The Magazine of the International Building Transportation Industry

ELEVATOR WORLD

November 2008

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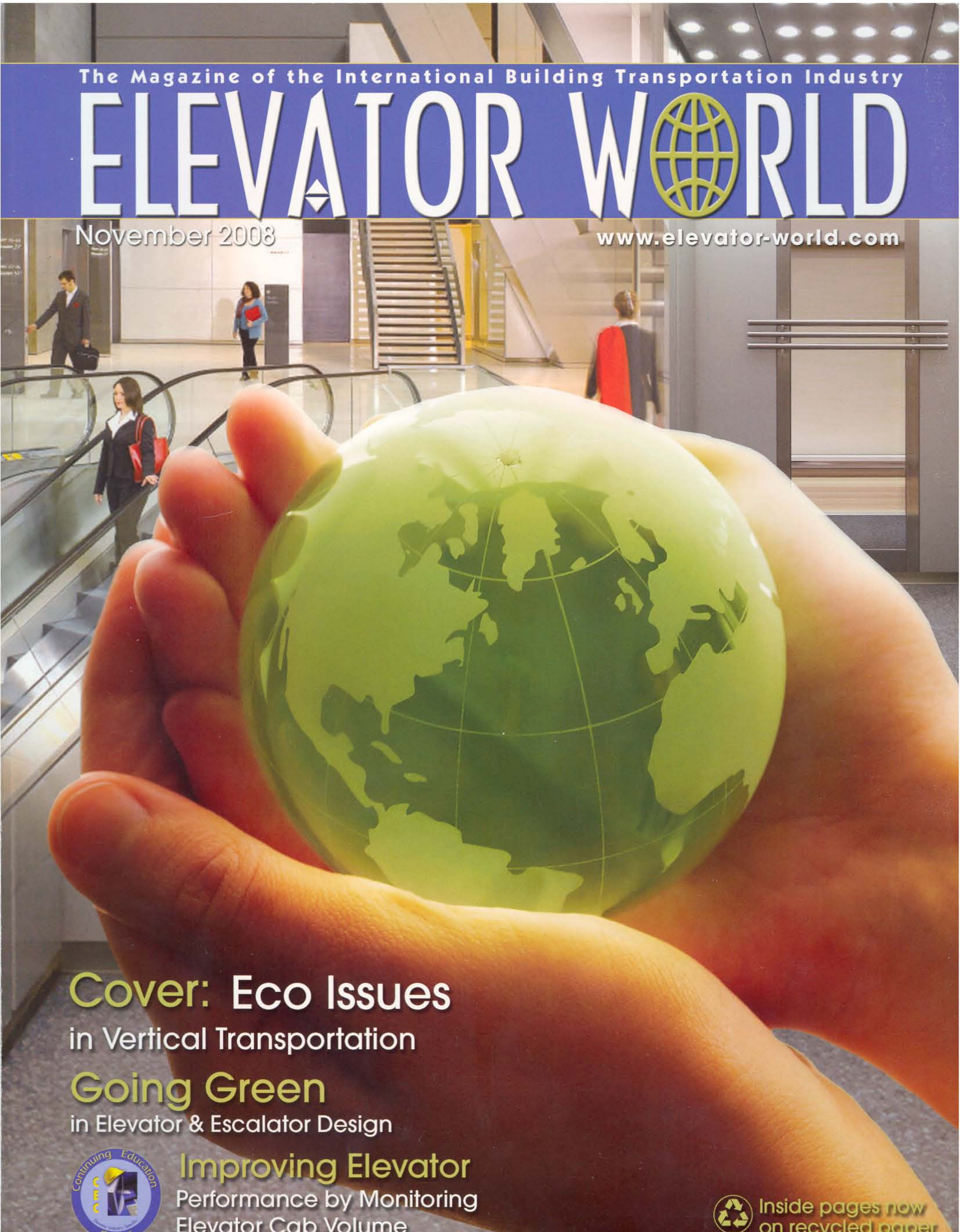

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NOVEMBER 2008 – VOL. LVI, NO. 11

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Advanced Dynamic Models for Escalator Simulation

by Jose Maria Cabanellas Becerra, Juan D. Cano Moreno, Berta Suárez, J.A. Chover and Jesús Félez

In this paper, the dynamic models developed for the analysis of solutions for new escalator designs are described. The current escalator design is an evolution of an ancient design that has added improvements over time. However, new solutions for a cheaper, safer and more reliable escalator design are being pursued. For this task, the models described here constitute a tool to test a series of new design ideas. With the dynamic models, it is easy to obtain values of tension, reaction, velocities, etc., to deduce the best solution before physically building the escalator. For more efficient results, an analysis of a statistical procedure has been developed that guides the improving trajectory.

Introduction

In previous papers,[1,2] the current situation of escalator design has been described as well as some of the improving lines that could be tested. Patent history shows that escalator mechanical-design evolution, from its appearance at mid-19th century to now, has maintained the same basic characteristics. Centro de Investigación en Tecnologías Ferroviarias (CITEF) has developed models and guidelines to analyze the static, kinematic and dynamic behavior of the escalator system.

Some of these guidelines are meant to lengthen the chainlink pitch, use pulse-free guides instead circular ones and replace rotational engines with linear traction systems. In addition, statistical models have been used to compact simulation results and explain some parameter variations.

An escalator is a closed-chain multibody system with several joints, loops and contact forces. These characteristics constitute great difficulties from the mathematical point of view that have been solved in the following ways:

- *Static* analysis programmed in MATLAB
- *Kinematic* models implemented in a computer-aided 3D interactive application
- *Dynamic* studies developed in SIMPACK
- *Statistical* analysis using the program STATGRAPHICS

This paper is focused on making statistical conclusions about dynamic models.

Dynamic Model Description

Several models have been developed in order to characterize the dynamic behavior of this multibody system. The methodology behind these models will be described using one of them. Overall parameters of the model are displayed in Table 1.

This model simulates a guide for an escalator with 4.5 meters between the upper and lower landings, powered by a linear motor that is located at the top of the upper inclined zone of the guide, as shown in Figure 1.

Continue

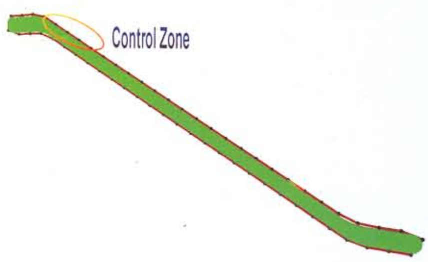

Figure 1: One guide model 3D representation

José Maria Cabanellas Becerra is associate professor in the Mechanical and Manufacturing Engineering Department of the Universidad Politécnica de Madrid. His Ph.D. thesis was on system modeling and simulation, similar to the major projects that he manages for Centro de Investigación en Tecnologías Ferroviarias (CITEF).

Juan David Cano Moreno works as research engineer for CITEF. He specializes in escalator simulation and design. He received his master's degree in mechanical engineering from the Universidad Politécnica de Madrid. At present, he is preparing his Ph.D. thesis.

Berta Suàrez is head of Railway Dynamics for CITEF. She received her master's degree in mechanical engineering from the Universidad Politécnica de Madrid. At present, she is preparing her Ph.D. thesis.

J.A. Chover works as research engineer for CITEF. He specializes in railway mechanical systems simulation and design. He received his master's degree in mechanical engineering from the Universidad Politécnica de Madrid. At present, he is preparing his Ph.D. thesis.

Jesús Félez is full professor at the Universidad Politécnica de Madrid. He is also currently the director of CITEF. He has wide experience in system modeling and simulation and has published a large number of technical papers on the subject.

Parameters	Measures
Number of links and rollers	58
Chain link pitch (m)	0.405
Guide-roller contact stiffness (N/m)	3,520,000
Guide-roller contact damping (Ns/m)	15,000
Linear velocity (m/s)	0.5
Guide diameter in reversing zones (m)	0.39265
Transitions diameter (m)	2.1
Roller diameter (m)	0.075
Pre-load in the tensioner (N)	3,000

Table 1: Parameters of the One Guide Dynamic Model

The concepts and basic guidelines of how to design and simulate the model are herewith explained.

Geometries

There are four different kinds of bodies: roller, chainlink, guide and tensioner (Figure 2). Roller and chainlink include a combination of basic geometries. Guide and tensioner curves are defined by points programmed in MATLAB, a program in which any kind of curve can be simulated and analyzed.

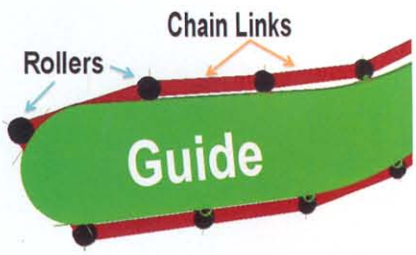

Figure 2: Geometries of the model

Joints and Loops

Dynamic and kinematic relation among the different bodies is shown in Figure 3, which represents a topological diagram of the model reduced to four chain links. These joints, loops and forces define the multibody system equations and behavior.

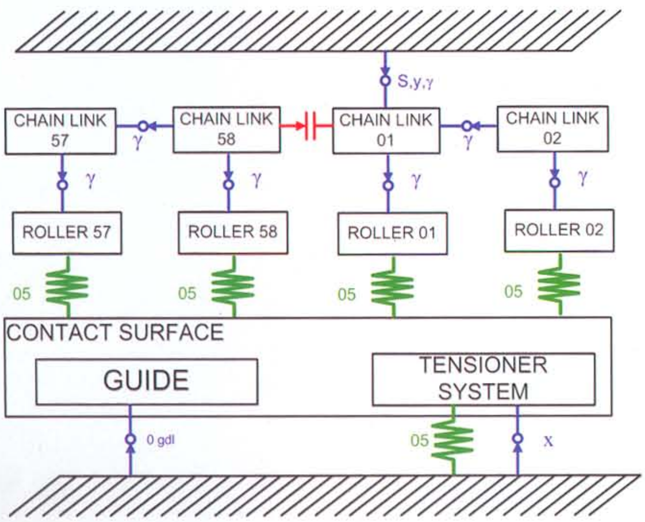

Figure 3: Topological diagram

Contact Forces

To define contact forces between two bodies in SIMPACK, a force from one marker to another has to be defined. Each marker must belong to a different body.

To simulate the roller-guide contact, *parent/child* mobile markers have been used. These markers can move around a curve defined for each, maintaining a minimum distance from a corresponding marker. There are 116 mobile markers: 58 follow the roller circumference (children), and the rest follow the guide curve (parents).

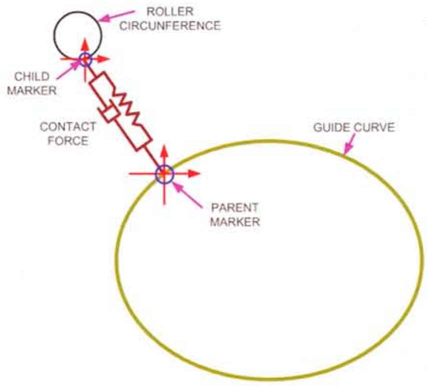

Figure 4: Contact force definition with parent/child markers

Tensioning System Design

Tensioning system design is not a trivial task. Contact force between each roller and guide is defined with *parent/child* markers, which have to follow a closed curve. If the tensioner is added (like the guide geometry) as a closed curve defined by points, there are two different curves that the roller markers have to follow. In addition, the tensioner curve is mobile, and the guide curve is fixed. Therefore, some markers can lose their correct positions, as shown in Figure 5. Unreal forces could appear, and the model analysis would be wrong.

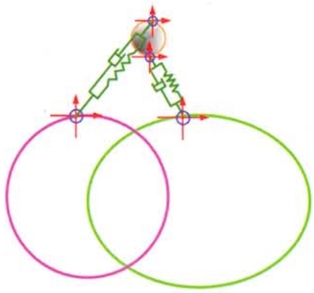

Figure 5: Contact forces between a roller and guide with tensioner geometries and markers out of order

The solution to resolve this problem has the following characteristics:

- Tensioner and guide geometries have to be the same. Thereby, markers will never be out of order due to tensioner displacements.
- Two different contact forces are defined using expressions to detect if the roller must take contact with the guide or with the tensioner. Thus, when one roller is in the tensioner zone, the expression for the contact

force between this roller and the guide has to be null, and the opposite.

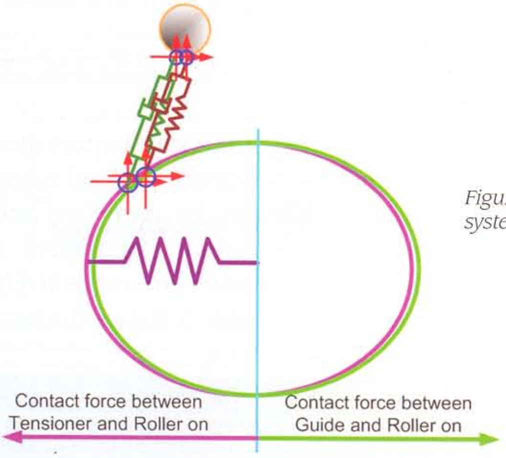

Figure 6: Tensioning system design solution

By way of illustration, the following figure shows details of a tensioning system design solution for the model.

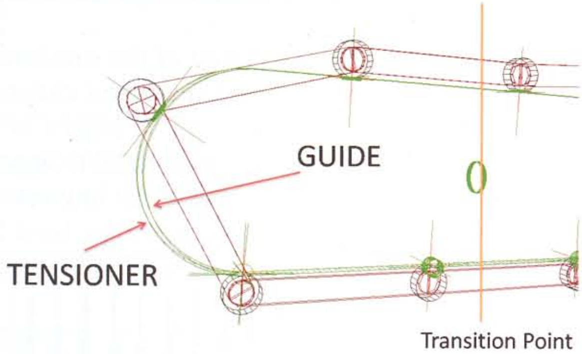

Figure 7: Detail of the tensioner and guide of the model

Linear Motor Simulation

Several aspects have been taken into account to simulate a linear traction system:

- *Velocity control system*'s overall scheme is shown in Figure 8. This system is the key to simulate the linear traction system designed in SIMPACK. Proportional control has been used in this model. Nevertheless, a proportional integral derivative control system could be used in future models. The force output expression for this control type is:

  $Force\ Output = K_p \cdot (V_{measured} - V_{reference})$

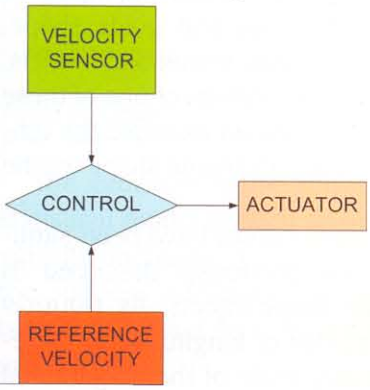

Figure 8: Velocity control system scheme

- An *expression* wherein the value coincides with the output force value of the velocity control system when the corresponding roller is inside the control zone. This value shall be null for the rest of time.
- An applied *longitudinal force* in the direction of the displacement of each chain link (axis X), as shown in Figure. Thus, this force value is defined by the expression explained in the previous point.

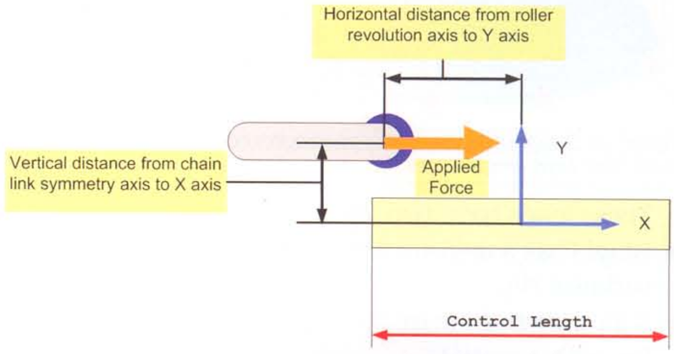

Figure 9: Velocity control system of SIMPACK model

Statistical Models

Managing the results of the previous points could easily become unaffordable when the number of tests and inputs increases. Thus, statistical models have to be developed by using small models in such a way that computational cost decreases. Statistical models are required to reach these objectives:

- *Compacting results.* Statistical parameters will characterize each model output.
- *Explaining some dependent variables* (outputs) as a function of the changed parameters (inputs)
- *Robust design.* Signal to noise ratios can be obtained by introducing random noise signals, such as variable loads or geometrical parameters, in the experiment designs.
- *Model validation.* This is a better way to compare real and simulated results of a model and to quantify the resemblance of the dynamic model with the prototype.

Simulations to develop statistical models can be performed from SIMPACK, MATLAB or by a combination of both.

A small chain of passenger conveyors has been implemented in SIMPACK. This chain has the same characteristics as the guide of 4.5-meter–high escalator: contact and tensioner parameters, bodies, traction system, etc. Figure 8 schematizes the design of this experiment. Random passenger loads have been programmed in MATLAB, and input functions that can be read by SIMPACK have been created.

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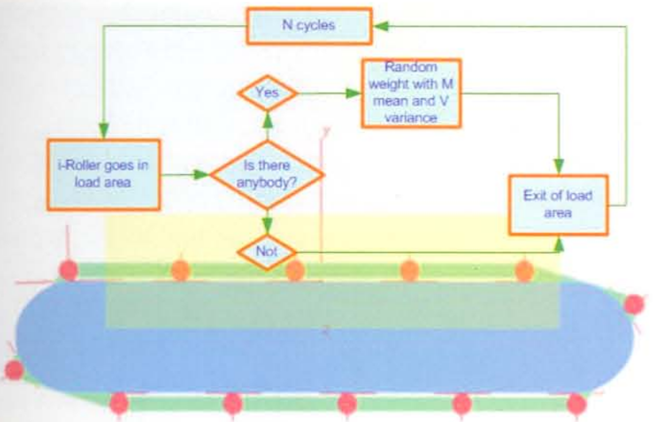

Figure 10. Design of experiment of passenger conveyor: how random loads have been programmed

These loads have two variables (Figure 10):

- *Weight* has a uniform distribution with a mean (M) and variance (V).
- *Is there anybody?* In each step, a person may be accounted for, with a probability of 0.5.

The figure below show the input functions of each roller for 10 cycles (approximately 100 seconds). These functions are the noise signal of the experiment.

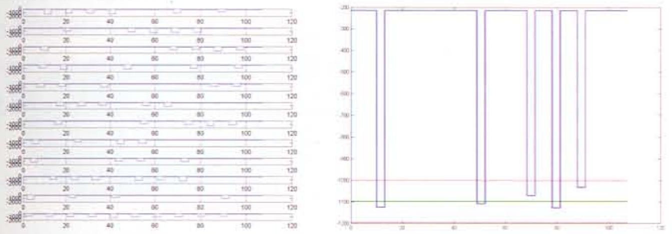

Figure 11: (l-r) Random load functions of the 12 rollers and the function of one roller

The experiment has three factors, or control parameters, and three levels per factor, as shown in Table 2.

Control Parameters	Level 1	Level 2	Level 3
Tensioner pre-loan (N)	1,500	3,000	4,500
Stiffness (N/m)	10,000	55,000	100,000
Damping (Ns/m)	5,000	10,000	15,000

Table 2: Control parameters and levels of the experiment

Therefore, 27 combinations of factors are simulated for each noise signal (two means and two variances), with a total of 108 performed simulations.

Linear-velocity standard deviation has been the measured output of each case. Thus, it can be explained as a function of the control parameters using a multiple-regression analysis. The next equation shows this relationship. This analysis explains 95.0682% (R-square) of the linear-velocity standard-deviation variability.

$STD = A - B * Amortiguamiento + C * Precarga - D * Rigidez$

$A = 0.049829700$

$B = 5.25323E - 8$

$C = 6.90286E - 7$

$D = 2.95552E - 9$

Equation 1: Multiple regression analysis

Variance analysis shows the statistical importance order of the control parameters. Tensioner preload is the most important parameter, followed by damping and stiffness. The sign before each constant in Equation 1 indicates if the *standard deviation* variable grows positively or negatively, in a marginal sense. Table 3 shows the best and the worst parameter combinations.

Control Parameters	Best	Worst
Tensioner pre-load (N)	1,500	4,500
Stiffness (N/m)	100,000	10,000
Damping (Ns/m)	15,000	5,000

Table 3: Best and worst parameter combinations

Figure shows linear-velocity output of the simulations corresponding to both the best and the worst cases. As Equation 1 predicts, velocity variability is bigger in the worst case than in the best one. This variability appears mainly in the return zone, where there is not any velocity control.

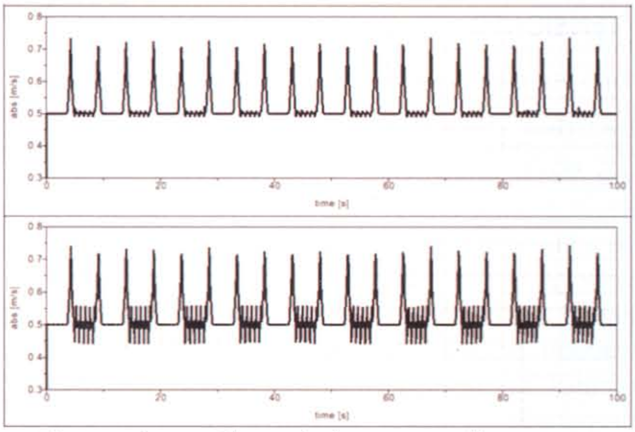

Figure 12: (top to bottom) Linear velocity at worst and best parameter combinations

Simulation Results

For each model, tests exist for the following inputs of the system: load, stiffness, damping and guide shape. CITEF has developed several dynamic simulation models. This paper examines parameter variations of one of these models that has been described. As an example the tensioner parameters, load per roller and guide shape will be changed.

Circular and pulse-free guide curves have been simulated under the assumptions previously described in order to compare the guide-shape effects. As Figure 9 shows, although the peak values of longitudinal and reaction forces are near, the amplitude of the longitudinal force is more elevated in the circular guide case. This effect can be explained as a consequence of the polygonization that these kinds of curves produce.

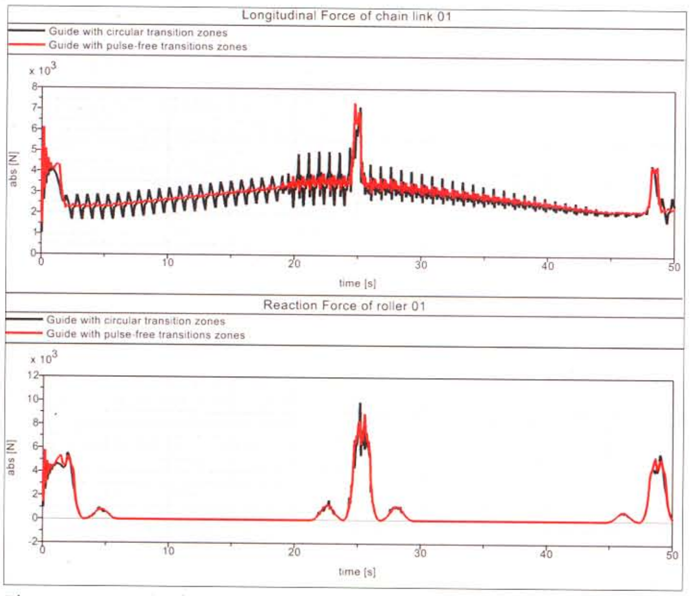

Figure 13: Longitudinal and reaction forces using both circular and pulse-free guide shape models

To infer statistical model results, one guide model of 4.5 meters high has been simulated searching the most and least significant tensioner parameter values. Linear velocity of both cases is shown in Figure 14.

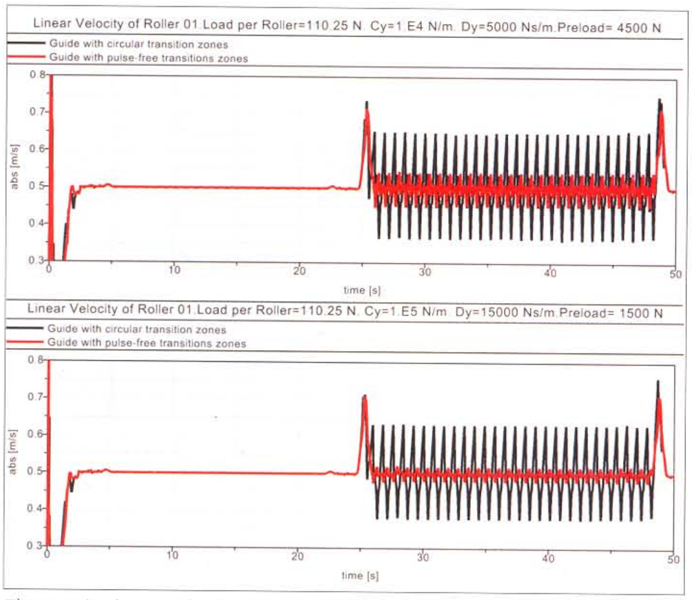

Figure 14: Linear velocity for two different guide shapes in the best and worst values of tensioner parameters obtained from one statistical model

The previous figure shows the coherence with the statistical model in such a way that the variability of the velocity increases when the preload is enlarged and the stiffness and damping are reduced. This tendency is also followed by the guide with circular transition guide shapes.

Two different load states are shown in Figure 15, reflecting the logical increase in reaction and longitudinal forces.

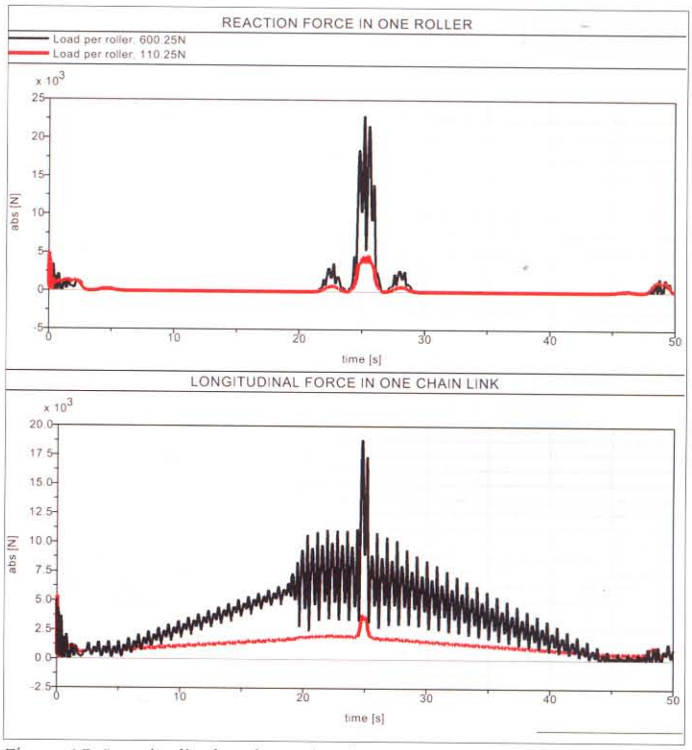

Figure 15: Longitudinal and reaction forces in varying the load per roller

As in the statistical point was described the tensioner preload forces has an important influence in the variability of velocity in the return zone. The result is slightly different from what the intuition says and it has to be tested in the real prototype.

Conclusions

The developed models are useful tools for the design of new solutions for escalators. The results obtained from these models show the influence of design changes on escalator behavior. The escalator prototype described has been designed following the conclusions obtained from its model. This prototype will be finished in brief and the results tested. The experimental results will help to improve the model. The improved model will be able to better predict the escalator behavior and obtain a better design.

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