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Simulink Model for Teaching the 'Stick–Slip' Friction Phenomenon in 'Machine Vibration and Noise' course

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One of the most essential competencies that all mechanical engineers need to acquire during their studies is the ability to model and simulate problems and mechanical systems, in order to be able to predict the influence of parameter changes and optimise the solving of any problems. Simulation programs such as 'Simulink' can be applied in Mechanical Engineering, not only as Design tools but also for Teaching. The Simulink models that have been developed to supplement theory classes can be at the students' disposal, so that they can check the influence of changes on different system parameters and properties. The theoretical study of the 'stick–slip' friction phenomenon, which appears in some low-speed contacts, and its simulation using Simulink is presented. The influence of parameter changes is also presented and explained as an essential part of the Design Criteria. In the 'Machine Vibration and Noise' course at Universidad Politécnica de Madrid, several Matlab and Simulink simulators of real problems related to vibrations in machines or installations are being used as teaching tools. The 'stick–slip' phenomenon simulator is detailed as an example.

Keywords: Mechanical systems simulation; Simulink and Matlab; educational innovation; 'stick–slip' phenomenon

INTRODUCTION

MECHANICAL SYSTEMS with contacts between elements, where one surface slides over another surface with dry or insufficiently lubricated contact, are usually doomed to suffer autoexcited vibrations due to friction. Under some operating conditions, the movement becomes unstable and these vibrations increase with time, causing damages to the system.

In many machine elements, the relative motion between pieces is intermittent, which produces noticeable autoexcited vibrations that are sometimes a danger to the machine's integrity and are uncomfortable for users, due to unpleasant noise (Ibrahim, 1994).

Autoexcited vibrations with dry contact have been widely studied; they can appear as a response to a variety of mechanisms (D'Souza and Dweib, 1990) and promote various phenomena as mentioned by some authors (Spurr, 1961; Brockley, Cameron and Potter, 1967; Jarvis and Mills, 1963).

Of these, the 'stick–slip' phenomenon usually occurs at low speeds and because the static friction coefficient is greater than that of the dynamic friction. During adherence, potential energy is stored due to the elasticity of the system. During sliding, the potential energy stored almost instantly turns into kinetic energy. The periodic vibration curve thus has a saw-tooth shape (Ko and Brockley, 1970).

Above a critical sliding velocity the 'stick–slip' disappears (Brockley and Ko, 1970; Singh, 1960). However the occurrence of this phenomenon is difficult to predict because friction cannot be modelled as a simple parameter as it also depends on several features of the mechanical system under consideration. In such problems the use of simulation tools plays a special role as explained in this paper.

The theoretical study of the 'stick–slip' friction phenomenon that appears in some low-speed contacts and its simulation using Simulink is presented. This phenomenon has been modelled with the help of the 'mass-actuator' problem, as considered previously by some authors. However using Simulink in such a complex way for its simulation has not previously been reported.

The influence of parameter changes is also presented and explained as an essential part of the design criteria and helps to show the importance of using simulation tools for solving and comparing solutions of complex problems.

Such a simulator can also help to predict the evolution of the mass-actuator system as a function of different parameters and to study the appearance of the stick–slip phenomenon. It can

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also be used as a design tool for machine elements with low-speed or dry sliding contacts.

For teaching applications it is also really useful to have some Simulink models as examples of different dynamic problems. These models can be used during theory lessons to show students, in a quick and easy way, the effects of parameter modification in all types of engineering systems.

The 'stick–slip' model explained below is used as an example of autoexcited vibration in the subject 'Machine Vibration and Noise' course, taught at the fourth course of the Mechanical Engineering Degree at Universidad Politécnica de Madrid (www.upm.es). It has helped to show student complex effects of parameter changes, such as the fact that instability due to friction can be minimised by increasing the difference between static and dynamic friction or by increasing the velocity of actuation, the spring constant, the mass or the damping factor.

These models and examples can be placed at the students' disposal thanks to e-Learning and b-Learning tools, such as Moodle or Aulaweb (García Beltrán), which allow students to revise the acquired concepts, to study the effects of data change and to obtain conclusions, both quantitative and qualitative, for machine design and problem solving.

Simulink has been used for our subject because of its appealing visual nature and the ease of system construction that it offers. After the model and simulation are explained, the level of acceptance of this kind of simulation tool among students is discussed.

We truly believe, as obtained from the results given in this work, that computer tools help to develop students' intuition and allow them to focus on the results of an analysis rather than on the steps required to obtain a solution. Simulink, for instance, enables students to integrate equations of motion easily, allowing them more time to focus on the meaning of the solution.

THE MATHEMATICAL MODEL OF THE STICK–SLIP FRICTION PHENOMENON: THE MASS AND ACTUATOR PROBLEM

The 'stick–slip' phenomenon is a common case of autoexcited vibration caused by successive slipping and sticking at a frictional interface with the following characteristics.

- The amplitude is not time-dependent.
- There is no external force responsible for the excitation and the system does not answer with its natural frequency.
- Oscillations are non-harmonic.

As there is no external periodic force (the excitation belongs to the system itself), the parameters of the mechanical system must be modified in order to remove the 'stick–slip' vibration (Den Hartog, 1964).

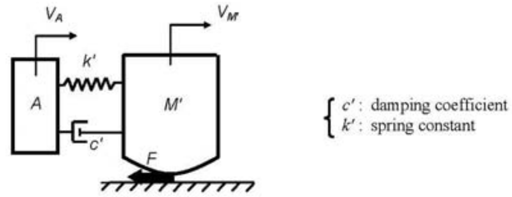

Fig. 1. Diagram of the 'mass-actuator' problem to study the 'stick–slip' phenomenon.

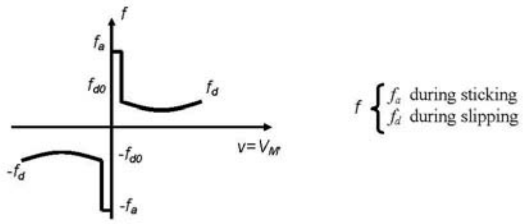

Fig. 2. The relationship between friction coefficient f and sliding velocity $V_{M'}$.

A simple mechanical system that is useful for studying 'stick–slip' is shown in Fig. 1. In this system, a mass M' is being pushed along by an actuator A, with a constant driving velocity V_A. The mass moves with a velocity $V_{M'}$ and vibration appears as a result of the change in the friction force F (Halling and Eaton, 1975). This model takes into account damping, inertial forces and a Stribeck friction curve as shown in Fig. 2.

This model can help students to study low speed contacts between machine elements such as brakes, shock absorbers, clutches, machine tools, hinges, dry contacts, violins, AFM probes and other mechanical systems (Den Hartog, 1964; Bell and Burdekin, 1970; Kato, Matsubayashi and Sato, 1972).

At the start, mass M' sticks to the floor, with a friction coefficient f_a. When the actuator A moves, the different elements become the following efforts:

$$\text{Damper: } c' \cdot V_A$$
$$\text{Spring: } k' \cdot = k' \cdot V_A \cdot t$$

where $\rho = V_A \cdot t$ is the spring deformation (shortening) and t the time.

At time t_0 the force over the mass M', reaches the adherence limit force F_a:

$$c' \cdot V_A + k' \cdot V_A \cdot t_0 = F_a$$

and mass M' begins to slide, with an acceleration given by:

$$\ddot{\rho}_0 = \frac{F_a - F_{d0}}{M'} = \left(\frac{dV_{M'}}{dt}\right)_0$$

During the movement of M' the equation of motion is similar to a simple one degree-of-freedom system:

$$M'\left(\frac{dV_{M'}}{dt}\right) + c' \cdot \dot{\rho} + k' \cdot \rho + F_d = 0$$

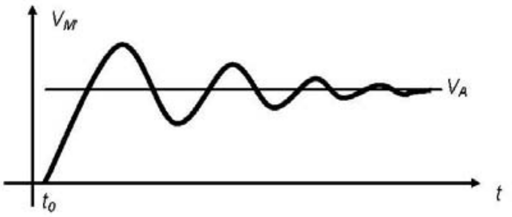

Fig. 3. Possible evolution of mass M' (velocity vs. time).

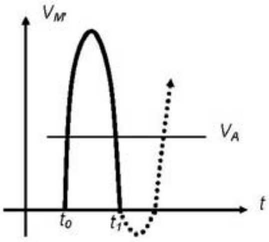

Fig. 4. Another possible evolution.

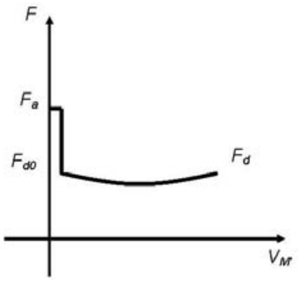

Fig. 5. Friction force F as a function of sliding velocity $V_{M'}$.

Under some boundary conditions VM' quavers and tends to VA, as shown in Fig. 3.

But if the oscillation is too intense, the behaviour is as explained in Fig. 4. At time t_1 the mass velocity $V_{M'}$ becomes zero, remaining the mass stuck again to the surface, together with and increase of friction force from its sliding value (F_d) to its value during sticking (F_a), as shown in Fig. 5.

Adherence continues until the combined forces from spring and damper over the mass again reach the value of the friction force F_a. Thus, at time t_2 sliding begins anew and the 'stick–slip' phenomenon continues indefinitely (Fig. 6).

As explained above, the equation of motion during sliding is:

$$M'\left(\frac{dV_{M'}}{dt}\right) + c' \cdot \dot{\rho} + k' \cdot \rho + F_d = 0$$

which can also be expressed as shown in Fig. 7:

$$M'\ddot{\rho} + (c' - \lambda) \cdot \dot{\rho} + k' \cdot \rho + (F_{d0} - \lambda \cdot V_A) = 0$$

with the relationships explained in Fig. 8. Being the

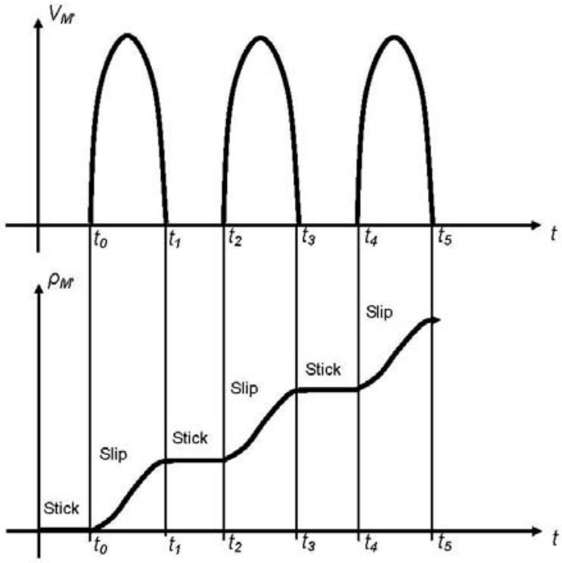

Fig. 6. Velocity and displacement of the mass under 'stick–slip' conditions.

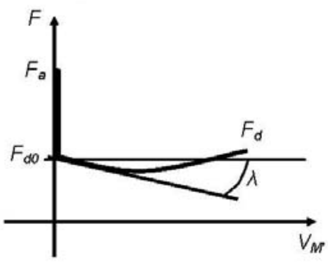

Fig. 7. Slope of Stribeck friction curve.

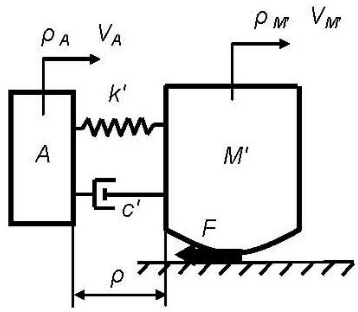

Fig. 8. Model parameters.

last term of the differential equation constant, it can also be expressed as:

$$M' \cdot \ddot{\rho} + (c' - \lambda) \cdot \dot{\rho} + k' \cdot \rho = 0$$

whose solution and subsequent studies in the field have been published previously (Beranek, 1992; Bautista E. and Bautista A., 1994; Feeny, Guran, Hinrichs and Popp, 1998; Wensrich, 2005).

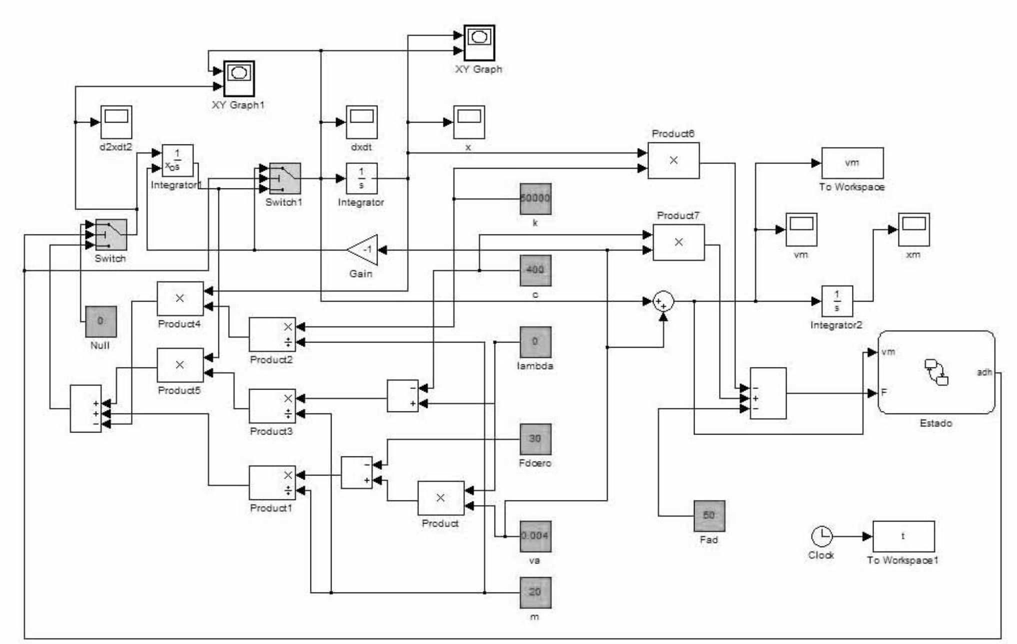

Fig. 9. Simulink model for the 'stick–slip' friction problem.

SIMULATION OF THE PROBLEM WITH HELP OF SIMULINK

The great help of simulation tools: the mass-actuator problem and the 'stick–slip' phenomenon

One of the most essential competencies that any mechanical engineer needs to acquire during his or her studies is the ability to model and simulate problems and mechanical systems, in order to be able to predict the influence of parameter changes and optimise the solving of any problems.

At Universidad Politécnica de Madrid, Matlab and its simulation tool Simulink are commonly used for the simulation of kinematic and dynamic problems. In the 'Machine Vibration and Noise' course, simulations of real problems are used as examples for increasing the understanding of the theory lessons. The Simulink model for studying the 'stick–slip' phenomenon is explained below with two different applications. This phenomenon is responsible of noise, wear and damage between machine elements and the simulator that has been developed can help to predict or solve functional problems.

Figure 9 shows a simulator block-diagram that represents and solves the mass-actuator problem used to study the stick–slip phenomenon, according to the equations and data explained in the previous chapter.

The mass-actuator problem has a special feature: when the problem data and boundary conditions lead to the appearance of the 'stick–slip' phenomenon, the differential equation necessarily changes to represent the difference in behaviour between sliding and sticking.

During sliding, the equation of motion is:

$$M'\left(\frac{dV_{M'}}{dt}\right) + c' \cdot \dot{p} + k' \cdot \rho + F_d = 0$$

During sticking, the equation of motion is:

$$VM' = 0$$

The change from sticking to sliding appears when the spring and damper forces become greater than adherence force. The change from sliding to sticking takes place when VM' becomes negative and the spring and damper forces cannot overcome the adherence force. These conditions are represented schematically in the Stateflow block shown in Fig. 10.

- Condition for changing from the sticking to the sliding equation:

$$c' \cdot V_A + k' \cdot V_A \cdot t > F_a$$

(t represents the time from the start of sticking)

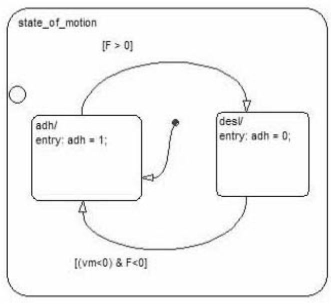

Fig. 10. Stateflow. Simulink block that controls the change in differential equation.

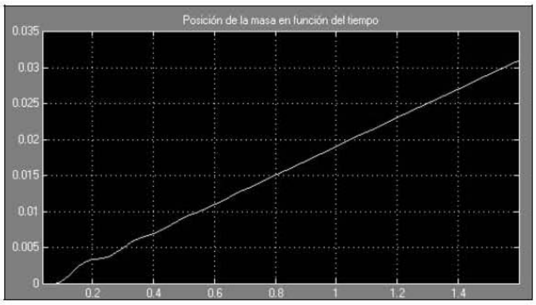

Fig. 11. Mass displacement (m) as a function of time (s).

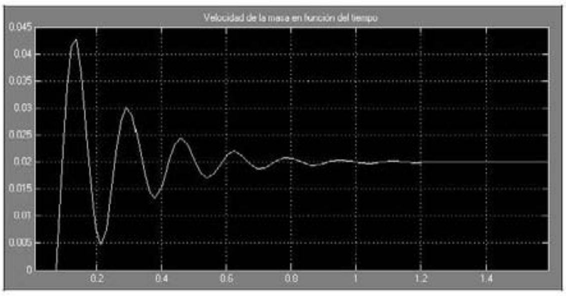

Fig. 12. Mass velocity (m/s) as a function of time (s).

- Conditions for changing from sticking to sliding equation:

$$V_{M'} < 0 \quad \& \quad c' \cdot V_A - k' \cdot \rho < F_a$$

The simulator is next used to simulate the mass-actuator problem under different conditions, so as to study the 'stick–slip' appearance. The data of the first simulation lead to stability; however, the low actuation speed during the second simulation promotes the 'stick–slip' phenomenon.

First simulation example: steady sliding

The problem data for the first example as used in the 'Machine Vibration and Noise' course for teaching the mass-actuator problem are:

Mass	$M' = 20$ kg.
Spring stiffness	$k' = 30000$ N/m.
Viscous damping	$c' = 200$ N s/m
Adherence friction force	$F_a = 50$ N
Friction force during sliding	

$$Fd = F_{d0} - \lambda \cdot V_M = 30 - 0.0001 \cdot V_M \text{ N}$$

Actuation velocity	$V_A = 0.02$ m/s

The following figures show the main results of the simulation for the mass-actuator problem described above using the Simulink model developed at Universidad Politécnica de Madrid. From the start the mass remains stuck to the surface until spring and damper forces overcome the adherence force and the mass begins to move. A damped vibration develops until finally mass and actuator move with the same velocity (system stability).

Figure 13 shows how, during movement, the difference in velocity and acceleration between mass and actuator become zero and stability of the mechanical system is reached.

The following example shows how a reduction in actuation velocity makes the 'stick–slip' phenomenon appear. This phenomenon can commonly be found in door hinges, window frames, object dragging and other everyday situations.

Second simulation example: 'stick–slip' phenomenon

The problem data for the second example are (only the actuation velocity is changed):

Mass	$M' = 20$ kg
Spring stiffness	$k' = 30000$ N/m
Viscous damping	$c' = 200$ N s/m
Adherence force	$Fa = 50$ N
Friction force during sliding	

$$Fd = F_{d0} - \lambda \cdot V_m = 30 - 0.0001 \cdot V_M \text{ N}$$

Actuation velocity	$VA = 0.01$ m/s

The following figures show the main results of the second simulation. The 'stick–slip' appearance of the phenomenon can easily be observed, as the mass velocity periodically becomes zero.

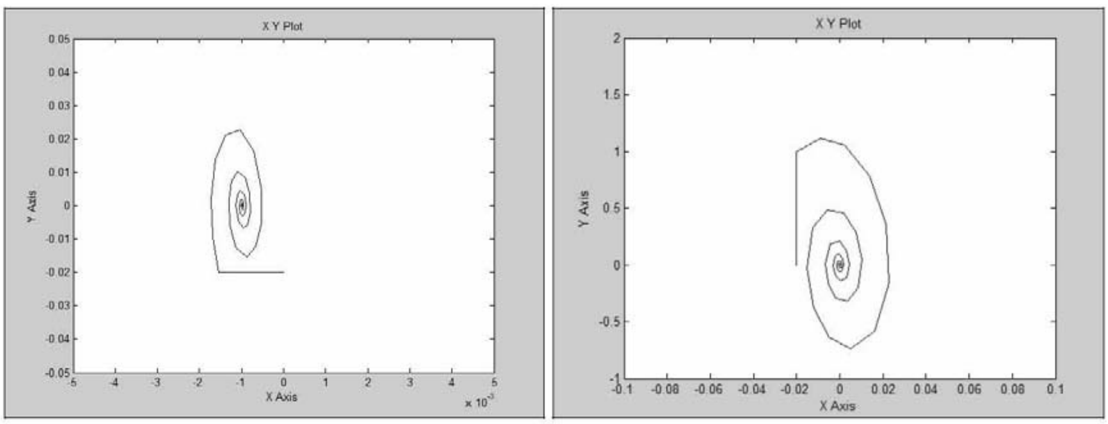

Fig. 13. System polar diagram (stability): (a) difference in velocity between mass and actuator ($\dot{\rho}$) as a function of the distance between them (ρ) and (b) difference in acceleration between mass and actuator ($\ddot{\rho}$) as a function of the velocity between them ($\dot{\rho}$).

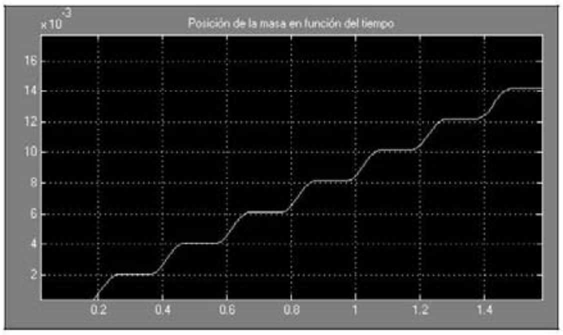

Fig. 14. Mass displacement (m) as a function of time (s).

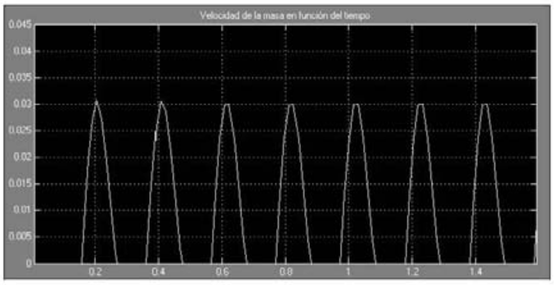

Fig. 15. Mass velocity (m/s) as a function of time (s).

Figure 16 shows how neither the difference in velocity nor acceleration between mass and actuator become zero and therefore the mechanical system does not reach a stable situation.

The examples have shown the influence of actuation velocity on the mechanical system behaviour, but the model also allows students to change and to study the effects of all the other system parameters such as mass, spring stiffness, viscous damping and the friction curve, which leads students to a better understanding of the whole problem.

EVALUATION OF THE USE OF SIMULINK IN A 'MACHINE VIBRATION AND NOISE' COURSE

The Simulink models that have been developed to supplement theory classes are at the students' disposal (on the following website: www.aulaweb.etsii.upm.es) so that they can study the concepts acquired in depth. The models available are listed below and the total number of downloads is shown in Table 1.

These simulations, especially the most complex ones such as the 'Mass-actuator problem' explained above, help to achieve the following major teaching aims of the 'Machine Vibrations and Noise' course, greatly reducing the time needed to be expended before introducing these tools. It is important to note that the emphasis in the course is on conceptual understanding of the basis of machine vibration and of the main strategies for problem solving. This involves a great deal of visual interpretation, and some calculating ability involving numbers and formulae, of course, but the hand calculation is not the central goal. The main aims of the course, the attainment of which is boosted using the simulation programs, are:

- to learn to model mechanical systems;
- to learn to adjust the design parameters such as mass, damping and stiffness;
- to model systems where the differential equation changes (using the Stateflow block);
- to analyse the sensitivity of the response when faced with a variation in parameters.

The average number of downloads of the different Simulink examples reached 94% during the 2006–2007 course. This result is noteworthy and gives an indication of the level of acceptance of simulation tools among students, as a support for a better understanding of the subject.

At the end of the course, a questionnaire was given out to collect the students' impressions of the subject. A total of 46 students (out of 52 registered

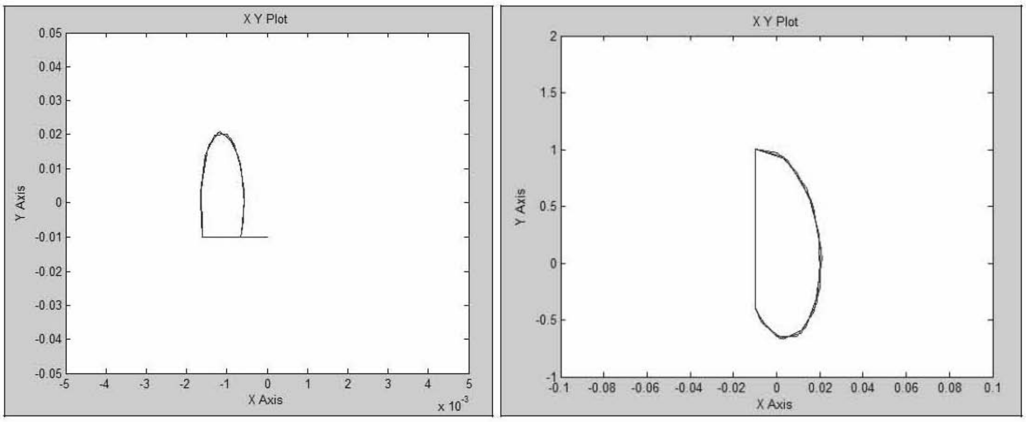

Fig. 16. System polar diagram (stability): (a) difference in velocity between mass and actuator ($\dot{\rho}$) as a function of the distance between them (ρ); (b) difference in acceleration between mass and actuator ($\ddot{\rho}$) as a function of the velocity between them ($\dot{\rho}$).

Table 1. Simulink models and number of downloads.

Didactic Simulink models		No. of downloads (98 students)
System with 1 degree of freedom	Mass with spring and damper	94
System with 1 degree of freedom	Packaging problem	84
System with 1 degree of freedom	Unbalanced engine	70
System with 1 degree of freedom	Resonance study	71
System with 2 degrees of freedom	Two masses in series	96
System with 2 degrees of freedom	Automobile suspension	95
System with 2 degrees of freedom	Mass with perpendicular springs and dampers	76
System with 2 degrees of freedom	Vibration absorber	77
Stick–slip vibrations	Mass-actuator problem	94
Self-excited vibrations	Van der Pol's equation	84
Self-excited vibrations	Variable force	90

Table 2. Students' personal scores.

Concept	Score (from 1 to 5)	Standard deviation
Simulation tools		
Importance of simulation tools for solving technical problems	4	0.63
Importance of simulation tools for designing machines and products	4.1	0.52
Importance of simulation tools for understanding theoretical problems	4.1	0.56
Simulinks' features		
Ease of learning	2.8	0.47
Ease of use	2.9	0.49
Versatility for studying different physical phenomena	3.7	0.72
Simulink compared with other simulation tools used during the degree	3.2	0.63
General score for the program	3.5	0.51
Evaluation of the Simulink models used as examples in the 'Machine Vibration and Noise' course		
They help you to understand theoretical problems within the subject.	3.6	0.37
They help you to predict the influence of changes during machine designs.	3.5	0.41
They are related to the theory that has been explained.	3.4	0.57
They can be used as part of the examination.	2.5	0.71
They can be useful for models that I will realise in the future.	3.3	0.32
General score for the models available.	3.4	0.34

for the subject) filled in the questionnaire. The structure is set out below in Table 2 along with the average score given by students to each section (from 1, minimum, to 5, maximum).

Some of the personal opinions and suggested improvements to the experience are given below:

- Some additional practical sessions would help to enhance the understanding and use of Simulink for simulating more complex systems.
- The number of theory classes should be reduced and the practical part of the subject boosted, especially regarding the use of simulators.

From these results it can be concluded that the scores given by the students are positive, particularly the scores for simulation aided design and the use of simulations as a way of improving their understanding of theoretical problems. However, there are still certain points that need improving and that could be tackled by designing a set of practical sessions on the use of Simulink, which would also benefit many other subjects related to mechanical engineering.

The results regarding what students actually learnt, after simulators had been introduced as teaching support tools, help to show the effectiveness of the new methodology for achieving the aims of the course.

Exam questions with similar difficulty and discrimination indexes were selected from a question database, developed over the last 20 years of teaching topics and courses related to machine vibrations, so as to assess the students' knowledge under similar circumstances. The results are shown in Fig. 17.

From this evolution it can be noted that the proportion of failures in the subject was reduced by about 4% and the proportion of students with excellent marks increased by over 10%. The mean mark also increased from 63% to 71%, with standard deviations of 15.2% and 16.3%. A total of 47 students registered for the subject the year before the Simulink experience and a total of 52 the following year, when Simulink the experience was introduced. Regarding such data, the null hypothesis 'qualification has not increased' is rejected with a confidence level of 95%, as the statistical estimator $t = 52^{1/2} \cdot (71 - 63)/15 = 3.85$ is greater than the confidence interval limit $t_{50;0.025} = 2.009$. Therefore we can consider there to be a

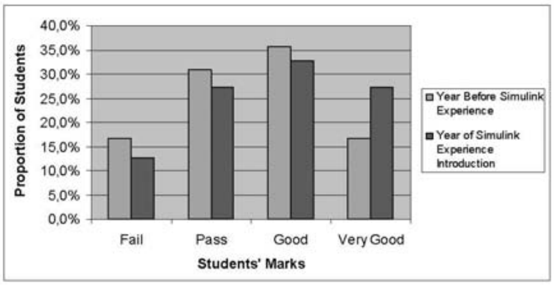

Fig. 17. Evolution of students' marks with the introduction of Simulink simulators as a learning tool.

significant increase in the students' marks after the introduction of the Simulink experience. The following experiences will help to contrast these results.

We consider Simulink models helped students to understand the basic concepts in an easier way, and so prevented failure. At the same time Simulink models were used to study in depth more complex relationships between model parameters, so that the proportion of students that acquired a profound knowledge about machine vibrations also increased.

Analysis that includes the results from current and future courses will add valuable information to the continuing validation of the benefits of using simulation tools, such as Simulink models, for optimising teaching—learning strategies in subjects related to machine vibrations and dynamics of mechanical systems.

CONCLUSIONS

Simulation tools are very powerful tools for solving engineering problems and help in the study of the effects of parameter change and to compare different solutions. They are widely used as support during design tasks, but their teaching applications are also worthy of praise due to the complex problems that they can explain in a more in-depth and easier way.

The theoretical study of mass-actuator problem, in which the 'stick–slip' friction phenomenon can appear, and its simulation using Simulink have been presented. This model and the simulator can help in the study of low speed contacts between several machine elements such as brakes, shock absorbers and clutches, and other phenomena related to dry contacts.

A broad number of engineering subjects can benefit from placing of the Simulink models or examples at the students' disposal, thanks also to e-Learning and b-Learning tools. These simulators allow students to revise the acquired concepts, to study the effects of data change and to obtain conclusions, both quantitative and qualitative, for machine design and problem solving (as well as for many other disciplines especially in mechanical, electrical or chemical engineering).

The acceptance and use of Simulink models, such as the mass-actuator simulator presented here, among students on the 'Machine Vibration and Noise' course, taught at the 4th course of the Mechanical Engineering Degree at Universidad Politécnica de Madrid, can be regarded positively. Additional practical lessons regarding the use of Matlab and Simulink are currently being prepared as a consequence of the opinions in the survey.

At the same time, as part of their assessment, students could look at real engineering problems related to different subjects and use the advantages of Simulink to build models for simulating and solving the problems found. Problem Based Learning could thereby be enhanced and active learning promoted, as we hope to do in the following experiences.

REFERENCES

1. E. Bautista and A. Bautista, Comportamiento de sistemas vibratorios de un grado de libertad con amortiguamiento por fricción bajo causas excitadoras periódicas, *VI Congreso Nacional de Ingeniería Mecánica*, (1994).
2. J. Dabney and F. Ghorbel, Enhancing an advanced engineering mechanics course using MATLAB and Simulink, *International Journal of Engineering Education*, **21**(5), (2005).
3. J. P. Den Hartog, *Mechanical Vibrations*, Dover Books on Engineering (1985).
4. M. Denny, Stick–slip Motion: an important example of self-excited oscillation. *European Journal of Physics*, 2004.
5. R. Devon, S. Bilen *et al.*, Integrated design: What knowledge is of most worth in engineering design education. *International Journal of Engineering Education*, **20**(3), 2004.
6. A. F. D'Souza *et al.*, Self-excited vibrations induced by dry friction. Part 2: Stability and limit-cycle analysis, *Journal of Sound and Vibration*, 1990.
7. J. Echavarri, Vibraciones en adherencia-deslizamiento lubricado. Aplicación a amortiguadores de automóviles, Ph.D. thesis, Universidad Politécnica de Madrid, (2006).
8. S. Esche, PBL in a course on mechanics and machine dynamics, *World Transactions on Engineering and Technology Education*, **1**(2), 2002.
9. A. García Beltran, User interface and features of Aulaweb e-learning system, *Proceedings of the II International Conference on Multimedia and Information & Communication Technologies in Education*, (2003).
10. M. S. Habib, Enhancing mechanical engineering deep learning approach by integrating MATLAB/Simulink into its curricula, *International Journal of Engineering Education*, **21**(5), 2005.

11. R. A. Ibrahim, Friction-induced vibration, chatter, squeal, and chaos. Part I: Mechanics of contact friction, *ASME Applied Mechanics Reviews,* 1994.
12. M. Muraki *et al*., A laboratory simulation for stick–slip phenomena on the hydraulic cylinder of a construction machine, *Tribology International*, 2003.
13. A. Smaili, N. Attalah and F. Zeineddine, SoftLink: A MATLAB /Simulink based code for the analysis, synthesis, optimization and simulation of mechanisms, *International Journal of Engineering Education*, **21**(5), 2005.
14. S. Timoshenko and D. H. Young, *Vibration Problems in Engineering*, 3rd edn, Stanford University, (1955).
15. C. Wensrich, Stick–slip motion in harmonic oscillator chains subject to Coulomb friction, *Tribology International,* 2005.
16. J. A. Williams, *Engineering Tribology*, Oxford Science Publications, (1994).

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