SIMULATING ELEVATOR TRAVEL: A MECHATRONIC APPROACH

Aldaia J.M.
Aranburu I.
Pagalday J.M.
ORONA. S.Coop. P. O. Box 1312. 20080 San Sebastián. Gipuzkoa. Spain

1. ABSTRACT

In this report an approach for modelling elevator installations is presented. Models contain components ranging from electrical motors and their control, reducers, traction sheaves, suspension cables, car frames and cabins to counterweights and compensating cables. The simulation of resulting models offers characteristic magnitudes of working systems such as vertical displacements, velocities and accelerations in cabins or any other variable like torques, forces, reactions, angular velocities, etc... at any point of the system. Models have proved to be very useful in training technicians, predicting the influence of different modifications over the system and studying the vertical movement comfort. The report includes a real application on a controlled electrical lift installation of ORONA where experimental measurements have been successfully correlated with simulated ones.

2. ELEVATORS ARE MECHATRONIC SYSTEMS

Mechatronic systems have been described as systems having mechanical, electrical and electronic components. In the last few years, the introduction of electronic components for the control of mechanical systems have made mechatronic systems increasingly popular. Good examples of these appearances of mechatronic systems are numerical control machine tools or active vehicle suspensions.

Such an appearances of electronic devices have also occurred also in the elevator industry. Old elevators had almost no electronic components, and although they could be considered electromechanical devices, the mechatronic adjective hardly fit them.

More recently, the increasing levels of complexity of the operation, the comfort requirements and the increasing travel speeds have made the use of electronic components almost indispensable, especially at the travel and operation control.

3. THE BOND-GRAPH APPROACH

The main difficulty in simulating mechatronic systems lies in the communication of languages and formulations concerning different physical fields.

Bond Graphs allow scientists and technicians coming from different areas to speak a common language. The basis of the Bond Graph approach is to consider any physical system as a set of interconnected parts that interchange energy through their connections (Bonds).

A complex system can be decomposed in smaller subsystems. This decomposition, at the end, leads to the most simple and used kinds of elements.

Element	*Symbol*	*Mechanical example*	*Electrical example*	*Hydraulic example*	*Thermal example*
Common flow	**1**	Common velocity point	Common intensity point	Common flow point	
Common effort	**0**	Common effort point	Common voltage point	Common pressure point	Common temperature point
Inertance	**I**	Mass	Inductance		
Capacitance	**C**	Spring	Capacitance		
Resistance	**R**	Damper	Resistance		
Transformer	**TF**	Gear box	Transformer	Section change	

Figure 1: Most widely used Bond Graph components and their meaning.

As can be seen in Figure 1, elements from different fields can be linked to form a complex system, thus making Bond Graphs the most suitable language to treat mechatronics problems.

The differential equations of any system can be derived in a straightforward way from its Bond Graph. In our case, a commercial software has been used to derive such equations in an automated way.

4. DESCRIPTION OF THE SIMULATED SYSTEM

4.1 MACHINE ROOM

4.1.1 Electrical motor

The first point when modelling the behaviour of an electrical motor is its speed-torque characteristic. In this case, the motor supplier provided the curve, that has been approximated piecewise in the model. In every instant of the travel, the shaft speed is known, and the speed-torque curve is used to obtain accelerations using the system differential equations, that are integrated along with time to obtain shaft speed at the next time instant, as expressed in Fig. 2.

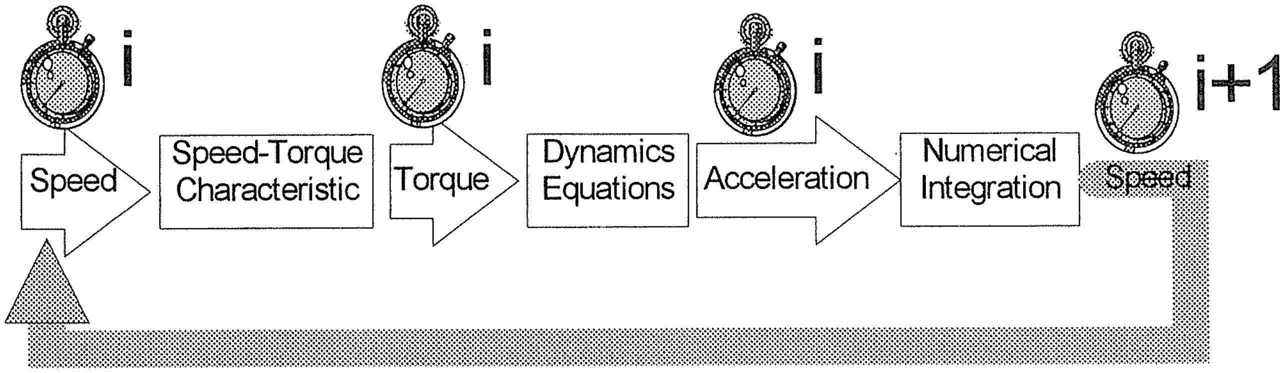

Figure 2: Generation of motion equations and unbalanced shaft

Secondly, a very important parameter influencing the amount of vibration introduced on the system is motor shaft unbalance. In such motors, no matter how good a balancing has been carried out, some residual unbalance exists, producing induced vibrations on the whole lift, due to the centrifugal forces generated by the unbalance, that can be seen as a concentrated mass located at some distance of the shaft rotation axis. The model takes into account this unbalance, allows the user to choose the amount of residual unbalance the system is supposed to have and transmits its effect to the whole system. Then, the user is allowed to redefine other parameters on the system in order to minimise the effect of unbalance.

4.1.2 Control

Although other control strategies could have been used, in this job a simple PID scheme has been applied. A determined motor speed is given as input command. This input is compared to the actual motor speed, and the difference is considered to be the existing error. This error goes through a traditional PID scheme, and the resulting value is used to modulate the speed-torque characteristics of the motor. This controlling scheme has been traditionally known as voltage variation regulation.

4.1.3 Reducer and pulleys

Reducers and pulleys are used in elevator installations to transform the fast rotating velocities on the electrical motor shaft to the relatively low velocities of travel.

The most widely used kind of gear reducers in the elevator industry are worm gears. One of the main problems with worm gears is that they need a small amount of backlash to operate properly and avoid interference between the worm and wheel teeth.

Nevertheless, this backlash has an adverse effect on the behaviour of the elevator, specially when the weight of the cabin plus the carried load balances the counterweight. In this situation, a small vibration can be clearly felt when the lift breaks or accelerates, depending on some of its characteristics and on its quality.

The reason of this behaviour can be seen in Figure 3. When the lift is carrying no load, the teeth of the wheel pressing one side of the worm and, although backlash exists, it has no effect, and a smooth motion at the worm produces a smooth motion at the wheel and, consequently, at the lift cabin. A similar situation happens when the elevator is fully loaded.

But when the installation is half loaded and the total weight of the cabin and the carried load balances the counterweight, the teeth of the wheel might be anywhere along the space left by the backlash. If we take in account that some elasticity exists, the teeth of the wheel might well bounce along the backlash space, producing a shaking motion that sometimes can be felt at the cabin, even if the motion of the worm itself is smooth.

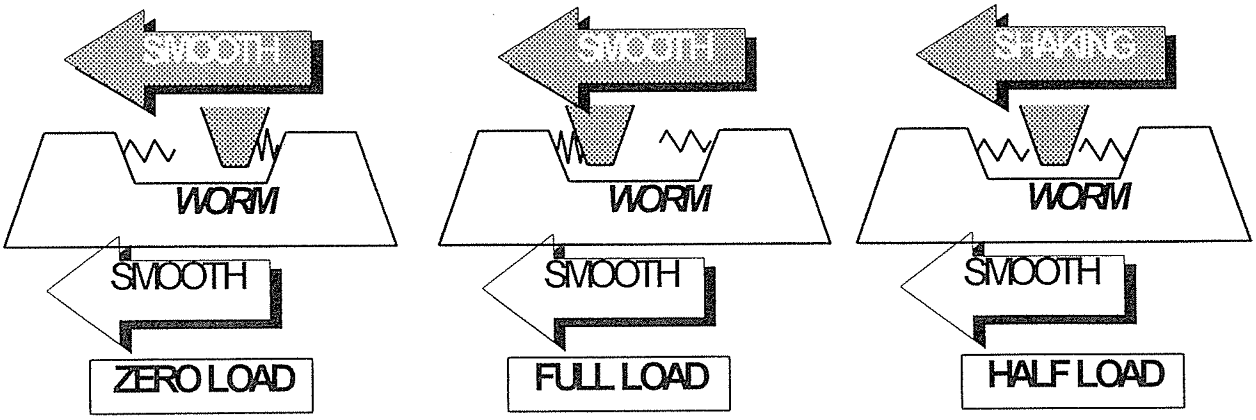

Figure 3: Combined effect of load and backlash

The developed model allows the user to introduce as much backlash as desired in the worm gear, and propagates its effect through the whole installation. The effect of changing other parameters such as the radius of the pulley on the propagation of the backlash is also accounted for.

4.1.4 Housing

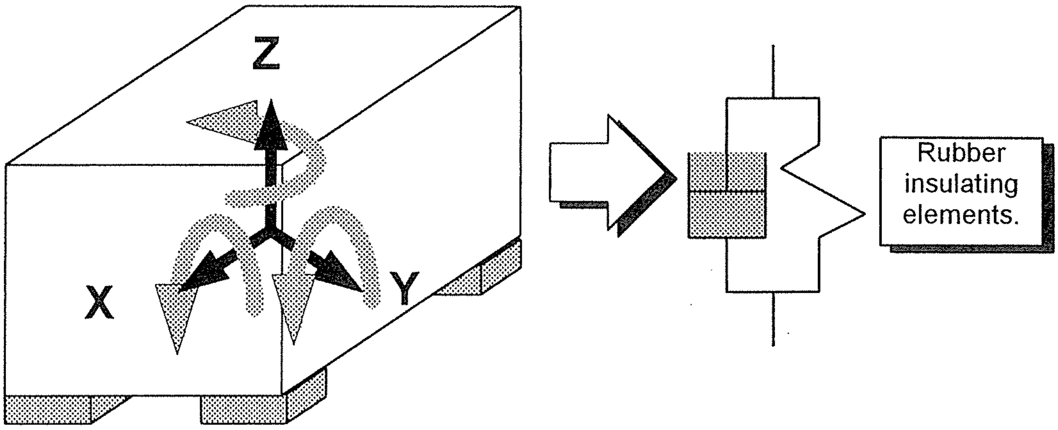

Figure 4: Housing model

The housing has been modelled as a solid body with all the degrees of freedom in space (X, Y, Z translations and rotations). These degrees of freedom have been given to the housing in order to take in account the vibrations induced by several excitations existing in the system, such as motor unbalance.

The existing vibrations are damped out by four rubber elements between the housing and the floor of the machine room. The stiffness, damping and dimensions of these rubber elements can be modified, in order to achieve minimum vibration transmission to the machine room floor and, consequently, to the building, thus reducing disturbing noise and vibration.

4.2 CABLES

The cables affect the system in three ways:

- Adding weight and inertia, due to their mass.
- Allowing the car and counterweight to vibrate when there is some kind of vertical vibration (i. e. the bouncing of the car can be clearly noticed by jumping on a cabin that is standing still), due to their flexibility.
- Allowing the above mentioned vibrations to disappear, due to the damping they introduce.

If the cable was modelled as a single mass-stiffness-damping triplet, this would only allow to take into account the first vibration mode of the cable. The frequency of this first mode is usually quite low (2-10 Hz) depending on the characteristics of the system and especially on the position of the cabin or counterweight, that determines the length of the cable.

As some authors (Harwood, 1986) have remarked, the excitations existing on elevators can be of much higher frequency, and can be closer to the second vibration mode of the cable than to the first. Besides, since the length of the cable changes along the travel, the above mentioned frequencies "sweep" a broad band of values, and the likelihood of having an excitation coincident with one of the vibration modes of the cable is very high.

In order to account for the higher frequency modes, a multi-segment model of the cable has been developed. The model can be seen in Figure 5.

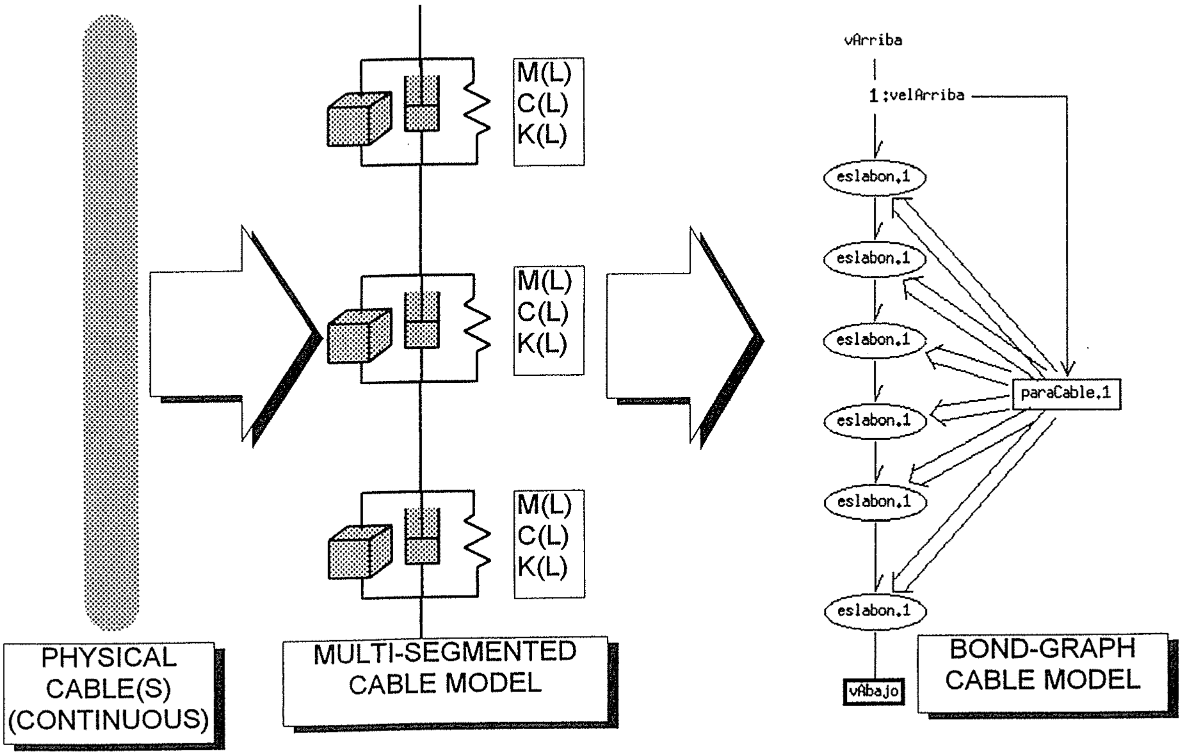

Figure 5: Development of a Bond-Graph model for the cable.

4.3 CABIN AND COUNTERWEIGHT

Cabin and counterweight cannot be considered to be a single rigid mass attached to the suspension cables. Usually, between the cables and the cabin or counterweight there are a set of flexible elements used to damp the vibrations originated in other points of the system.

The treatment given to the cabin in the presented model can be seen in Figure 6. On the left of the image, some of the most usual elements in lift cabins can be seen. The cables are held by a set of cable holders. After these, a first set of buffers is used to damp the vibration coming from the cables to the chassis. Then, the vibration goes trough the chassis, which is a steel frame specifically designed to contain the cabin. The cabin suspension damps still more the vibrations between the chassis and the cabin, trying to get as comfortable a ride as possible.

The mathematical model of the described subsystem consists of a set of masses and stiffnesses connected in serial form. The set begins just where the multi-segment model of the cable, described in section 4.2, ends. Each of the stiffnesses has also a certain amount of damping, because of two reasons: First, because the damping physically exists, and secondly, because some damping is necessary to get accurate results from the mathematical model.

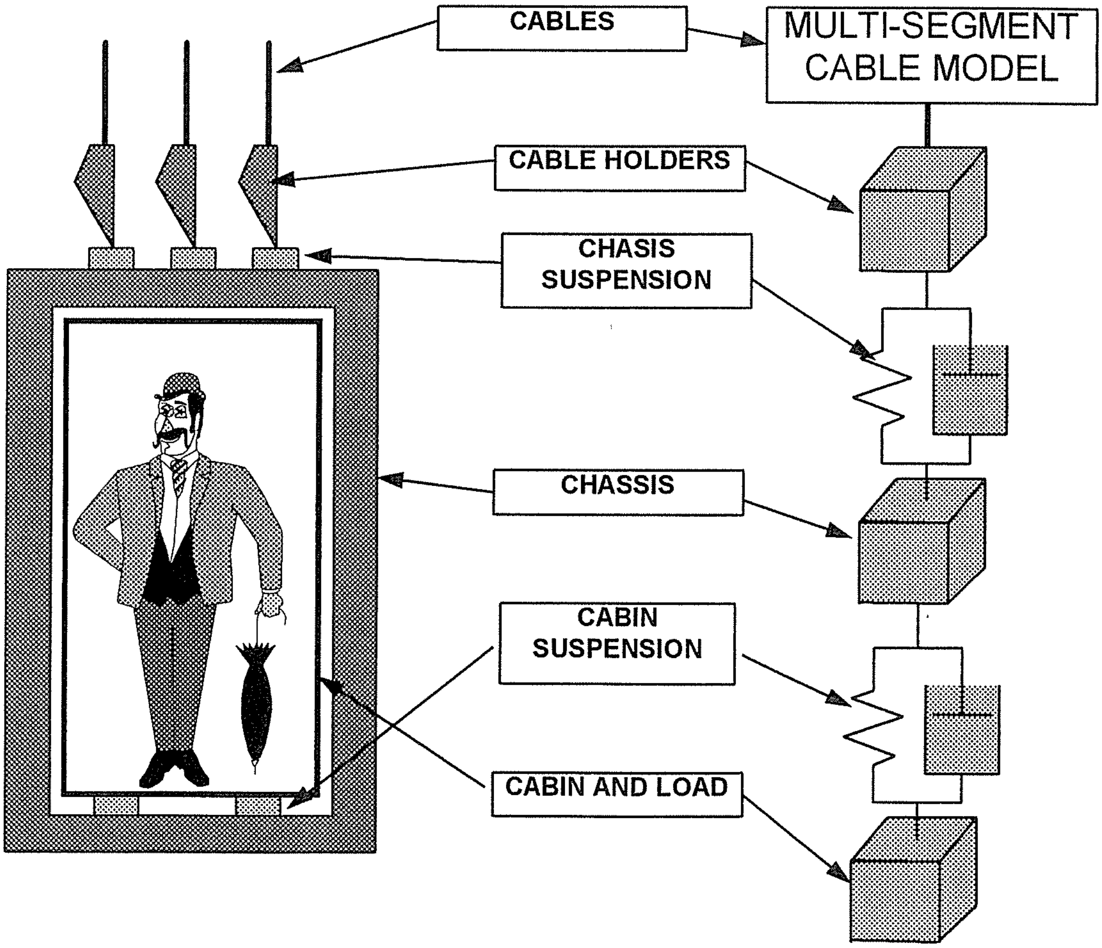

Figure 6: Cabin. Physical system and mathematical model

5. EXAMPLE

Vertical acceleration measurements have been carried out in several ORONA lifts. Figure 7 shows a direct copy of the screen of the measuring device. Although acceleration at the end of the trip should be zero (the lift is standing still) a small drift happens, due to the inability of the used accelerometers for measuring continuous acceleration.

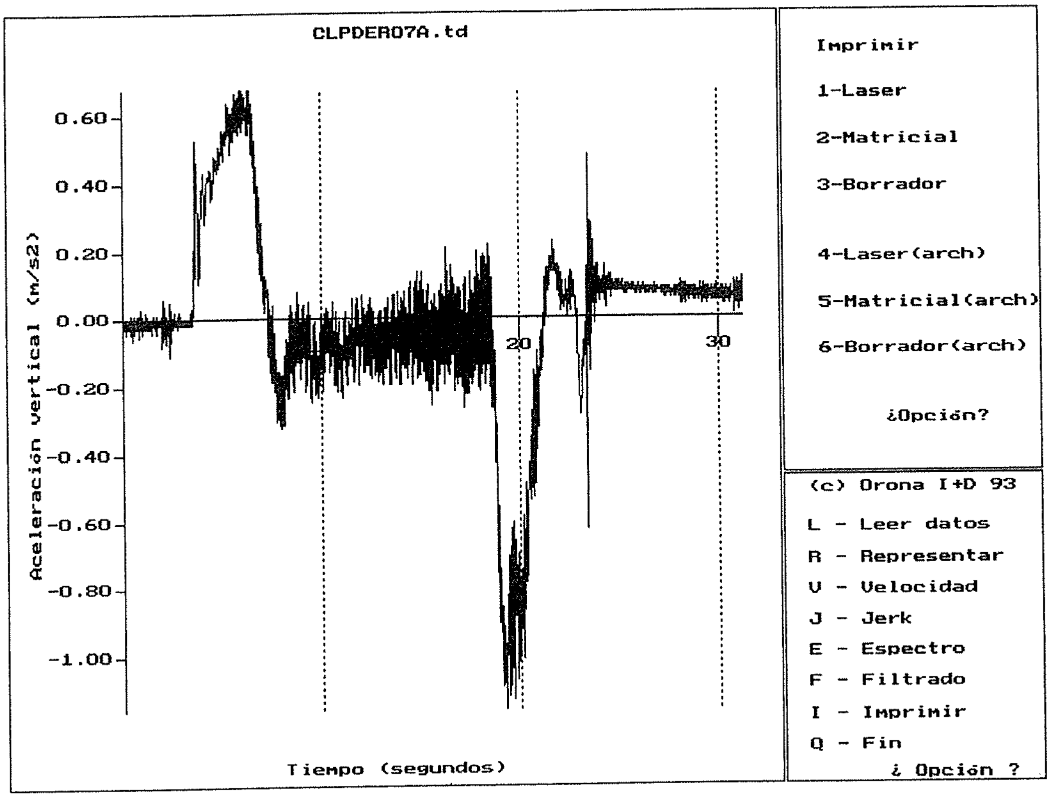

Figure 7: Measured acceleration at the cabin.

Figure 8 shows the simulated acceleration for the same case. The continuous component does not appear and the acceleration values are slightly lower, since the control a the simulated model has been optimised. This optimisation is not an straightforward task in real control.

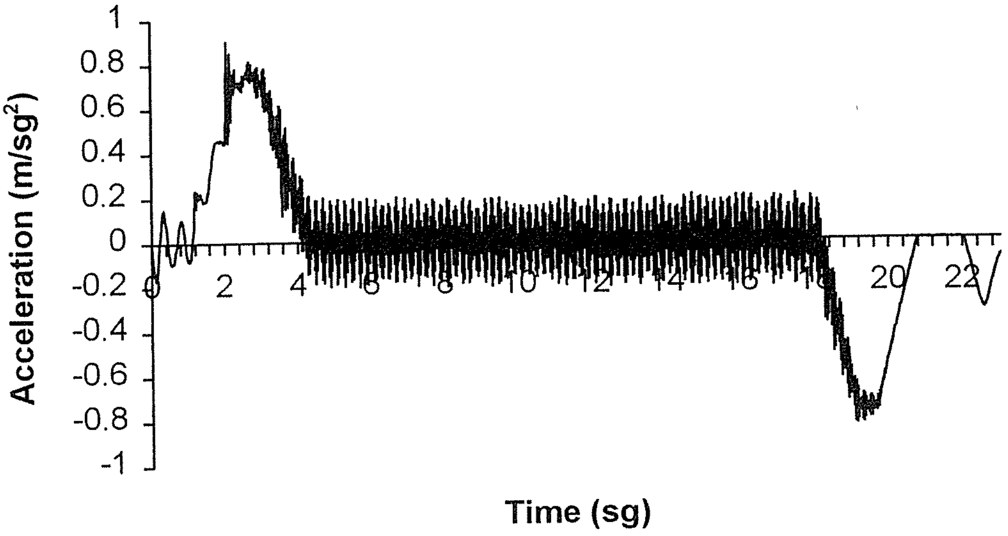

Figure 8: Simulated acceleration at the cabin.

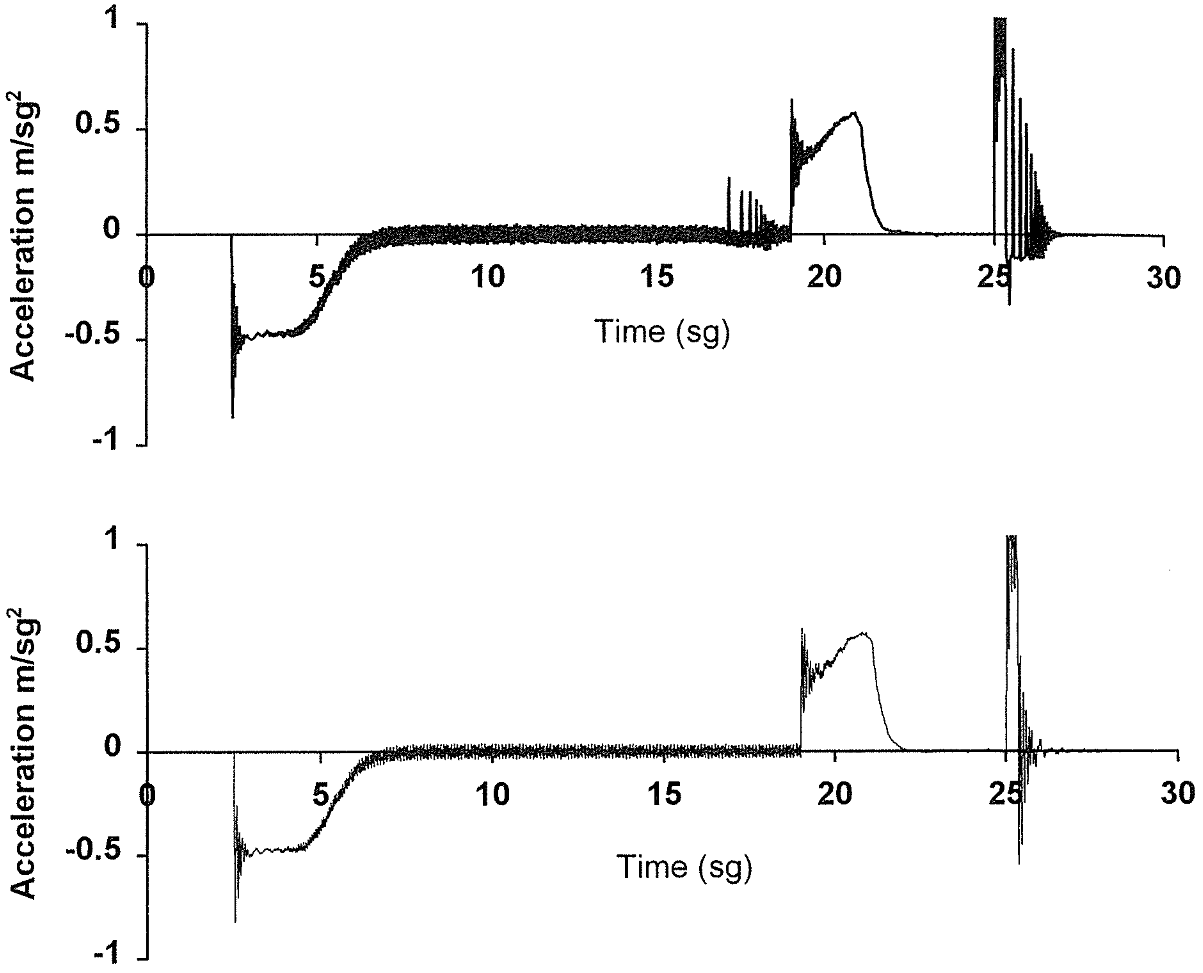

Figure 9:Two velocity lift simulation at half and full load

Figure 9 shows the simulation of a two velocity lift, at half and full load. The acceleration peaks due to the lack of control and the higher effect of backlash when the system operates at half load can be clearly noticed.

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7. AUTHORS BIOGRAPHY

Aldaia J.M. obtained his Engineeering degree from the University of San Sebastian in 1968. He has worked as a scientist in ORONA S.Coop. in R&D department since 1979 as Mechanical R&D Manager, he has involved in many high technology proyects.

Aranburu I. obtained his Higher Engineering degree from the University of Navarra in 1982. He has worked as a scientist in the IKERLAN Research Centre of the MCC Industrial group since 1982 where he has been the head of the Mechanical Engineering Dept. for seven years. Involved in many structural integrity projects and noise and vibration research.

Pagalday Juan M. was born in 1965.After graduating from the Engineering School of San Sebastián, hi got his PhD, in 1994 at tha same School, where he taught Structural Analysis.He works in IKERLAN since 1993, and his main interests are mechanism dynamics and mechatronik systems simulation.