order to increase the level of understanding of the phenomena studied is easy, both in an organized environment, such as school, and at home. In conclusion,

In conclusion, it can be said that the use of virtual instruments is a desirable alternative in the learning process.

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