Simulation Model and Validation Method Analysis of an Electric Passenger Elevator

Mihail Grovu
Siemens Industry Software
Brasov, Romania
mihail.grovu.ext@siemens.com

Calin Husar
Siemens Industry Software
Brasov, Romania
calin.husar@siemens.com

Maria Raluca Raia
Siemens Industry Software
Brasov, Romania
Department of Electrical Machines and Drives, TU Cluj-Napoca
raluca.raia@siemens.com

Davide Colombo
WEG Automation Europe S.r.l.
Gerenzano, Italy
dcolombo@weg.net

Alberto Speroni
WEG Automation Europe S.r.l.
Gerenzano, Italy
asperoni@weg.net

Daniela Sasu
Siemens Industry Software
Brasov, Romania
daniela.sasu@siemens.com

***Abstract*—Elevators play a crucial role in facilitating transportation within tall buildings. The drive system of an elevator, governing its initiation, acceleration, seamless operation, and gradual deceleration during braking, significantly impacts the overall quality and efficiency of the elevator's performance. This paper presents the modeling and simulation of the elevator drive system using Simcenter Amesim simulation platform. The command-and-control system performances are analyzed under varied conditions such as changed target floors, requested by passengers, correlated with a variable number of people using the elevator. For the validation of the simulation model, the results of the measurements conducted for different operating regimes, associated with imposed load and speed, are used. The results obtained confirm the fact that the presented methods make it possible to analyze the dynamic performance of an elevator with different control parameters, contributing to the optimal design of an elevator.**

***Keywords*—elevator, rope, modeling, simulation, Simcenter Amesim**

I. INTRODUCTION

During the conceptual design phase of an elevator, system simulation tools employ analytical models and functional relationships to simulate entire systems or subsystems. Individual components are simplified to capture their essential characteristics. The primary objective of the modeling process is to describe the interaction between these components in the analyzed model. At the heart of these simulations are lumped-parameter system models, represented as ordinary differential equations (ODEs) or differential-algebraic equations (DAEs). Within complex mechatronic systems, 1D system simulation models are becoming increasingly essential, constituting the core of the multiphysics system description [1-8].

The first electric elevator was built by Werner von Siemens in 1880. Before 1995, all high torque, low speed, precise operation and motor control, high precision leveling traction elevator used DC motor to drive. In the late 1990 s, Japan's Mitsubishi Electric Corporation developed the first variable frequency variable voltage (VVVF) speed control elevator. KONE Company developed a called Eco Disc gearless permanent magnet synchronous machine in 1996.

By using Simcenter Amesim software [9-10], a model is created to simulate the dynamic behavior and control of an electromechanical elevator. Simcenter Amesim, a part of the Siemens Xcelerator portfolio, offers a comprehensive collection of integrated simulation software encompassing mechanical, electromagnetic, control, hydraulic, and pneumatic domains, among others. To validate the simulation model, measurements from various operating conditions, including imposed load and speed, are utilized. Section 2 of the paper presents the elevator virtual model, the simulation presented in section 3 while the scenario used for validation are presented in Section 4.

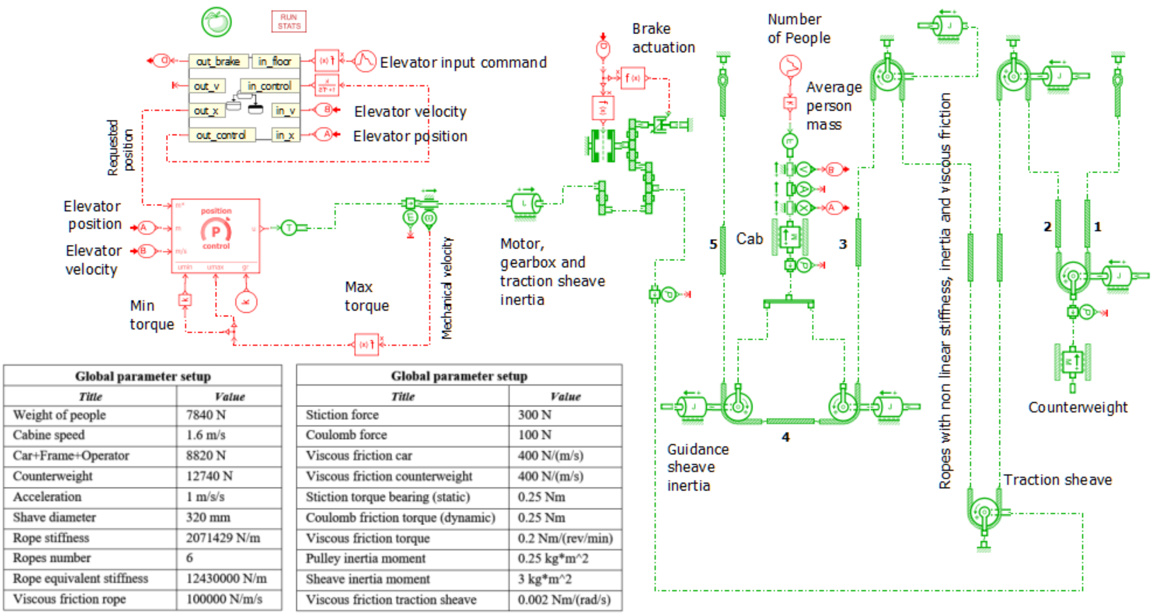
II. ELEVATOR SIMULATION MODEL

A. Simcenter Amesim simulation model

The current study is performed by using the modeling and simulation capabilities of Simcenter Amesim which is a versatile system simulation platform enabling design engineers to virtually evaluate and enhance the performance of systems. In the virtual model the elevator's drive system controls the elevator's start and acceleration, smooth operation, and braking deceleration. Traction elevators operate via a pulley system, using steel ropes and a counterweight to move the cabin up and down. The main structure the elevator is composed of five distinct parts:

- Hole: refers to the space within the building designated for the movement of the elevator car and contain various components such as the counterweight, guides, limit switches, sensors, doors, and cables.
- Machine room: inside it is located the motor, the tractor group, the protections, and all elements of controllers.
- Cabin: serves as the platform for users to travel between different levels in the building. It is designed as a closed structure equipped with automatic doors for passenger entry and exit.
- Counterweight: is positioned on the opposite side of the traction cable to balance the weight of the elevator car and its occupants, resulting in a reduced power requirement for the motor.
- Pit: is situated at the bottom of the elevator installation and houses safety dampers and other security devices.

Fig. 1 shows the Simcenter Amesim model of the elevator. The main components of the model include: a variable-mass cabin considering the number of passengers, a counterweight, cables, sheaves, a sequence of input commands for target floors requested by passengers, a statechart governing operating phases, a controller for elevator position control, and a brake system.



Global parameter setup	
Title	***Value***
Weight of people	7840 N
Cabine speed	1.6 m/s
Car+Frame+Operator	8820 N
Counterweight	12740 N
Acceleration	1 m/s/s
Shave diameter	320 mm
Rope stiffness	2071429 N/m
Ropes number	6
Rope equivalent stiffness	12430000 N/m
Viscous friction rope	100000 N/m/s

Global parameter setup	
Title	***Value***
Stiction force	300 N
Coulomb force	100 N
Viscous friction car	400 N/(m/s)
Viscous friction counterweight	400 N/(m/s)
Stiction torque bearing (static)	0.25 Nm
Coulomb friction torque (dynamic)	0.25 Nm
Viscous friction torque	0.2 Nm/(rev/min)
Pulley inertia moment	0.25 kg*m^2
Sheave inertia moment	3 kg*m^2
Viscous friction traction sheave	0.002 Nm/(rad/s)

Fig. 1 Simulation model of an electric passenger elevator

The simulation model is made using the components from the following libraries of the Simcenter Amesim platform: 1D Mechanical, Signal and Control, and Statechart Environment. The 1D Mechanical library consists of a set of components that are the base of any one-dimensional mechanical system.

The use of these components facilitates the modeling and observation of velocity, displacement, force, rotational velocity, angle, and torque evolution. The Signal and Control library comprises signal or "block" components, enabling the construction of block diagram models that visually represent dynamic physical systems. The Statechart Environment offers a user-friendly graphical interface for creating, integrating, executing, and animating statecharts to verify sequential decision logic based on state machines within your model.

The cabin and the counterweight are modeled using a one-dimensional component of a two port ports mass under the action of two external forces, weight, and frictional forces. The friction force considers stiction, Columb friction, viscous friction, windage and Stribeck effect. The passenger's mass is translated to a load applied to the cabin mass.

B. Ropes

Simcenter Amesim 1D cables expose variable stiffness dependent on their length, as well as variable mass and consideration of viscous friction. Among these, the cable element represents a longitudinal rope submodel that accounts for stiffness, internal viscous friction, gravity, and inertia effects. The total length of the rope is determined through calculations based on its initial length and uncoiling process:

$$l = l_0 + q_{mt1} + q_{mt2} + l_\Delta \qquad (1)$$

where l_0 is the initial length, l_Δ is the lengthening and q_{mt1} and q_{mt2} are uncoiling values at either end of the rope. The derivative of the length is calculated using the velocities of the rope ends:

$$l_\Delta = -v_{mt1} - v_{mt2} \qquad (2)$$

where v_{mt1} and v_{mt2} are the velocities. The total stiffness K and the total viscous friction R of the rope are calculated using rope's length but leaving out the lengthening:

$$K = \frac{n_r \cdot K_0}{l_0 + q_{mt1} + q_{mt2}} \qquad (3)$$

$$R = \frac{n_r \cdot R_{vis0}}{l_0 + q_{mt1} + q_{mt2}} \qquad (4)$$

In this equations n_r is the number ropes bundled together, side by side, K_0 is the stiffness of unit length of rope and R_{vis0} is the viscous friction of unit length of rope. The force at the load end of the rope, *fmt1*, is calculated using the equation:

$$f_{mt1} = -f_{mtca} - R \cdot da \qquad (5)$$

where f_{mtca} is the force directed into the spring stiffness, R is the total viscous friction of the rope and da is the derivative of the rope length. The force F_{mtca} is calculated by from its derivative using an integrator:

$$df_{mtca} = K \cdot dl_\Delta \qquad (6)$$

The equation uses the total stiffness K and the derivative of the rope length to calculate the spring effect.

The cables used in the working of the passenger elevator are of the type SEALE 8*9+9+1s+FC, having the following technical characteristics: class of strength 1570N/mm^2, rope diameter 8 mm, metallic section A=23 mm^2, elastic module E=95 kN/mm^2, minimum braking load (MBL) 29 kN, elastic elongation with a load of 10% of its MBL 0.14% of rope length. (http://www.metalpress-wireropes.com/products/lifts-and-elevators/elevator-ropes/198-8x19s-fc).

The stiffness can be estimated by two methods. If the elastic elongation is 0.14%, for a load of 10% of the MBL, K= 2.071e6 N/m. From the Hook's law (K=A.E), K=2.185 N/m, close values. Since it is about 6 cables in parallel, K=1.243e7 N/m.

To complete the simulation model of the elevator, the corresponding components are used from 1D Mechanical library.

C. *Position controller*

The elevation of the elevator is governed by a position controller. This controller utilizes a cascading approach, combining an inner speed loop with an outer position loop, as illustrated in Fig. 2.

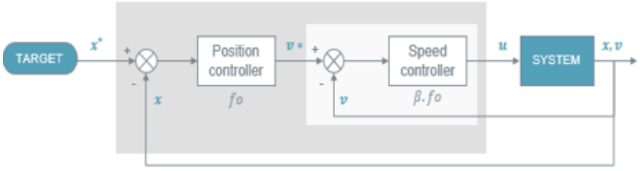


Fig. 2 Diagram of the position controller CTRPOS0

For this controller, a simplified representation of the moving body is needed, which includes the total moving mass and friction characteristics. The total mass comprises the cabin, counterweight, and one passenger. When considering friction, the controller primarily focuses on viscous friction as the most crucial parameter. The controller computes the drive command *u* so that actual position (elevator position) reaches the position setpoint (*out_x*). Lower and upper limits for the command signal can be given (*umin* and *umax*). Actual speed (elevator velocity) is used for the internal speed loop. Tuning frequency f_0 sets the expected position loop dynamic. Speed loop tuning factor β defines the tuning frequency of the speed loop compared to the position loop ($\beta \ x \ f_0$). Gear ratio (*gr*) is the ratio between the force applied to the body and the controller output:

$$gr = \frac{F}{u} = \frac{T_{mot}/R_{sheave} \cdot k_{reducer}}{T_{mot}} = \frac{k_{reducer}}{R_{sheave}} = 6.25 \qquad (7)$$

where $k_{reducer}$=1 and diameter of the sheave is 320 mm. The controller is set up for a second order response with a tuning frequency of 0.6 Hz. Output limitation is enabled to deal with *min* and *max* torque of the motor. Other parameters are default ones.

D. *Statechart*

The statechart, Fig. 3, manages the phases of a single lifting, from doors closing to doors opening at destination.

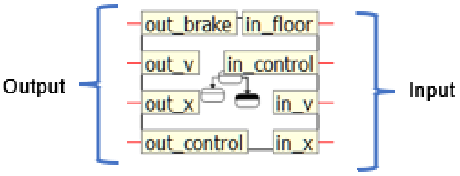


Fig. 3 The input and output variables of the statechart

The input and output variables are grouped as follows:

- *in_floor*: floor command input
- *in_x*: elevator real position
- *in_v*: elevator real velocity
- *in_control*: reading of the out_control value
- *out_x*: elevator position request
- *out_v*: elevator velocity request
- *out_control*: memorization of the floor command input for the duration of a lifting cycle
- *out_brake*: control the brake, when the signal is zero, the brake is fully opened, when the signal value is one, the brake is fully closed.

When the elevator moves between two floors, the state map models the following phases:

- Read lift command: the lift waits for an input command different of its position.
- Doors closing: the lift doors close.
- Acceleration: the lift accelerates at a constant rate.
- Constant speed: the lift maintains its maximum speed.
- Deceleration: the lift decelerates at a constant rate.
- Stabilization: during this state, the target speed is zero.
- Doors opening: this state represents the doors opening.
- Wait at floor: this state is just a delay for the people leaving or entering the elevator.

III. SIMULATION RESULTS

The primary aim of this article is to perform a dynamic simulation of the elevator. The elevator's input command corresponds to the target floor requested by passengers where this signal is directed to the statechart, which subsequently governs the various operating phases.

The passengers' requested elevator route follows this sequence: starting from the ground floor, it goes to the third floor, returns to the ground floor, and then proceeds to the third floor again. Throughout this route, the number of passengers using the elevator also varies. Fig. 4 shows height of the floor input command, the passengers inside the elevator, elevator position request and the elevator position. Below is shown the height difference between *out_x* and *in_x*, estimated when the elevator speed is almost zero.

The dynamic behavior of the elevator is linked to the changes in cabin speed and acceleration. The controller produces quantity *u* to align the actual position of the elevator cabin with the target position. In the simulation model, *u* denotes the torque necessary to attain the desired displacement profile within predefined limits. The speed, the acceleration and the torque required are presented in Fig. 5.

Rope behavior is displayed in the next graphs. Fig. 6 shows the rope forces in the rope 2 (counterweight) and in the rope 3 (elevator cabin). Below are presented the corresponding lengthening.

The output variable *out_brake* commands the activation of the elevator brake when the cabin's travel speed is zero. The mode of activation of the brake depending on the evolution of the cabin speed is shown in Fig. 7.

In the simulation process, the advantage offered of defining the parameters through the facility called global parameters is used. A global parameter is assigned in all the components where it is needed.

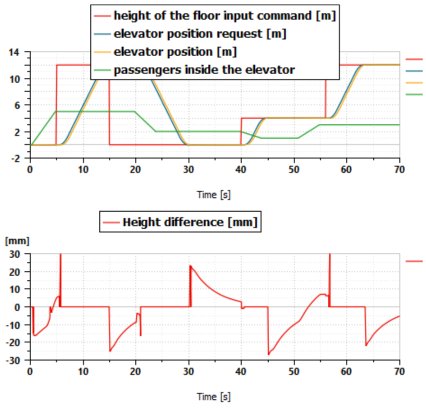


Fig. 4 Floor input command and passengers inside the elevator

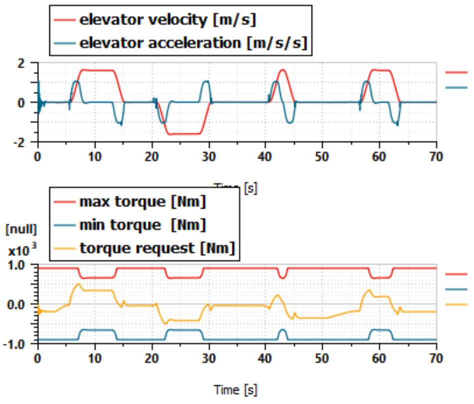


Fig. 5 Elevator cabin velocity, acceleration and requested torque

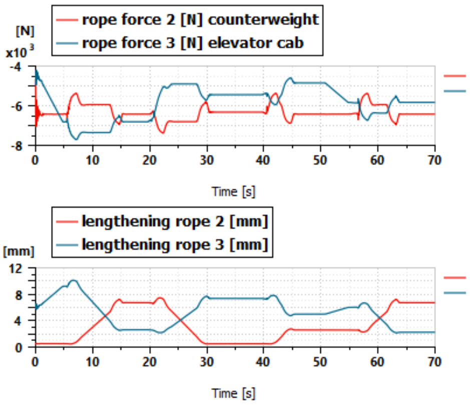


Fig. 6 Rope forces (2 and 3) and corresponding lengthening

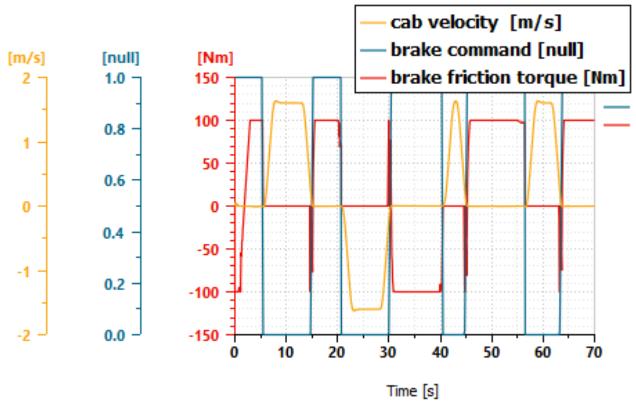


Fig. 7 Brake command, car velocity and brake friction torque

The numerical values of the parameters associated with the model components are specified in the two tables in Fig. 1. These values were established using the technical characteristics of the elevator proposed by WEG. In the situation where we had no information, the numerical values of the parameters were estimated, or information from the specialized literature was used.

In the context of energy efficient systems, it becomes critical to look at models from an energetic point of view. Simcenter Amesim offers several ways to look at how the energy transits, is dissipated, or stored in the system. The simulation model presented in Fig. 1 uses two methods for the analysis of energy exchanges between components: sensors specific to the submodels, or the local variables generated by option *energy/power/activity* of each component.

IV. VALIDATION MODEL ANALYSIS

The results obtained through simulation are compared with the measured ones at WEG. Both results are obtained from the same simulation and testing conditions.

The validation of the simulation model is performed for three speed profiles imposed on the elevator, 0.3 m/s (s0), 0.5 m/s (s50) and 1 m/s (s100), the cabin moving between two floors, in both directions (Up, Down).

These speed and displacement profiles are repeated for two load cases: zero load (L0), empty cabin (900 kg), and load 50% (L50) of the maximum allowed load (400 kg). The experimental measurements refer to the evolution of the cabin speed and the value of the drive torque.

The validation model contains the structural parts of the simulation model from Fig.1. In the control loop, the imposed speed and the reached speed are compared. The control loop also includes a controller P.I.D. and a second order filter, shown in Fig. 8.

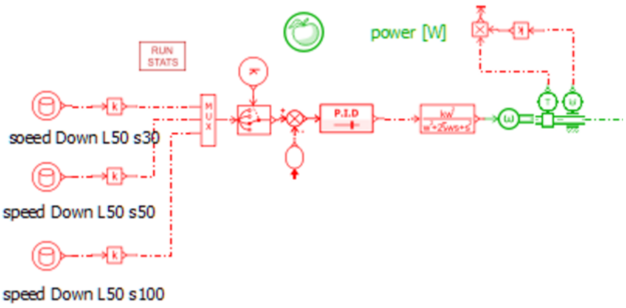


Fig. 8 Control loop for the validation model

In the following, the comparative analyzes of the torques resulting from the simulation and those measured for several specified situations are presented: Fig. 9 - L0s30UP, Fig. 10 – L0s100Up, Fig. 11 – L50s30Down.

During the validation process, the influence of the variation of certain numerical parameters on the simulated drive torque was analyzed for to be close to the measured one. The obtained values were used in the initial simulation model.

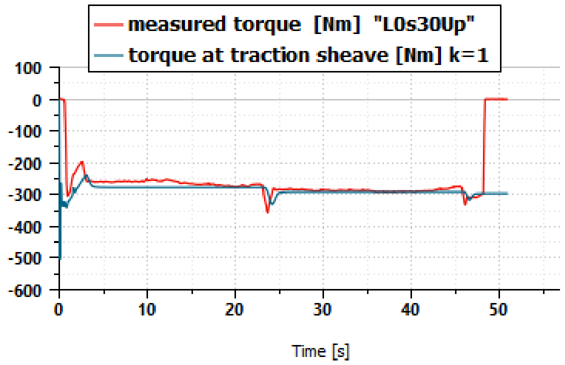


Fig. 9 Measured and simulation torques, load 0, 0.3 m/s speed, Up

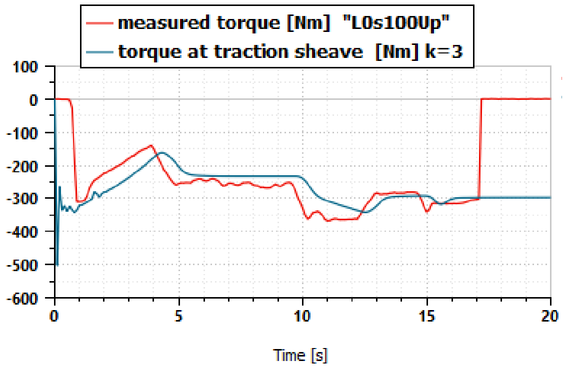


Fig.10 Measured and simulation torques, load 0, 1 m/s speed Up

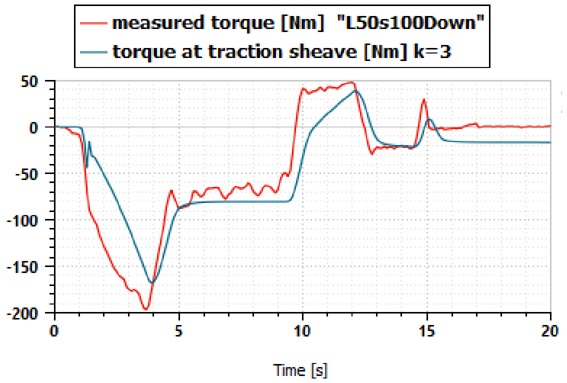


Fig.11 Measured and simulation torques, load 50, 1 m/s speed Down

V. CONCLUSIONS

This paper successfully demonstrated the significance of elevator drive systems in ensuring efficient and high-quality elevator performance within tall buildings. Through the modeling and simulation of the elevator drive system using the Simcenter Amesim simulation platform, the study analyzed the command-and-control system's performance under various conditions, considering changed target floors requested by passengers and varying passenger loads. By validating the simulation model using measurements from different operating regimes with imposed loads and speeds, the research confirmed the efficacy of the proposed methods in dynamically analyzing elevator performance with diverse control parameters. These findings contribute significantly to the optimal design of elevators, paving the way for enhanced transportation solutions within modern buildings. The study underscores the importance of robust simulation tools and methodologies for advancing elevator technology and ensuring safe, efficient, and reliable vertical transportation in high-rise structures.

Future research directions on this topic could include exploring energy-efficient and sustainable elevator technologies, investigating real-time adaptive control algorithms, enhancing elevator safety and passenger comfort, and optimizing traffic management strategies in high-rise buildings with multiple elevators.

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