Dynamic Simulations for Lift Door Health Diagnosis

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Abstract. System level simulations enables new possibilities to perform fault analysis of lift door systems to recognize root causes and malfunction indicators linked to the most critical failures. The simulation method utilized for the approach is object-oriented modelling where elements from all areas of engineering are connected to each other as building blocks. Elements such as controller, belt transmission and door mechanics are interconnected forming a complex system representing physical lift door systems. The approach provides explicit outputs of each included element of simulated systems in time domain. In this paper, the outputs of door drive system are described in more detail, including motor encoder data and torque output. Multiple malfunction simulations have been computed and validated with data acquired from physical counterparts of the simulated lift door system. The validation results have proved the credibility of simulations and demonstrated new opportunities to utilize the simulations for developing fault diagnostics.

1 INTRODUCTION

Increasing urbanization have led to higher utilization of lift systems and increased importance of reliability of lift systems. Kaariaho stated that lift doors have the highest call out rate from all lift system components [1]. Thus, by optimizing condition monitoring capabilities for lift doors, maintenance process for entire lift systems is improved.

The challenge is that the condition monitoring optimization requires data from faulty lift doors as the most of doors are functioning correctly. It is also unlikely for lift door systems to have isolated cases of individual malfunctions which is required to identify distinguishable fault related indicators. Furthermore, data collection, analysis and labelling are done with back reports which as a process has potential for improvement.

In this paper, a solution of using system level simulations to provide synthetic data for training machine learning (ML) models for condition monitoring of lift doors is presented. The method of providing synthetic data using simulations have been proven as an efficient method for improving ML algorithms as discussed in paper by Klein and Bergmann [2]. The simulations can provide data from lift door systems with individual malfunction cases which from the fault identification patterns can be isolated.

The lift door simulations model presented in this paper have been validated and discussed in a Masters thesis [3].

2 SIMULATION METHOD

Lift simulations targeted different aspects of door performance and design optimization. The studies are primarily conducted by analyzing the system from static perspective. In this paper the focus is on dynamic simulations, since they are the most effective in capturing indicators and root causes of underlying lift door related malfunctions. Dynamics of the lift doors must be captured to detect the subtle changes in the system before failure modes linked to studied malfunction cases occur during operation cycles.

The lift door model described in this paper has been created using object-oriented modelling method. In this method, different components from various fields of engineering are modelled as building blocks which are interconnected to each other forming the complex mechatronic system as demonstrated in Figure 1. Equations are formulated and calculated based on these building blocks and interconnections during simulation computations. [4] The quantities of system variables are solved explicitly in non-linear timesteps which is available as output data.

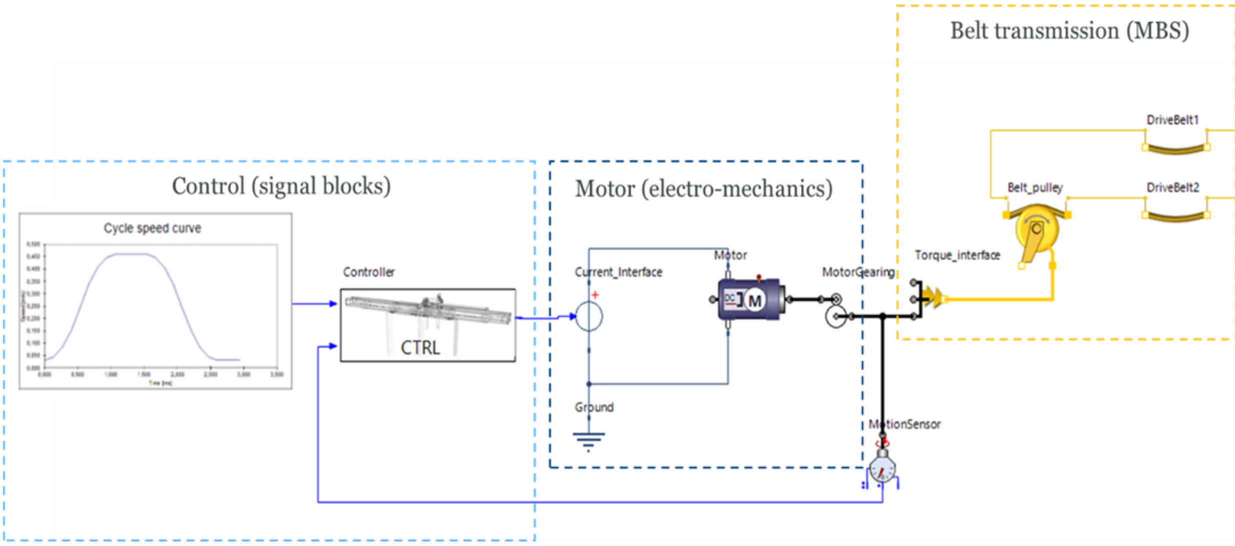

Figure 1. A belt drive system created with SimulationX

A major benefit of using the modular object-oriented modelling is the efficiency the method brings in altering between various configurations of lift systems which are simulated. Modular building blocks representing components of lift door system can be replaced, changed, and reparametrized. These variations can be for instance, lift door panel type, lift door dimensions, speed settings, coupling mechanism. Another benefit of the method is the possibility to include parts from all fields of mechatronic in a single model. By combining all fields of engineering in a system, risks of miscommunications or misconception between cross-discipline experts and engineers are reduced.

Failures of lift door related malfunctions are known to occur in system level. Therefore, cross discipline computation is required in order to include all major factors linked to the lift door malfunctions in simulations. The system level simulations enable high precision simulations with low computational time. However, the challenge for the method is the model simplification definitions. To capture the studied phenomena, contributing components and their interactions must be identified.

3 DOOR MODEL

A two-panel side opening lift door model has been created with a multi-physics software called SimulationX. The software consists of libraries containing elements of mechanics, electronics, and signal processing which have been utilized in the lift door model. (Figure 2)

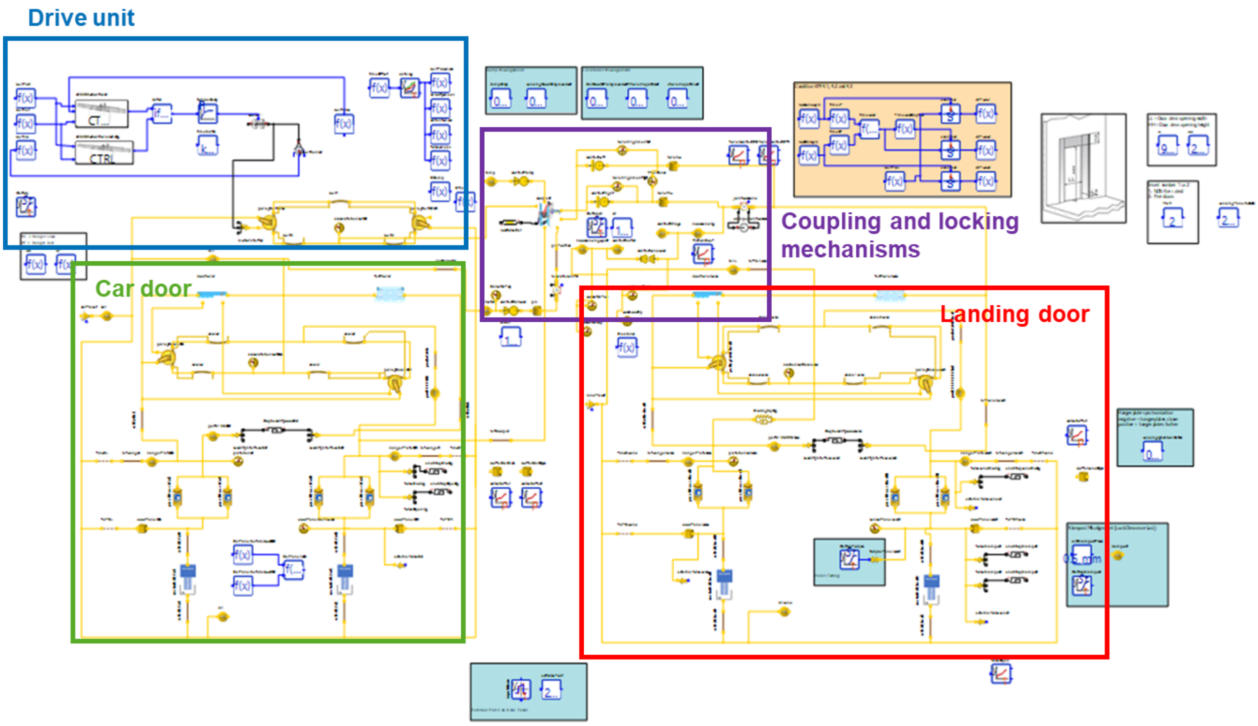

Figure 2. The architecture of lift door model

3.1 Mechanics

As described in the thesis related to the lift door model, mechanics of the model have been built from elements from multibody dynamics in SimulationX library [3]. The mechanical components have been modelled as rigid bodies which have been connected to each other via kinematic joints and various force elements. Elasticity in main contributing components have been simplified by connecting the rigid bodies with spring-damper force elements as demonstrated in Figure 3.

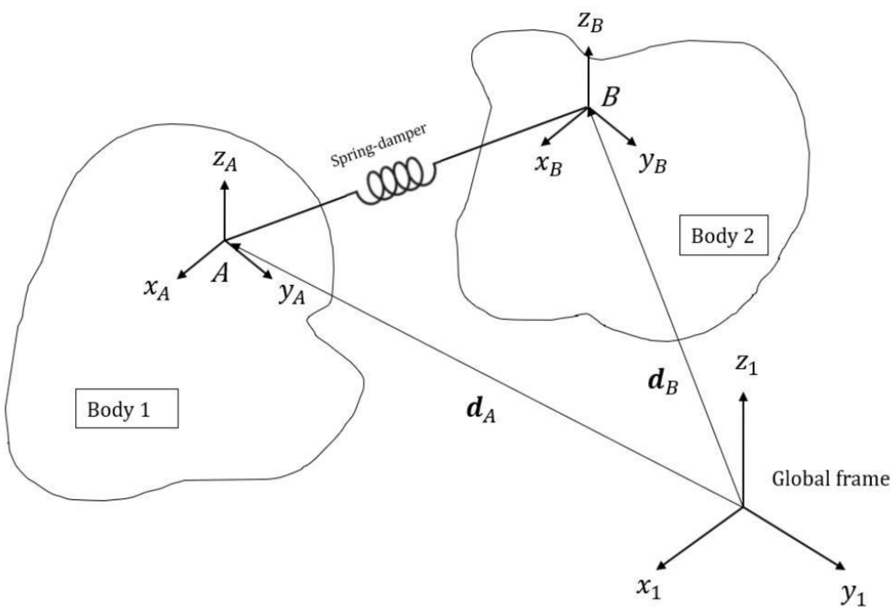

Figure 3. Creating elastic connections between rigid bodies. [3]

For each rigid body, mass, centre of gravity, inertia tensor, position and orientations must be defined from component documentations or 3D-models. The stiffness of elastic material, connections and contacts are defined from analytical methods or laboratory tests.

3.2 Control and electronics

Lift door drive systems operates with closed-loop feedback control as demonstrated in Figure 4. The controllers operate in principle of proportional-integral control mechanism. [3]

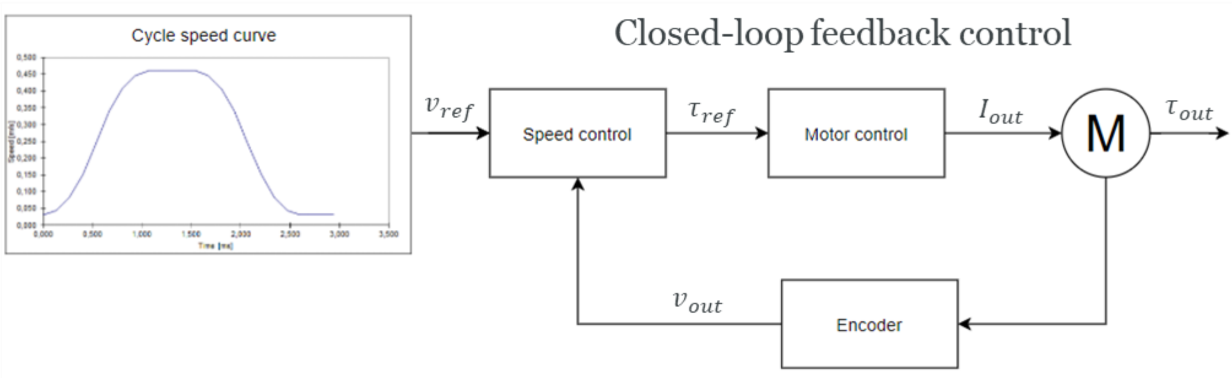

Figure 4. Door drive control loop. [3]

Reference speed curves for door drive cycles are generated inside the model which are defined by lift door speed profile standards which states four speed settings for the two-panel side opening doors. In the model, the motor is modelled as an external torque element connected to the belt transmission. This torque output element is then controlled by the control loop. A detailed motor architecture can be added in the model for studying drive system related malfunctions.

3.3 Outputs

Dynamic response of each element included in the lift door model can be saved and utilized for malfunction studies. Since the end goal of the malfunction analysis is to detect malfunction related indicators, data which are measurable in lift door systems have been selected as outputs for the simulations. Outputs available in lift door systems are door motor current intake and angular position. Other variables utilized for malfunction analysis such as belt position and belt force have been calculated from the lift door motor outputs. These variables have been collected from test lift doors for the validation comparisons displayed in the results section.

4 RESULTS

The simulation results of normal and faulty run for standard lift door cycles are presented in this paper. The faults focused on this paper are related to the issues occurring in lift door locking mechanisms which are safety mechanism for ensuring that lift doors are only opened when the doors are operated. Lift door lock related failures leads to situations where lift doors are stuck which may cause passenger to be trapped inside the lifts. Therefore, it is beneficial to prevent lock related faults occurring to improve lift door reliability, availability, and customer satisfaction.

The normal runs were simulated first to validate applicability of the lift door model used for the fault analysis. The procedure for validation was done by measuring the lift door data from test doors for standard door cycles and comparing the measured data with the simulation data from the identical drive cycles. Results of validation comparison for a normal door cycle are presented in Figure 5. Validation comparison shows deviance at the end of the door cycle because the simulated lift door drive was not programmed to hold doors close in close end force as the feature was not required for the malfunction analysis done in the study which is related to the first section of the door cycle. After the validation comparison for normal runs passes acceptance criteria set for the fault analysis, the validated model can be further utilized in malfunction simulations.

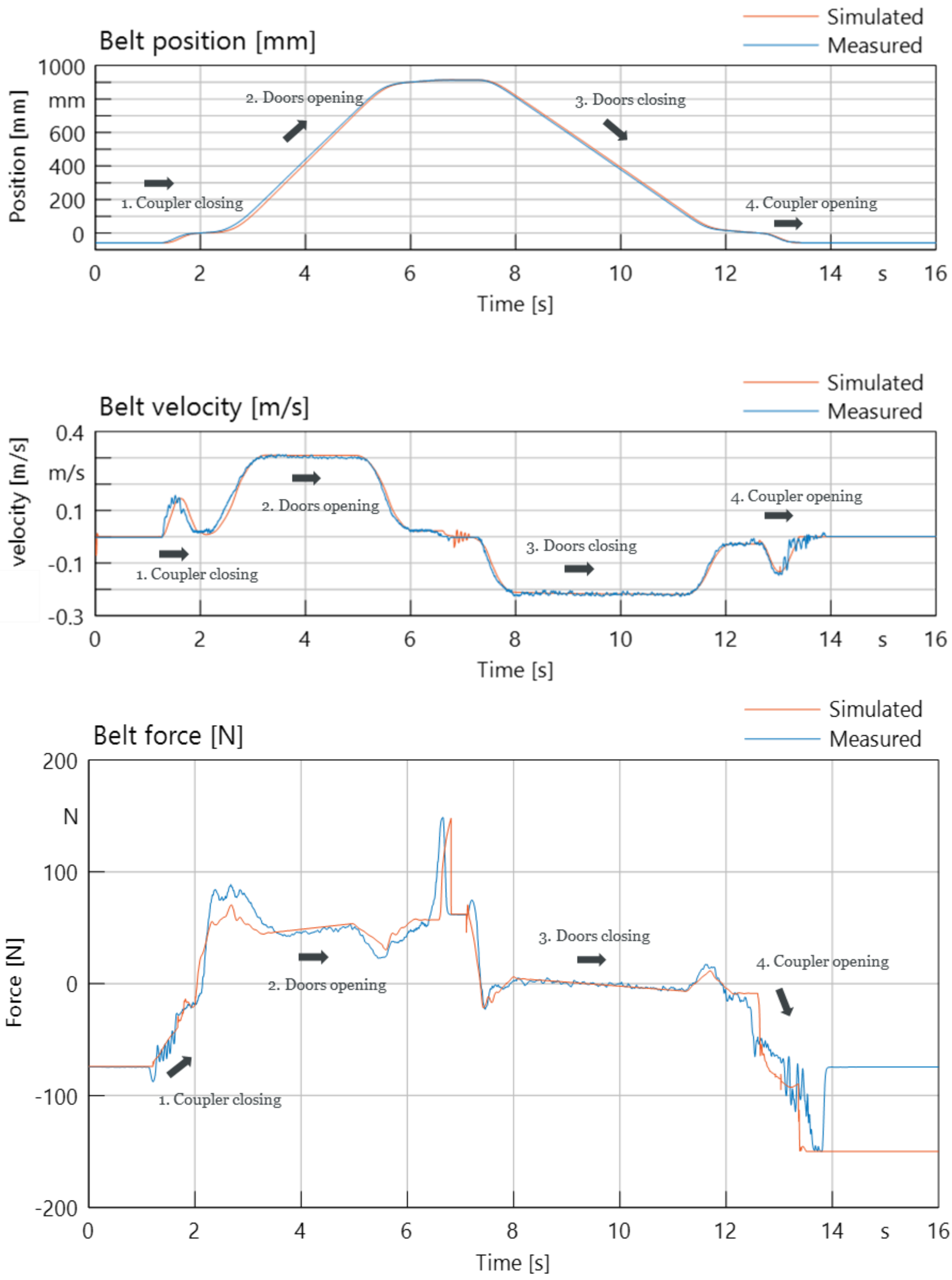

Figure 5. Validation comparisons for normal lift door cycles.

The malfunction simulations are performed by progressively impairing the simulated system to slowly approach the failure mode of the studied fault. For instance, the lift door lock related fault is known to be caused by diminishing lock clearance between lock hook and the counterpart of the lock hook. As displayed in Figure 6, malfunction simulations have been performed by removing lock clearance each simulated door cycle. Then by analyzing the simulation results, the pattern indicating lift lock jamming have been identified from the data. In this case, the jamming lock caused a surge in torque demand during lock opening which can be seen as belt force spike in the outputs.

Subsequently, the identified pattern is validated with laboratory tests by conducting the same cycles with test doors as computed in simulations. In the lock jamming tests, the lock clearance was decreased progressively over multiple door cycles. During each cycle, the motor outputs were measured. The test data is then compared with the simulated data to validate if the signature patterns for the studied case repeats in the measured data as demonstrated in the Figure 6.

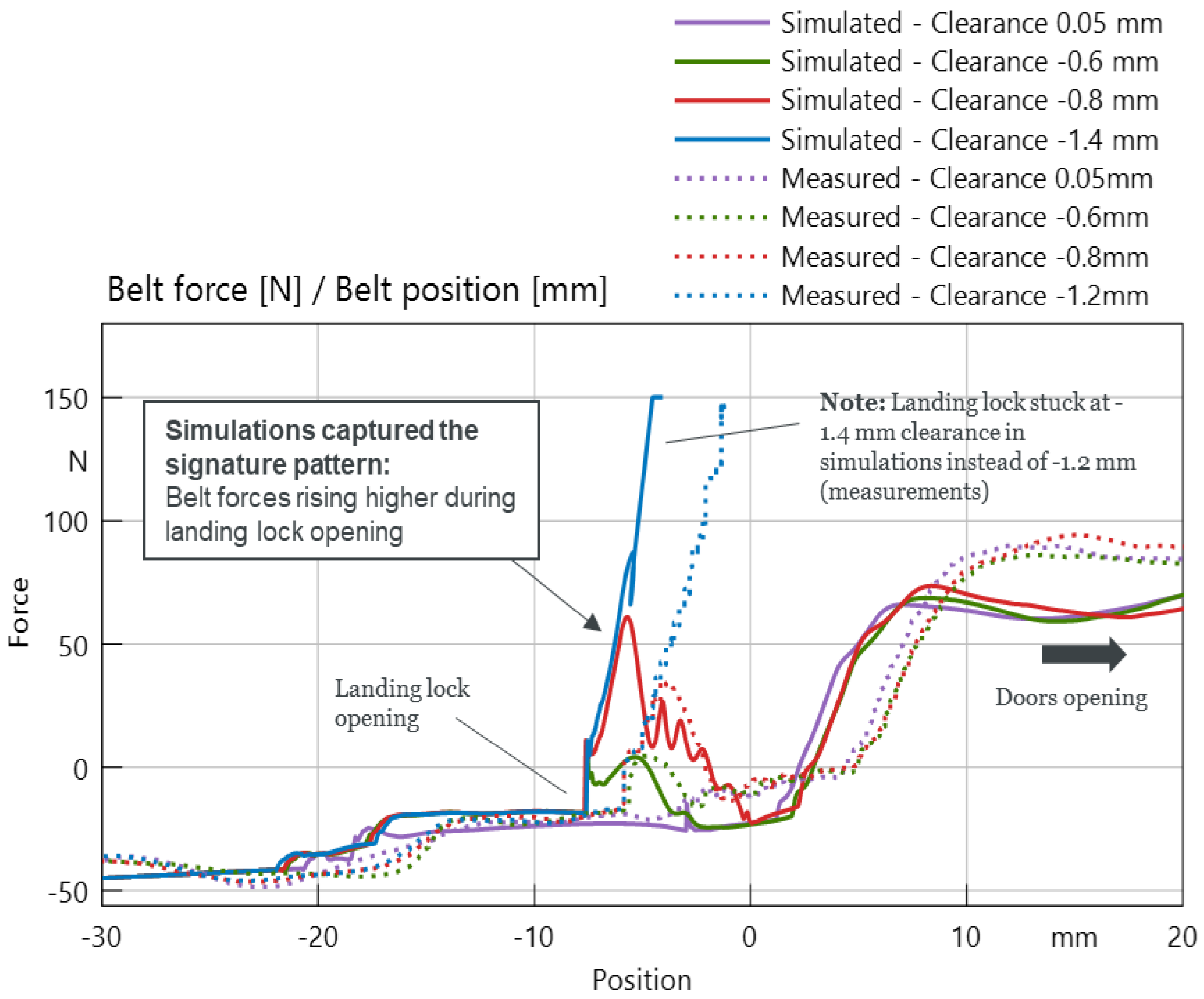

Figure 6. Identified malfunction pattern for lift door lock jamming. [3]

Conclusion

In this paper, simulation method and use cases for system level object-oriented simulation for lift systems have been presented. The lift door system presented in this paper was successfully validated for normal runs and the selected malfunction case. The simulation results correlated well with the measured outputs from test doors and capture the malfunction related pattern.

The validation results proved the capability of the simulations to be utilized for developing maintenance process of lift doors. By identifying the patterns leading to failure modes, thresholds can be set for condition monitoring algorithms in order to flag potential malfunctions in monitored systems. In addition, the faults with validated distinguishable identification patterns from either simulations or measurements can be labelled and utilized as training data for machine learning algorithms.

REFERENCES

[1] Kaariaho, Iiro-Elias. "Testing of elevator door sill assembly.", Bachelor's thesis, bachelors, Savonia University of Applied Sciences, Finland, 2018.
[2] P. Klein and R. Bergmann, "Data Generation with a Physical Model to Support Machine Learning Research for Predictive Maintenance", Business Information System II, University of Trier Germany, ISSN 2191-5652, Springer series, 2018.
[3] M. Lin, "Physics-based simulations of elevator door systems", Master's thesis, Aalto University, Finland, 2021.
[4] SimulationX [https://www.esi-group.com/products/system-simulation], 2022.

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Education

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