THE DYNAMIC SIMULATION AS INNOVATIVE TOOL IN THE TEACHING OF THE MECHANICAL ENGINEERING

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Abstract — *Till a few years ago, the analysis of movements in mechanisms and machines derived of the application of the conventional theories, required a long time of problem resolution. Therefore, these theories were difficult to be applied in the field of design. The possibility to automate these calculations by modelling tools means a challenge to the use of these new methodologies in the industrial environment. In regards to the design of a product, it becomes more and necessary having tools that besides generating the group of planes, lists of elements, etc., allow to have a clear idea about how the system will work. Up to date, the teaching in the field of mechanisms and machines was of complicate illustration, since it was to explain the operation of the mechanical systems, without having tools that allowed to display the movement of the different components. This had to be carried out through static images for certain positions of the system (transparencies, drawings on blackboard,...).*

Index Terms — *Mechanisms, Simulation, mechanical system, tridimensional modelitation.*

INTRODUCTION

At present there are many different tools available in the field of mechanical engineering for product design that cover both dynamic simulation and resistant behaviour. This paper presents a wide spectrum of these tools and applications for teaching purposes.

Firstly, this paper analyses the state-of-the-art of these computer tools for the different fields of mechanical engineering, and then it provides specific applications for teaching purposes.

With respect to the first aspect aforementioned, there are many computer programmes available for mechanical engineering. Different fields of implementation of these new approaches can be distinguished. One of such areas is the simulation of 2-D mechanical systems, including the static calculation of problems, and kinematic and dynamic problems of flat mechanisms.

The present tend is to consider product design as a global system. It consists of grouping all the processes related with product engineering in the so-called combined engineering. The principle of this approach is to consider all the stages involved in product design.

The first stage of this approach is 3-D product modelling. This will allow to accurately know product geometry, thus permitting to check assembly interaction, product technical characteristics (volume, mass, inertia, etc), assembly rendering for a better understanding of product geometry and promotion in marketing campaigns, drawing and layout of product components to illustrate assembly and maintenance instructions, etc.

The second stage of the process consists of simulating the dynamic behaviour of the product component assembly. Once the product has been modelled, the dynamic simulation of the product is carried out. At this stage, the different connections and links between the components of the product are established in order to calculate the external factors acting on the product, such as loads and forces, movement constraints, etc. The internal behaviour of the product components can be obtained from this model, thus allowing to determine the optimal geometry of the product.

The following stages of product analysis consist of studying the resistance of the different components of the product, characterisation for product manufacturing, etc. The present trend of computer software is to combine all these stages in only one programme, available from different working stations. The first stage of product design is included in the analysis software packages and from the results obtained in the dynamic analysis of the product, the programme permits to obtain the internal stresses and deformations of the product components.

The following sections of this paper analyse the aspects related with dynamic simulation and resistant behaviour and their application to the development of multimedia tools for teaching purposes.

THE FIRST STEP IN THE SIMULATION OF MECHANICAL SYSTEMS

Due to the complexity of some mechanisms and the difficulty of calculation and analysis, it is necessary to use computer programmes that analyse their behaviour and solve the calculations in a fast and efficient way.

Dynamic simulation offers the possibility of providing engineering students with a better understanding of

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mechanical systems. The combination of drawing and mathematical tools allows to develop complex models that simulate the physical world.

Conceptual design tools allow users to develop models, to simulate their operation, and to analyse them in a fast and simple way, providing accurate results for 2-D models, velocity analysis, analysis of the forces generated between in-contact or colliding bodies. They can also serve for the visual display of moving systems in analytic methods in the classroom.

The possibility of finding out "what would happen if" without the need to construct prototypes, and of making the learning process easier for both the teacher and the student, who understands the movement of the system more easily than with the static representations provided in the book, transparencies or blackboard.

Simulation programmes allow to obtain multiple versions of one product design, and to check, verify and assemble the product components very fast. They also offer a wide range of possibilities for the linkage of product parts, force definitions, momentum, or the elements that provide movement to the system. It is a fast cycle of construction, definition, simulation and analysis that helps to optimise product design.

In addition, calculation sheets and mathematical analysis programmes can be used for data input for the equations, and product geometries can be retrieved from other CAD programmes for complex designs.

Yield system results can be obtained in the form of numbers, graphs or vectors, allowing the use of both the imperial and metric units.

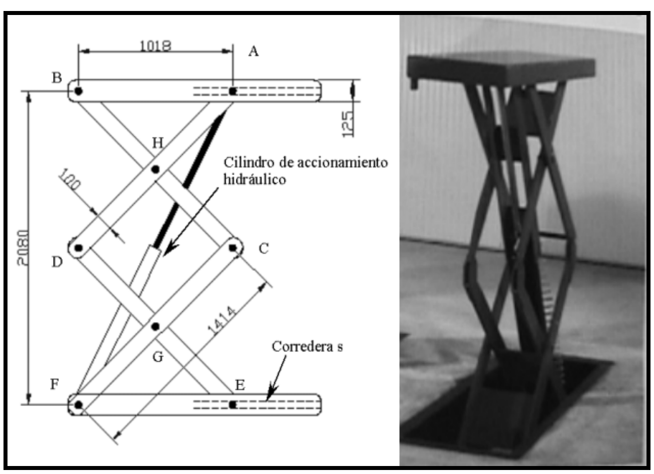

FIGURE. 1
DIAGRAM OF A FLAT MECHANISM CORRESPONDING TO A LIFTING BENCH.

Simulations can be seen on a wide range of representations. For example, the collision of two automobiles can be displayed using a simulation model that represents the vectors bar graph (velocity, acceleration, force, ...) and numerical values. The visual display of these representations allows for a better understanding of the concepts studied.

Therefore, dynamic simulation reduces costs and time, improves forecasting and provides a better analysis of product design, permits the easy re-definition and modification of product design parameters at any stage of the design process, guide product design in the correct direction to determine the best configuration under different working conditions or in-service conditions.

The following sections describe the procedure to follow with a dynamic simulation programme:

For any activity to be developed, the following aspects will be taken into account: the specification of the working environment, the specification of the units to be used, the activation of other elements necessary for the construction of the model, such as grids, axes, etc. In this paper we will use the design of a lifting bench (figure 1) as a practical example to illustrate the different stages of product modelling.

The first step consists of the construction of the model. Using the basic drawing tools available in the tool bar, more or less complex geometries can be generated for the representation of different objects. for more complex geometries, other drawing programmes can be used and stored.

Each object is then labelled with a specific name and provided with a number of parameters that define its geometrical and physical features (co-ordinates with respect to a reference system, shape, dimensions, positioning angle, material, mass, etc). Once the element has been created, these properties can be edited and changed.

Once the different elements or parts of a mechanism have been obtained, the following step consists of assembling them. There are different possibilities to link the components, so that they can be embedded or fixed, articulated, or guided with spurs, and the degree of freedom can be restricted as required.

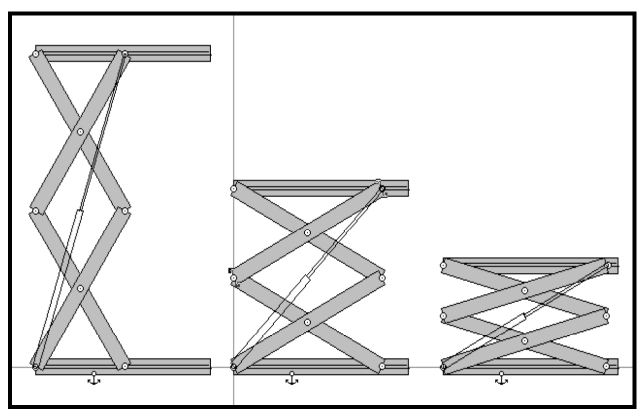

FIGURE. 2
MECHANICAL SYSTEM OF A LIFTING BENCH IN DIFFERENT POSITIONS

Subsequently, the external constraints, forces, and momentum acting on the different elements, on one or more points, are applied, with the possibility of changing the module, direction and application point, and of considering their application as a function of the variables associated with bodies or constraints.

Finally, the simulation of the operating system is performed, obtaining graphs for any position, velocity, acceleration, forces, etc of the mechanical system, and real-time display of the results. Figure 3 shows the values of the reactions and internal forces between links obtained for the example offered.

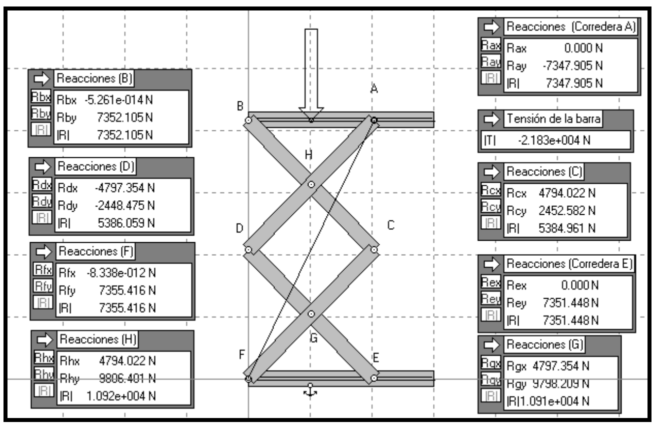

FIGURE. 3
MECHANICAL SYSTEM OF A LIFTING BENCH

PRODUCT ENGINEERING

As it has been stated in the introduction of this paper, the development of the actual product involves the modelling of the different components of the product using a 3-D modelling programme. This implies the use of these models for the implementation of the final product, including the required mechanical testing (structural resistance, heat transfer and temperature distribution, vibration analysis, etc), as well as for preparing the product for the manufacturing stage, generating the simulation of the processes of mould injection, bending or welding of the different components, and even numerical control programmes for the machining process.

PRODUCT 3-D MODELLING

The first step in product design consists of 3-D modelling. There are different tools for 3-D modelling provided by computer programmes. Usually, it consists of a number of planes and layouts from which the other operations, such as extruding, revolutions, rounding, flattening, etc, are performed to obtain the final geometry of the component. Figure 4 shows the window of a modelling programme that using different tools provides a 3-D representation of the product, and which can be used as the starting point from which to generate the required documents for manufacturing.

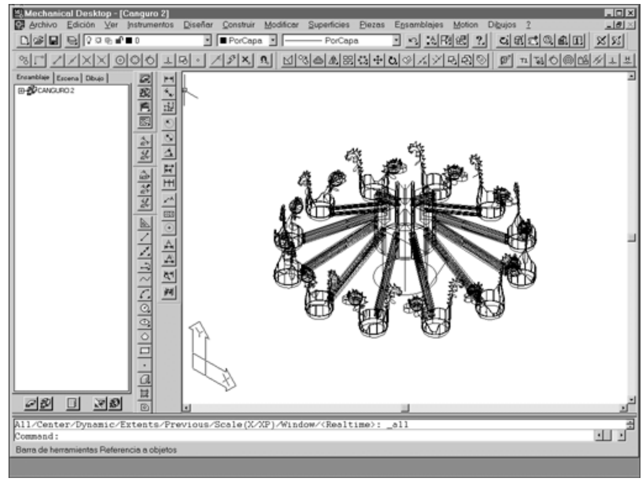

FIGURE. 4
3-D MODELLING OF AN AMUSEMENT PARK ATTRACTION

3-D assemblies are established joining the component parts depending on the constraint conditions. In this way, the pieces are positioned in relation to each other, displaying the final representation of the whole set.

One of the most relevant advantages of parametric modelling systems is the possibility of displaying any of the operations performed. In addition, the inference of the pieces can be determined, and explosion or rendering diagrams can be represented. Fig 5. shows an illustration of an explosion system.

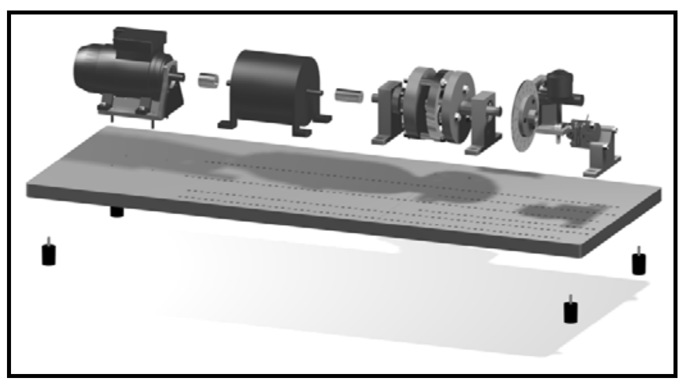

FIGURE. 5
OUTLAY OF A SIMULATION BENCH

DYNAMIC SIMULATION

An important step in actual product design is to consider the 3-D movement of the different modelled pieces. There are different programmes for system movement simulation.

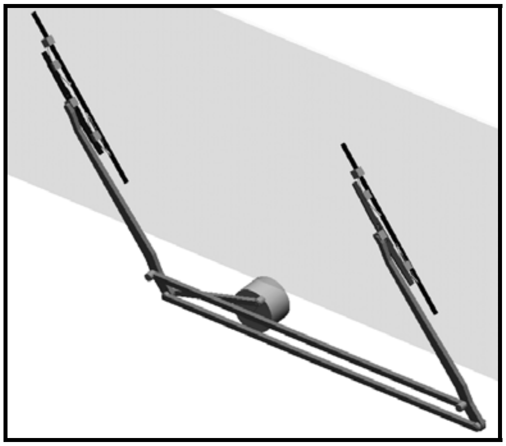

FIGURE. 6
EXAMPLE OF THE APPLICATION OF CONSTRAINTS FOR A CAR WINDSHIELD WIPER

The simulation of mechanical systems usually combines with 3-D modelling. It starts from the product geometry generated with modelling software to apply the movement constraints of the system. Fig 6 illustrates an example of such restrictions, in which for each of the bars of the articulated square mechanism of the windshield wiper system, the kinematic couples or corresponding linkages are established.

This, together with the tools available for generating system movement and for modelling elastic behaviour, stabilizer, etc, will provide a system equivalent to the actual system in which system positions, velocities, accelerations, as well as the forces and reactions acting on the different components can be determined.

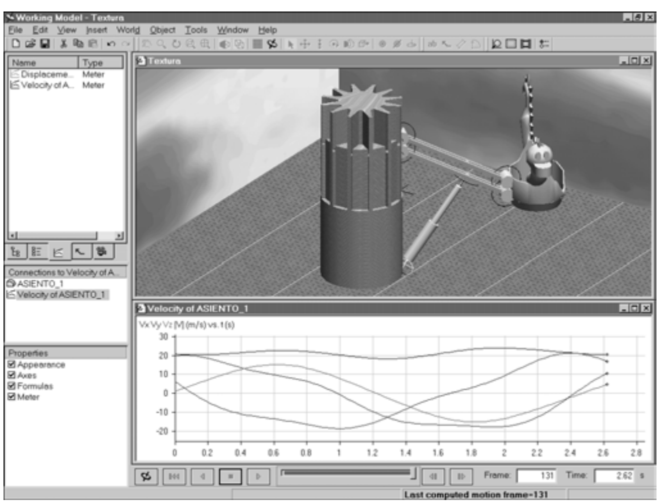

FIGURE. 7
EXAMPLE OF THE RESULTS OBTAINED WITH A DYNAMIC SIMULATION PROGRAMME

Figure 7 shows a representation of the amusement park attraction displaying the operating constraints more similar to the actual performance of the system. In addition, it includes the corresponding control systems that simulate the application of motors and hydraulic cylinders to the system, and the external forces, such as the forces caused by gravity on the different components. The results shown in the previous diagram illustrate the velocities to which human bodies are subjected in this type of machines; the values of the accelerations and total forces can also be simulated, thus providing information about the safety measures to be taken.

PRODUCT RESISTANCE ANALYSIS

An additional characteristic that can be obtained from these programmes is the possibility to perform the resistance analysis of the product. As the dynamic analysis programme can calculate the values of the reactions and internal stresses and forces acting on the different product components for each position, these values, together with product geometry and material characteristics, can be used to obtain a representation of the different deformations and stress values occurring in the pieces. Fig. 8 shows a representation of these values for the shaft of a domestic appliance.

SIMULATION AS A COMPLEMENTARY TEACHING TOOL

Once we have described the applications of the simulation programmes in the field of mechanical engineering, now we will show their advantages as a complementary teaching resource, both to obtain data results for design optimisation and to provide learning support multimedia resources.

SIMULATIONS IN THE CLASSROOM

The present possibility of using personal computers in the computer rooms of the Schools allows teachers to use the tools presented in the previous paragraphs as supporting teaching resources and improve the student's understanding of the interpretation of the results of product design.

The experiences developed by the teaching staff of the Department of Mechanical Engineering have permitted to draw certain conclusions on the topic.

Firstly, one of the most motivating factors for students is to dispose of real cases and examples that show practically the methodologies explained in the theoretical sessions.

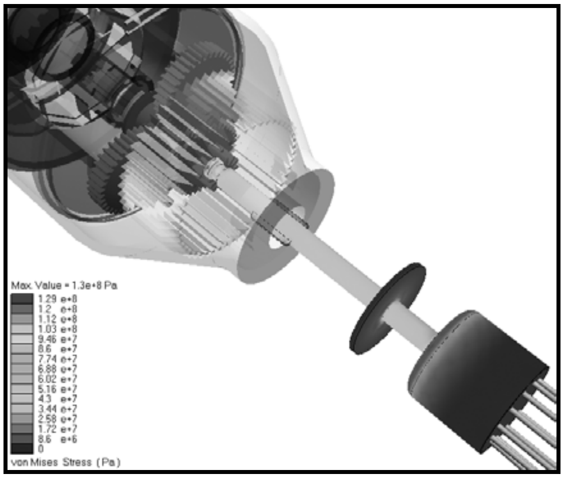

FIGURE. 8
STRESS VALUES FOR THE SHAFT OF A DOMESTIC APPLIANCE

Another significant factor to make the student participate in his/her learning process is to solve the problems presented using different techniques and approaches, and to compare the results thus obtained with the results obtained in the simulation. This allows students to became aware of the different ways of solving a given problem and to generalise the problem thanks to the powerful calculation operation of the computer programmes.

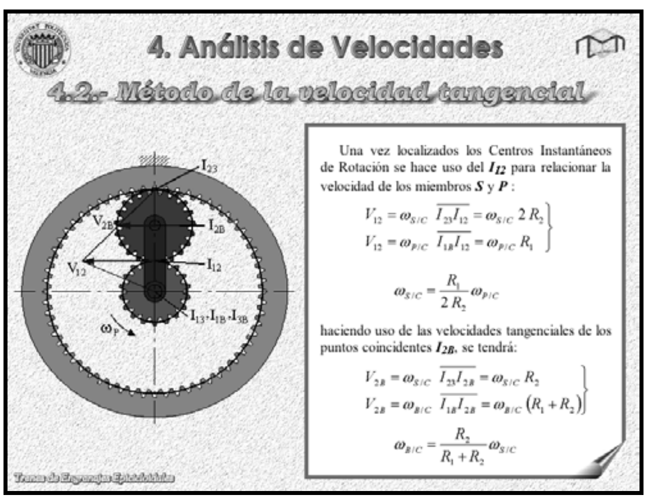

FIGURE. 8
MULTIMEDIA APPLICATION THAT COMBINES GRAPHS AND TEXT TO COMPLEMENT CLASSROOM EXPLANATIONS

An additional factor is the wide range of possibilities to display the results provided by the computer programmes. As aforementioned, they can display graphical representations for all the variables acting on the design process of mechanical components of a product. They also permit to display velocity, acceleration, force and stress vectors in real time. This allows students to transfer the concepts explained in the theoretical sessions to practical examples and to interpret the effects on the components when the values of different variables are modified. In other words, they permit students to interpret the phenomena occurring in real systems using the common engineering techniques.

LEARNING SUPPORT MULTIMEDIA TOOLS

Up to now, one of the main lacks in the learning process in the field of machines and machine mechanisms was to dispose of tools that allowed students to interpret intuitively the movement of the different mechanical systems and the effects of external forces, changes in the geometry or variations in the mass characteristics of the different mechanical components.

The wide range of possibilities offered by the computer and multimedia resources permit to employ learning resources, unthinkable a few years ago. The new learning approaches complement the conventional teaching methods with the new technologies to improve the quality of the learning process.

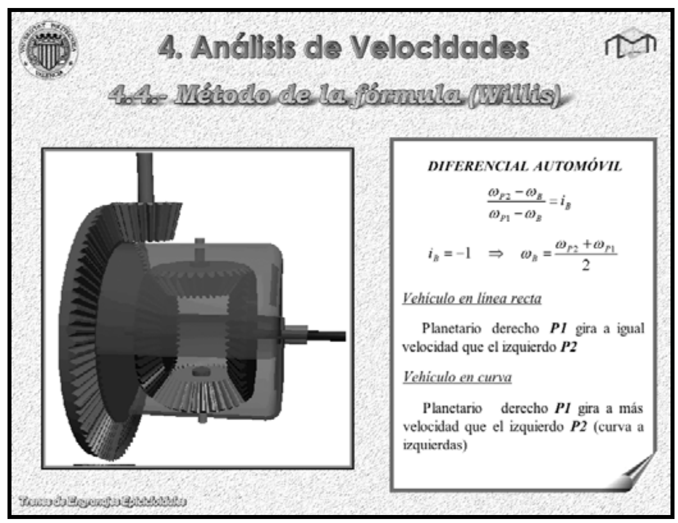

FIGURE. 10
TEXT COMMENTS ILLUSTRATED WITH A VIDEO

Most of the programmes described present the possibility of retrieving image or video files to illustrate the different concepts explained in class, and can be integrated in a multimedia programme, thus "breaking the conventional static teaching methodology" followed in the field of mechanical engineering.

This paper includes examples of a multimedia representation corresponding to one of the course units. The first illustration (figure 9) shows the basic application of the multimedia tool, combining text and image to illustrate the theoretical explanations given in class.

Figures 10 and 11 show the animation of the mechanical system of a car differential and automatic gear box, helping students understand visually some concepts otherwise difficult to comprehend using conventional teaching techniques.

FIGURE. 11
ANIMATION THAT ALLOWS STUDENTS TO UNDERSTAND THE OPERATION OF A CAR AUTOMATIC GEAR BOX

REFERENCES

[1] Khamashta, M.; Freire, J.; Gibert, J.; Alvarez, L.; Codina, E.; De las Heras, S, "Simulación cinemática y dinámica de mecanismos básicos para prácticas docentes", *Anales de Ingeniería Mecánica*, 1998.

[2] Lladó, J.; Sánchez, B.; Laiz, J., "El ordenador como apoyo a la docencia de la mecánica clásica en ingeniería", *Actas VII Congreso universitario de innovación educativa en las enseñanzas técnicas,*, 1999.

[3] "User's manual Working Model 2D". Knowledge Revolution, 1996, California (U.S.A.).

[4] http://www.vndesktop.com

[5] http://www.simulationcenter.com