Simulation of Simple Harmonic Oscillator using Xcos

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Abstract

In the new era of online teaching and learning process, digital learning and critical thinking are the two vital components. This could be effectively augmented in an online environment by combining theoretical knowledge with the basic dynamics of teaching and learning. In engineering curriculum, in accordance with Bloom's taxonomy levels, higher order critical thinking such as analysis, evaluation and model making are the backbone of Outcome Based Education. The present work uses Scilab as a teaching / learning tool. It is an open source software tool which facilitates to develop higher order critical thinking and analysis skill.

The fundamental concepts of Physics could be understood effortlessly using simulating model Xcos tool. This tool helps students to develop analysing, computing and model building skills through critical thinking. In this paper, a step by step constructivist approach is used to perform simulation of the simple harmonic oscillator. The constructivist approach makes active learning process better by constructing the knowledge rather than acquiring it. Initially, modelled simple harmonic oscillator and time period of the oscillator is visualized by computing angular frequency in the model and results are validated by conducting real time experiment. Similarly different conditions of damped harmonic oscillator and forced harmonic oscillator are computed and visualized.

Keywords: *Simulation, Constructivism, simple harmonic oscillator, Xcos.*

1.0 Introduction

Physics learning in particular is far perceived to be complex. Teaching does not appear to have the expected effect, with students possessing only a vague memory of unconnected ideas and a hazy mental picture of equations, symbols and graphs. As real learning that enables to understand, predict and verify ideas is glaringly absent, students' resort to the next possible option of the rote memorization of facts which has short term relevance but will not provide any learning experience to students. Research has shown that traditional classroom lectures fail to make any tangible impact which only accomplishes simple transmission, hence often referred as a *transmissionist model*. This being the case, a new area of research that probes into the details of how a learner processes information has become the central focal point of the new area of education Research [1-2].

Research has shown that students do not attain the expected level of proficiency in understanding concepts when trained by the traditional teaching methods. It has also looked into the outcome of pedagogy and the use of transformed course for improving student learning. The pedagogical adaptations range from escalating active engagement of students in large lecture class to reconfiguring of the instructional environment [3]. Reformed courses demonstrate improved conceptual understanding as students are actively engaged in constructing their own knowledge. The studies on the influence of transformed course approach describe how a pedagogical strategy promotes in the advancement of physics drives students to be creative in implementing Physics concepts in real life applications. Whereas, traditional teaching methods, are less encouraged in the direction of developing thinking skills. In Physics conceptual understanding is influenced by a principles and physical laws. In this direction, to train students in developing critical thinking (CT) skill is most important in science education. Critical thinking entails the skill to identify relationships, illustrate inferences, analyze and solve problems [4].

The aim of the paper is to examine the use of computational teaching approach in the study of harmonic oscillations [5-6]. The conceptual understanding of oscillatory motion requires the coherence of physics with mathematics. Computational teaching approach uses Xcos of Scilab tool dedicated to the modeling and simulation of dynamic systems. Xcos includes a graphical editor which allows to easily representing models as block diagrams by connecting the blocks. Differential equations are used to model a problem with various independent variables. The study focused on modeling of harmonic oscillator (example mass-spring system). To execute thinking tasks involve predicting, analyzing and reasoning which necessitates teaching of critical thinking skills in coherence with the concept of harmonic oscillations [7].

2.0 **Methodology**

The present work uses computational approach in the domain of linear harmonic oscillator using Scilab open source software tool [8]. This performs numerical computation, data analysis, plotting, system modeling and simulation. The first step involves modeling of second order differential equation of motion using Xcos . The modeling created to study the dynamics of the motion of a particle of mass for free oscillations, damped oscillations and forced oscillations necessitates Newton's equation of motion [9]. Xcos consist of two windows ie., edit window and pallet browser. The model of harmonic oscillator designed in edit window as block diagram helps in learning of underlying concept of harmonic oscillation. The model built on edit window step by step by starting with simple sine wave, free, damped and forced harmonic oscillator. This helps to create their own mental model which helps to enrich critical thinking skills such as analyzing and reasoning based on output waveforms such as displacement – time and velocity – time graph [10-11].

Model formulation

2.1 To model Simple Harmonic Oscillator (SHO), consider second order differential equation as given below.

$$m\frac{d^2y}{dt^2}+ky = 0\text{-----------}(1)$$

Where 'm' represents oscillating mass, 'y' represents displacement, 'k' represents spring constant and d^2y/dt^2 represents acceleration of the oscillating mass.

Re-arrange the equation (1) and express in terms of acceleration

$$\frac{d^2y}{dt^2} = -\omega^2 y \text{------------}(2)$$

Where ω^2= k/m is the natural angular frequency in rad/s

The equation (2) pictorially represented is shown on Fig 1.

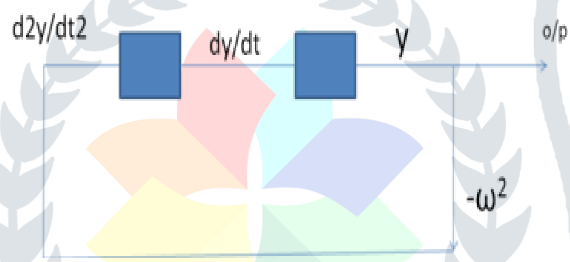


Fig. 1: Pictorial representation of SHO

The two solid blocks shown in the above figure represents integral operation steps. The output wave form can be visualised using oscilloscope. The natural angular frequency $\omega = 2\pi f$ should be computed by considering natural frequency 'f' as an input variable and observed the output wave form by running the simulation.

2.2 Damped Harmonic Oscillator (DHO) modelled using Xcos tool using the differential equation given below.

$$m\frac{d^2y}{dt^2}+r\frac{dy}{dt}+ky=0\text{---------}(3)$$

Where 'r' is damping constant and 'k' is spring constant.

Rearranging equation (3) will get equation (4).

$$\frac{d^2y}{dt^2} = -2b\frac{dy}{dt}-\omega^2 y\text{---------}(4)$$

Where 'b=r/2m' is damping coefficient and 'ω^2=k/m' is the natural angular frequency.

The pictorial representation of damped harmonic oscillator is shown in Fig.2 clearly explains the equation (4).

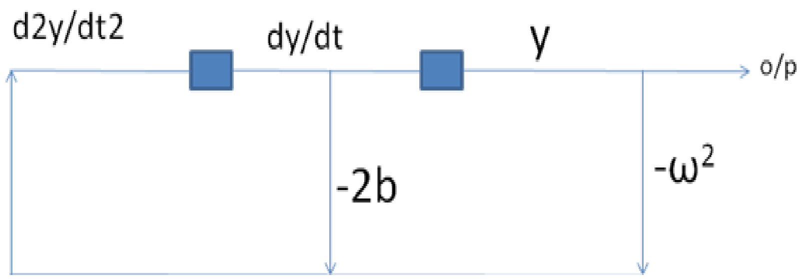


Fig. 2: Pictorial representation of DHO

2.3 Forced Harmonic Oscillator (FHO) modelled using Xcos tool using the differential equation given below.

$$m\frac{d^2y}{dt^2}+r\frac{dy}{dt}+ky = F_o\sin\omega_d t\text{---------(5)}$$

The applied external periodic force is represented by $(F_o \sin\omega_d t)$,

Where 'r' is damping constant, 'k' is spring constant, F_o is the maximum force and ω_d is the angular frequency of the driving force.

Rearranging equation (5) will get equation (6).

$$\frac{d^2y}{dt^2} = -2b\frac{dy}{dt}-\omega^2 y + F_o\sin\omega_d t\text{ ---------(6)}$$

Where '$b=r/2m$' is damping coefficient and '$\omega^2=k/m$' is the natural angular frequency.

The forced harmonic oscillator is clearly explains in the equation (6).

3.0 Results and discussion

3.1 Simulation of Sine wave

As a first step to visualise the sine wave in Xcos platform, sine wave generator, cscope and clock are imported from palette browser to edit window. Sine wave model is built using building blocks of oscilloscope, sine wave generator and clock shown in Fig. 3a. Frequency of 1 rad/s and magnitude of displacement 1m is set in signal generator. Refresh period is set for 30 s in single scope and simulation time is set for 30 s and run the simulation.

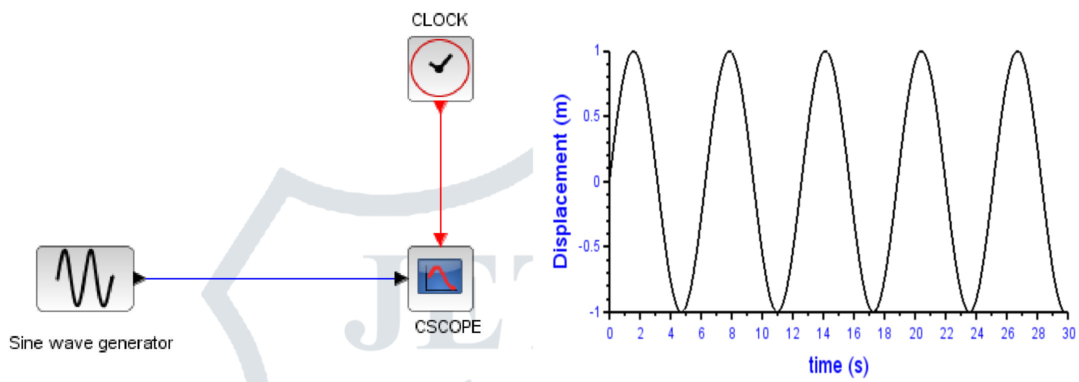


Fig. 3. Xcos model for sine wave (3a) and its wave form simulation (3b)

The output sine wave is shown in Fig 3b. The wave form shows displacement 1m matches the input data fed to sine wave generator. It can also be observed that the time period of 6.28s on the output wave form matches with the input frequency 1 rad/s fed to sine wave generator.

3.2 Simple Harmonic Oscillator (Free oscillator)

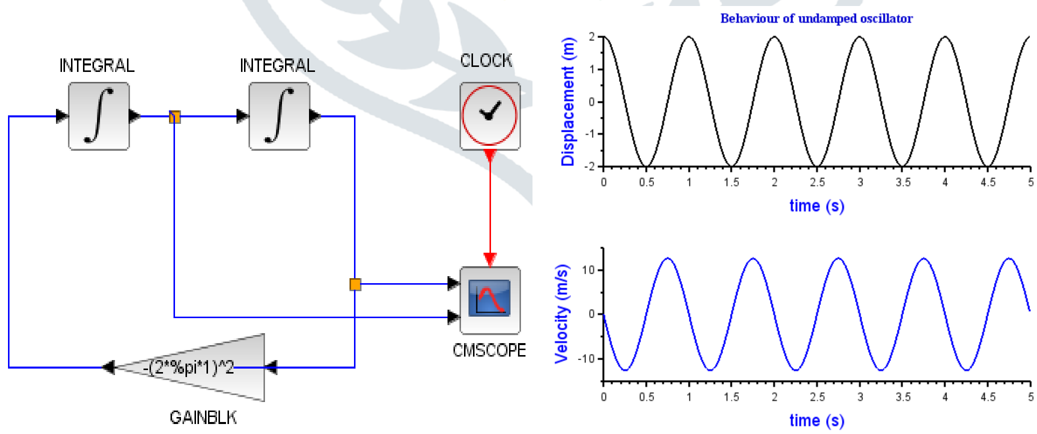
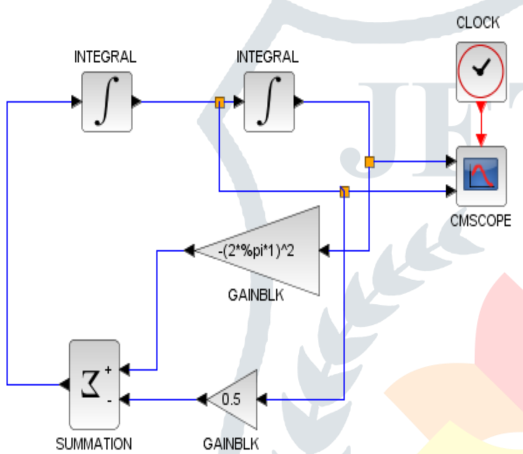


Fig.4 Xcos model for simple harmonic oscillator (4a) and its output wave forms (4b)

Xcos model for simple harmonic oscillator and its output wave forms are shown in Fig.4a and 4b respectively. Frequency of 1 Hz is fed to the gain block as shown in the Fig.4a and initial condition is set in the second integrator block as 2 (Amplitude). The displacement – time graph (channel 1) is observed in Fig.4b . The displacement- time graph clearly show the time period 1s due to input frequency 1Hz in gain block which validate the model. By setting the amplitude value A = 2m in second integral block, at time t=0s it is observed that displacement is maximum (y = A) and the velocity is minimum (v = 0) as shown in the Fig. 4b. The maximum velocity is calculated using the formula $v=\omega\sqrt{A^2-y^2} = A\omega = 12.56\ m/s$ observed and validated in the output waveform. This stimulate the critical thinking in the learner to correlate the mathematical equation and the graph, which helps to identify as simple harmonic oscillation based on output waveform of displacement - time and velocity –time graph.

3.3 Damped Harmonic Oscillator (Under damped condition)

Xcos model for damped harmonic oscillator and its output wave forms for under damped condition are shown in Fig. 5a and 5b respectively.



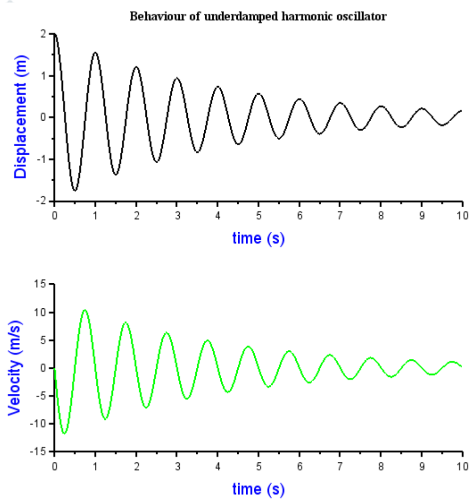


Fig 5. Xcos model for Damped harmonic oscillation 5(a) and its output waveform 5(b).

In the damped harmonic oscillator natural frequency is set for 1Hz in the first gain block and damping coefficient 'b' as 0.5 in second gain block which is connected to middle position of two integrator blocks. Since natural frequency is 1Hz and natural angular frequency 'ω' is 6.28 rad/s, and the damping coefficient 'b' is 0.5, the condition is b <<< ω executes under damped oscillation. The exponential decay of displacement and velocity validates the under damped harmonic oscillation shown in Fig.5b. To understand the behaviour of critical and over damped harmonic oscillation, the value of damping coefficient 'b' is computed using the condition b = ω and b >>> ω respectively. The observed output wave forms are shown in Fib. 5c and 5d respectively.

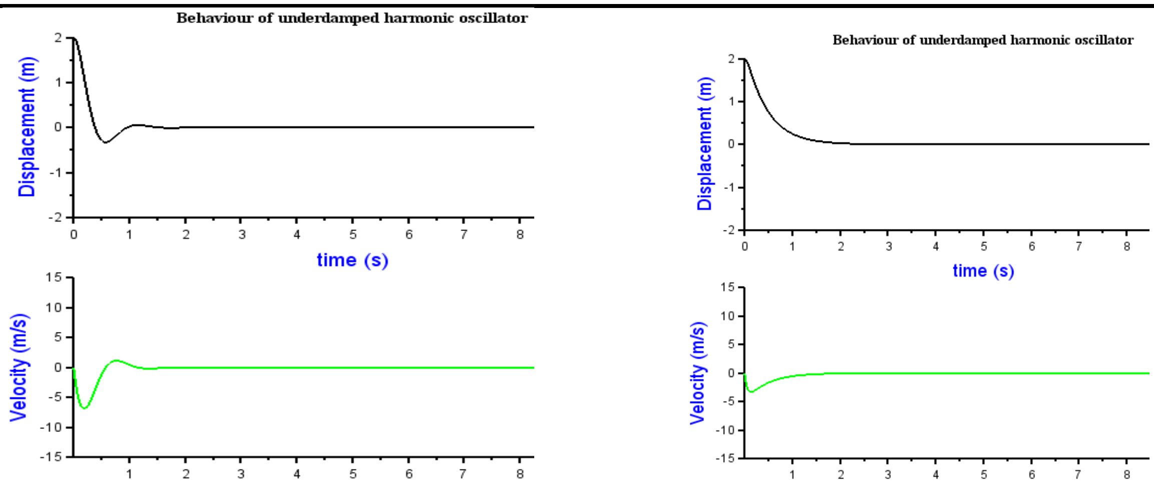


Fig. 5. Output wave forms for critical (5c) and over damped (5d) harmonic oscillator.

It can be observed from Fig. 5c and 5d that the oscillating mass comes to rest position without performing oscillation. But it is clearly indicate that the oscillating mass takes longer time to reach mean position (y=0) in over damped condition when compared to critical damping condition. This is very much essential condition required in design thinking of automobile industry where the fabrication of spring damper system places a major role locomotive system. This inculcates the concept in the learner through critical thinking by analysing the output waveforms of underdamped, critically damped and overdamped condition of damped harmonic oscillator.

3.4 Forced Harmonic Oscillator (Resonance Condition)

Xcos model for forced harmonic oscillator and its output wave forms are shown in Fib. 6a and 6b respectively. Forced harmonic oscillator is used to sustain the oscillation by applying external period force. We have added external source block (sine wave generator) and shown in Fig. 6a.

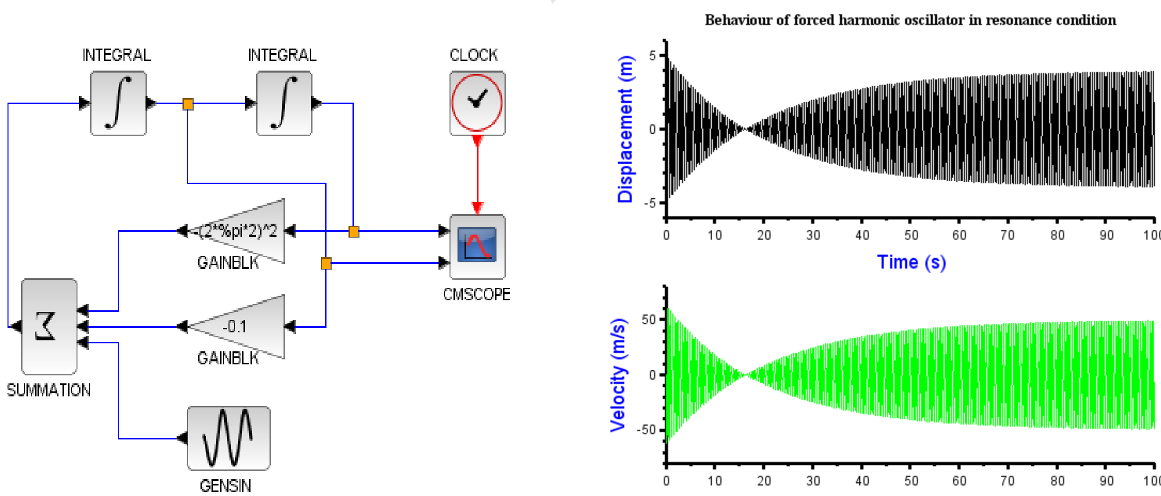


Fig. 6 Xcos model for forced harmonic oscillator (6a) and its output wave form (6b)

In the case of damped oscillations, the amplitude of oscillations decrease with the time exponentially due to dissipation of energy and the body eventually comes to mean position. When a body experiences vibrations due to the influence of an external driving force the body can continue its vibration without coming to a rest. Such vibrations are called ***forced vibrations/oscillations***.

The forced harmonic oscillator is set for resonance condition where the natural frequency (ω) is equal to the applied frequency (ω_d). Natural frequency and applied frequency is set for 2Hz in gain block and sine wave block and both the amplitudes to be set as 5. In cmscope, y-axis scale at channel 1 is set as 5 and at channel 2 is set as 70 because displacement (y =A= 5m) and velocity (v =Aω= 62.8m/s). The observed output waveforms displacement-time and velocity-time given in the Fig. 6b shows that the amplitude of oscillator decreases initially in the transient region due to damping force observed for short duration (17 s) and further oscillating mass picks up the frequency (ω_d) due to external periodic force reaches steady state condition and vibrates with constant amplitude. This helps to visualise the output waveform that how oscillating mass picks up the external periodic frequency and vibrates with the constant amplitude.

4.0 **Conclusion**:

Learner can understand the basic concepts of oscillations by analysing Xcos model for simple, damped and forced harmonic oscillation. The Xcos harmonic oscillator model formulated by applying suitable initial parameters such as natural angular frequency, damping coefficient and external periodic force and the corresponding output waveforms can be visualised by running the simulation model. The identification of correct input parameters and critical thinking skills which are most vital to recognize and analyse the nature of oscillation. To validate, we fed the experiment data to Xcos simple harmonic oscillator model and observed the output waveform for simple harmonic oscillation. Similarly repeated for damped and forced harmonic oscillator which extend to analyze engineering problem such as filter circuits, tuning circuits and real life applications through learning by doing.

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