Digital Twin Elevator and Smart Elevator Technology

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Seoil University Dept. Digital Twin Elevator

Su Eog Cho

secho@seoil.ac.kr

Introduction to digital twin

- Digital twin refers to a digital replication of physical assets, objects, or processes in real space through 3D modeling, including location, shape, movement, and state.
- A digital space that is identical to a real space is called ‘digital twin space (DTS)’ and presented as a goal to be pursued by the next generation of national spatial information.
- Digital twin space refers to a virtual environment that is identical to the physical environment of the real world. It uses various data linked to the physical environment to monitor the real world or analyze problems and simultaneously find solutions and reflect them in the real world.
- A smart city or smart society requires an integrated system of hardware and software, and DTS is the most effective means of implementing a physical environment into a virtual environment and a platform that connects the real world and the virtual world.
- Using real-world data, information obtained through monitoring, analysis, prediction, and simulation in the digital twin space can be reflected in the real world to optimize operations, solve problems, and prevent problems in advance.

Introduction to digital twin

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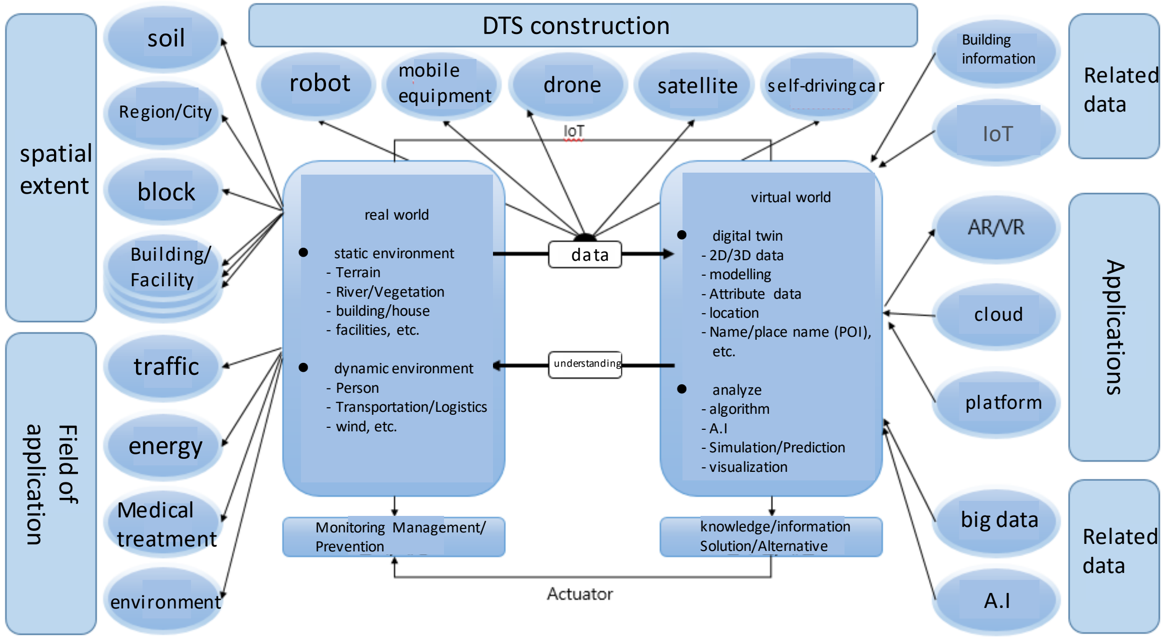
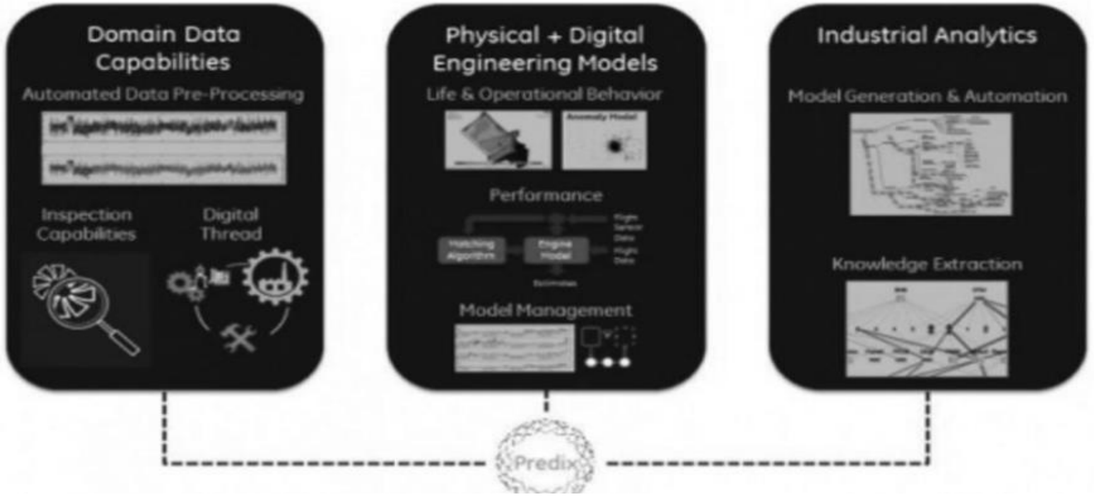
- The spatial scope of the digital twin space varies depending on the purpose of use, such as country, region, city, block, building, facility, etc., but is generally classified according to the purpose of use and operator.
- The areas of use of digital twin space cover all fields of society, including transportation, energy, medical care, and the environment. The public sector is divided by administrative purpose or target, and the private sector is divided by purpose of use.
- It is important to build a digital twin space and continuously maintain, manage, and update it. To this end, utilize existing data as much as possible while introducing cutting-edge equipment and new technologies to improve accuracy, precision, and economic efficiency.



Conceptual model of digital twin space

Introduction to digital twin

- Looking at Predix from GE, USA, which is similar to an elevator, Predix from GE, USA, is a digital twin development/operation platform developed for the purpose of providing digital application services in the manufacturing industry through an industrial Internet platform.
- It is a solution that comprehensively supports operating system, cloud, big data, and analysis SW, and provides tools and services for utilizing/analyzing data from GE's power plant's entire cycle of operation, including materials/parts/equipment/system.
- IoT-based industrial internet/big data/cloud platform supports collection, processing, storage, and analysis of various information generated during plant operation management.
- GE is building digital profiles of all industrial machines it produces, securing engineering models for the machines, and developing 551,000 digital twins running on Predix.



Predix platform concept diagram

Introduction to digital twin

- Currently, the Digital Twin Process is being applied to the elevator industry in Korea by global companies and is partially being applied by large corporations.
- In the case of small and medium-sized enterprises, it is difficult to apply the 4th Industry-related IOT, big data, and AI required when applying elevator remote control, monitoring, and life-related judgment technologies due to the lack of human and material infrastructure related to the 4th Industry (DX).
- To complement this, apply Ansys. (elevator structural analysis) Mathworks. (AI, IOT) Solid works. (3D, thermal analysis) PSIM. (power conversion, motor control, EMC) and elevator systems, algorithms, and parts. Modeling and 3D library creation are required, which improves the reliability of the elevator system and shortens the elevator development period.
- In addition, even during elevator maintenance, before service is possible by identifying the exact life cycle of elevator parts.

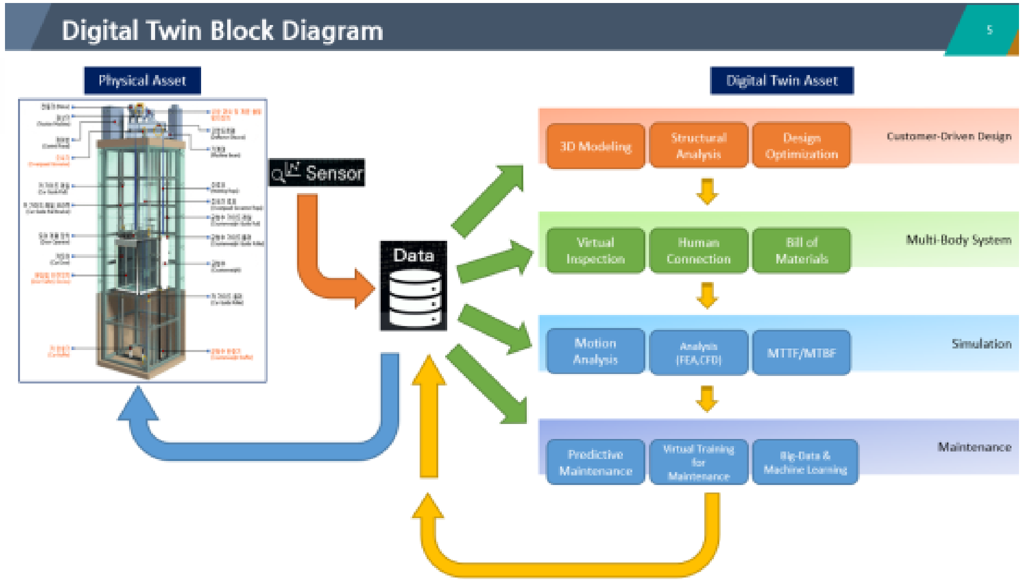
Why Digital Twins Are Necessary for the Elevator Industry

- Defining digital twins based on business models in the elevator industry

- This is a Digital Twin Block Diagram that diagrams the process of converting an elevator's physical asset into a digital twin asset.

- Customer-Driven Design of the elevator enables 3D Modeling, Structural Analysis, and Design Optimization. Through this, Virtual Inspection, Human Connection, and Bill of Materials of the Multi-Body System can be configured, and Motion Analysis, Analysis (FEA, CFD) through Simulation. , MTTF/MTBF, etc. can be easily checked.

- Maintenance can also perform Predictive Maintenance, Virtual Training for Maintenance, Big-Data & Machine Learning based on simulation results, and use this to create data and apply it to the actual elevator system.



Digital Twin Block Diagram

Why Digital Twins Are Necessary for the Elevator Industry

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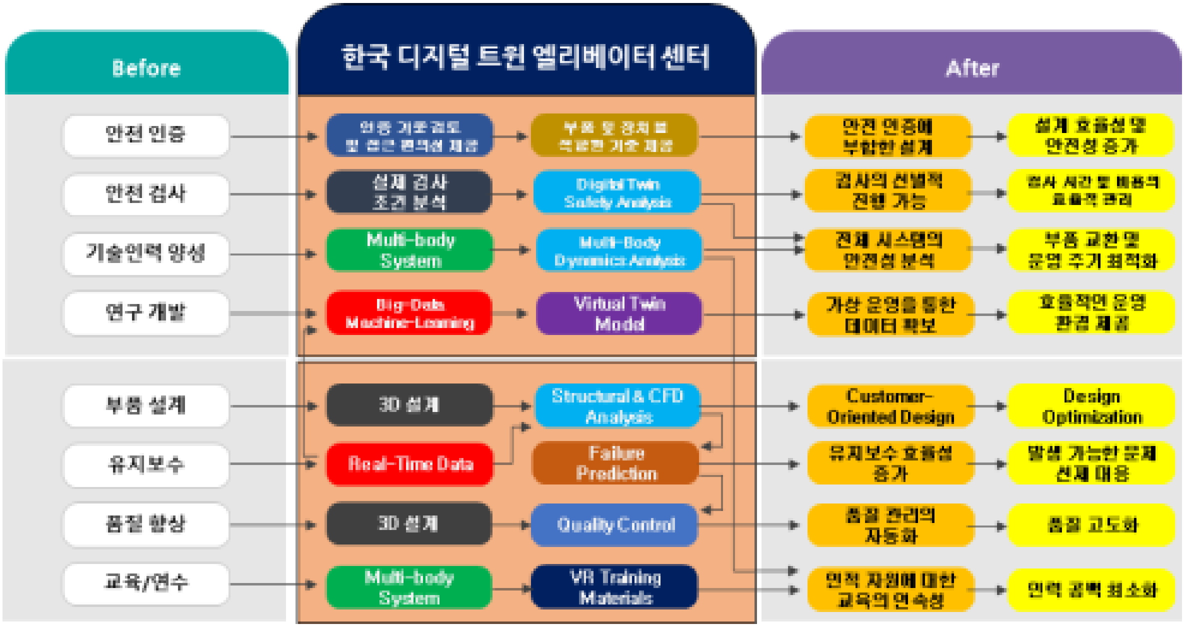
- Effects before and after using digital twins in the elevator industry



- The market utilizing digital twins is gradually growing, and the potential for future development is very high.

- By digital twining the elevator system and safety parts, it is possible to quickly change the design and shorten the development period for new products through design, development, and certification, and analyze elevator requirements and software-in-the-loop (SIL), hardware-in- Enables rapid design/development and verification through the-loop (HIL).

Elevator technology using digital twins

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1. EMI Filter Design PSIM Simulation
2. Elevator Simulation using Simscape Multibody
3. Safety assessment of mechanical components of digital twin elevator door system
4. Implementation of a digital twin model of an elevator door device using MATLAB
5. Digital twin model-based design workflow for elevator safety certification

1. EMI Filter Design PSIM Simulation

- **Understanding PSIM EMI Design Suite**

- EMI performance evaluation using EMI Design Suite is performed in three steps:

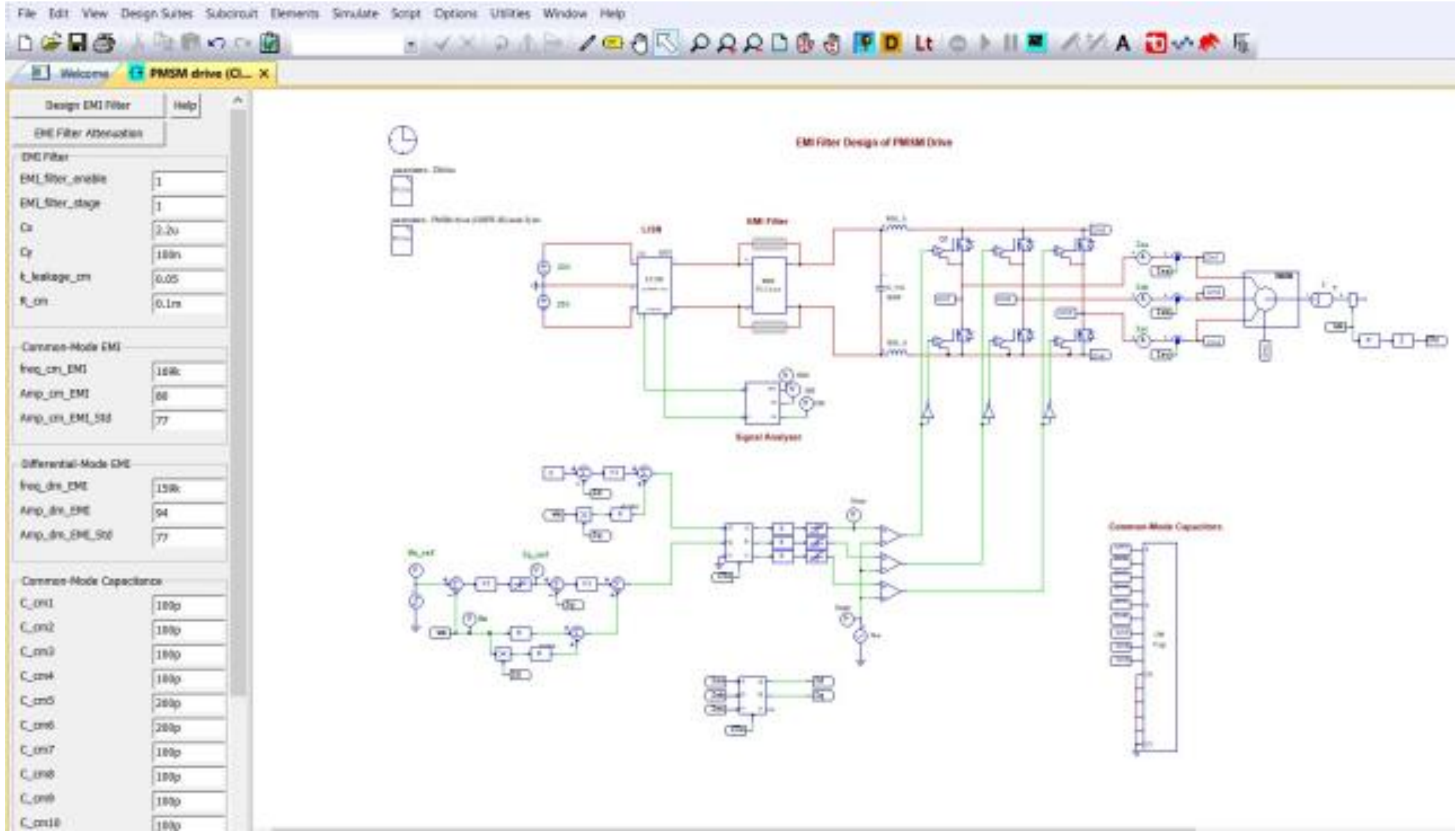
- Definition of elevator system parasitic parameters and some EMI filter parameters.
- Running simulation with EMI filter disabled. Record and enter the frequency and amplitude of CM and DM and the EMI standard level at the worst point when DM and CM exceed the EMI standard.
- Perform an EMI filter design and rerun the simulation with the EMI filter enabled.

EMI Filter:	
EMI_filter_enable:	0
EMI_filter_stage:	1
Cx:	6.8u
Cy:	100n
K_leakage_cm:	0.05
R_cm:	0.1m
Common Mode EMI:	
Freq_cm_EMI:	200k
Amp_cm_EMI:	81.5
Amp_cm_EMI_Std:	63.6
Differential Mode EMI:	
Freq_dm_EMI:	200k
Amp_dm_EMI:	81.5
Amp_dm_EMI_Std:	63.6
Common Mode Capacitances:	
C_cm1:	500p
C_cm2:	500p
C_cm3:	50p
C_cm4:	50p
C_cm5:	100p
C_cm6:	100p
C_cm7:	50p
C_cm8:	50pd

EMI Filter Design Example

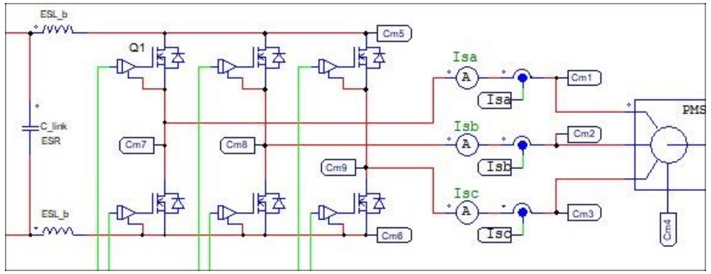
1. EMI Filter Design PSIM Simulation

- **Utilization of PSIM EMI Design Suite (PMSM inverter drive for elevators)**

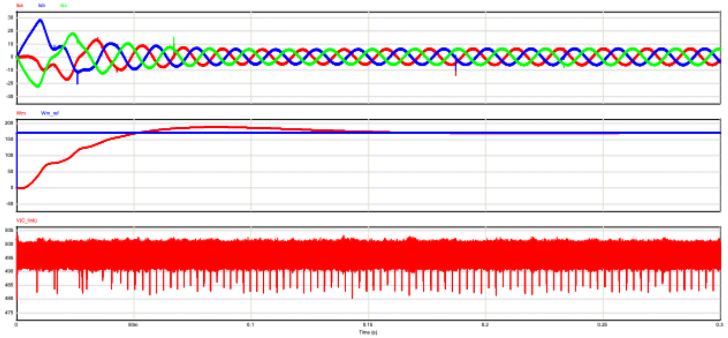


PSIM EMI Filter Design simulation circuit diagram

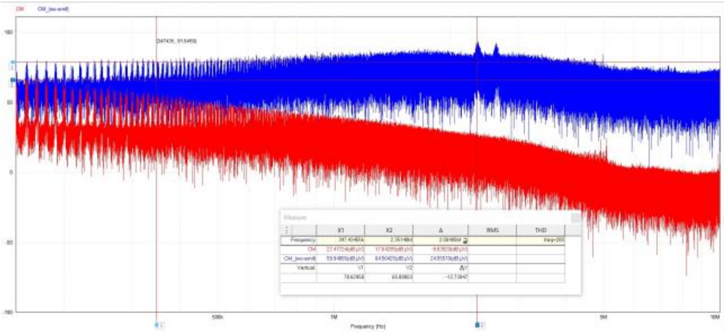
1. EMI Filter Design PSIM Simulation



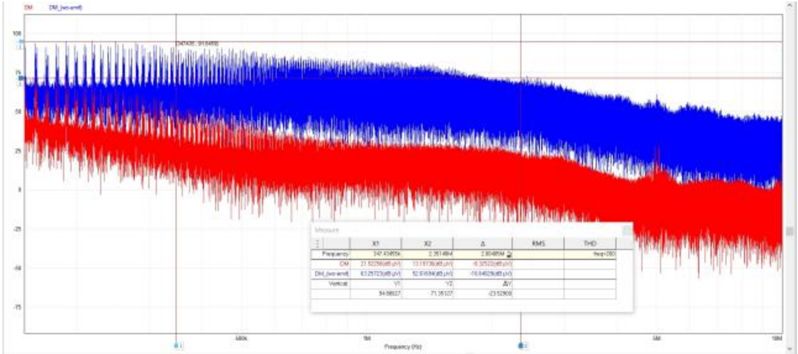
PMSM inverter drive
ESR, ESL_b, Cm1~Cm9



Simulation waveform of PMSM inverter drive (motor current, speed, voltage (C_link))

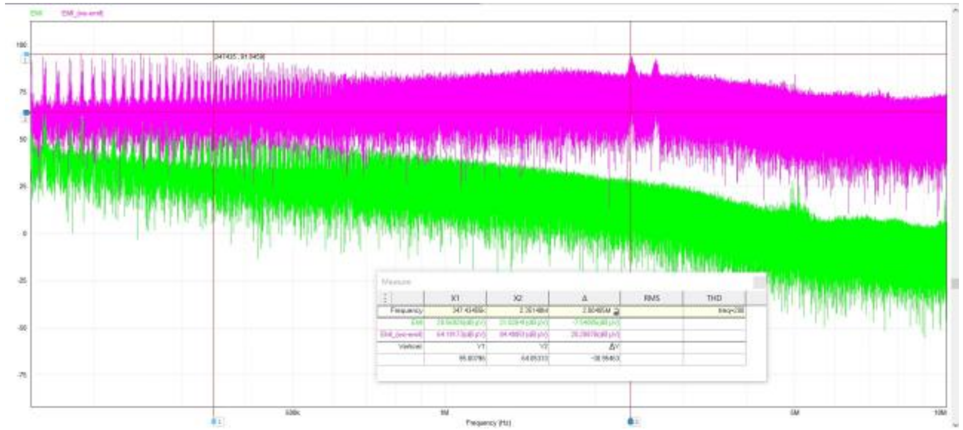


PMSM inverter simulation waveform
(Common Mode Noise)



PMSM inverter simulation waveform (Differential Mode Noise)

1. EMI Filter Design PSIM Simulation



PMSM inverter simulation waveform (EMI Noise)

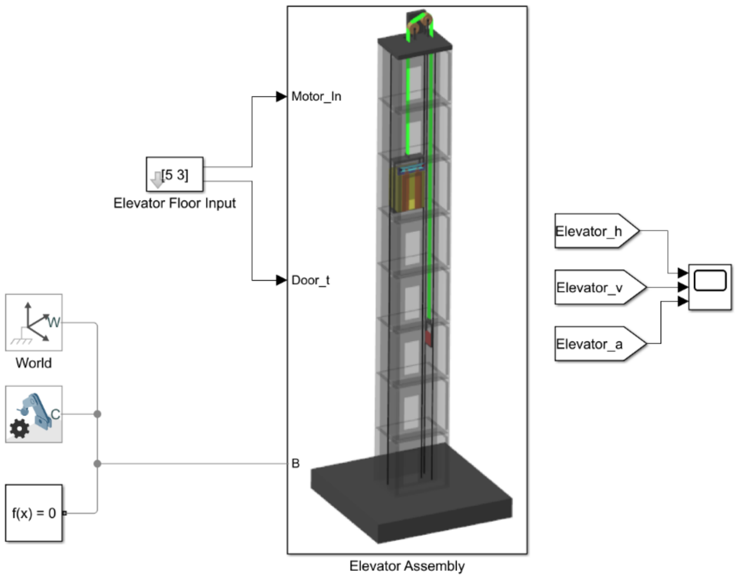
```
// Note: The parameter file needs to be regenerated from the Design Suite
//          when any of the input parameters are changed.

//*********************************************
//
//    Parameters from User Input
//
//*********************************************

//--------------- EMI filter ---------------
EMI_filter_enable = 1;  // 0 = EMI filter disabled; 1 = EMI filter enabled
EMI_filter_stage = 1;   // 1 = 1-stage EMI filter;  2 = 2-stage EMI filter

Cx = 2.2E-06;       // X capacitance
Cy = 1E-07;     // Y capacitance

k_leakage_cm = 0.05;    // ratio between L_leakage and L_cm of the common-mode choke
R_cm = 0.0001;      // Common-mode choke winding resistance

//---------------  Common-mode Capacitances  -----------------
C_cm1 = 1E-10;      // common-mode capacitance, in F
C_cm2 = 1E-10;
C_cm3 = 1E-10;
C_cm4 = 1E-10;
C_cm5 = 2E-10;
C_cm6 = 2E-10;
C_cm7 = 1E-10;
C_cm8 = 1E-10;
C_cm9 = 1E-10;
C_cm10 = 1E-10;
C_cm11 = 5E-11;
C_cm12 = 5E-11;
C_cm13 = 5E-11;
C_cm14 = 5E-11;
C_cm15 = 5E-11;

//--------------- Common-mode Noise -----------------
freq_cm_EMI = 169000;   // Lowest frequency of CM noise where EMI standard fails
Amp_cm_EMI = 80;    // CM noise at freq_cm_EMI, in dB uV
Amp_cm_EMI_Std = 77;    // EMI standard at freq_cm_EMI, in dB uV

//--------------- Differential-mode Noise -----------------
freq_dm_EMI = 159000;   // Lowest frequency of DM noise where EMI standard fails
Amp_dm_EMI = 94;    // DM noise at freq_cm_EMI, in dB uV
Amp_dm_EMI_Std = 77;    // EMI standard at freq_cm_EMI, in dB uV


//*********************************************
//
//    Parameters from Calculation
//
//*********************************************

//--------------- EMI Filter -----------------
fc_cm = 100666.9022564028
fc_dm = 42305.52845080107

L_cm = 1.315567854550814E-05;       // inductance of common-mode choke, in H
L_leakage = 6.577839272754068E-07;      // leakage inductance of common-mode choke, in H

L_dm = 2.55878852473713E-06;        // differential-mode inductance, in H. If L_dm = 0, L_dm is not needed.

```

PMSM inverter simulation waveform (EMI Noise)

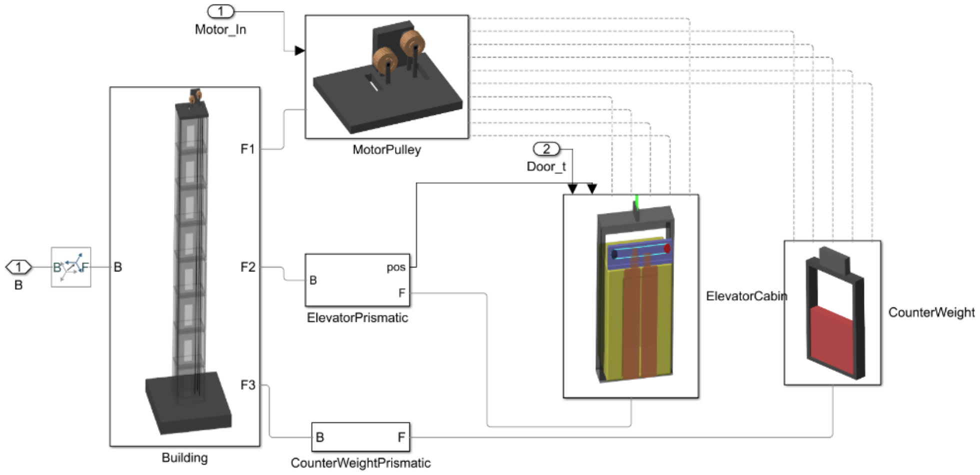
2. Elevator Simulation using Simscape Multibody

- Model the elevator as a third-order multibody and analyze the rope stiffness relationship according to the speed, acceleration, and acceleration of the elevator.
- When changing the weight and speed components of the elevator service floor and car, the elevator vibration problem can be easily accessed and cause analysis can be easily performed.

Elevator System composed of Simscape Multibody program

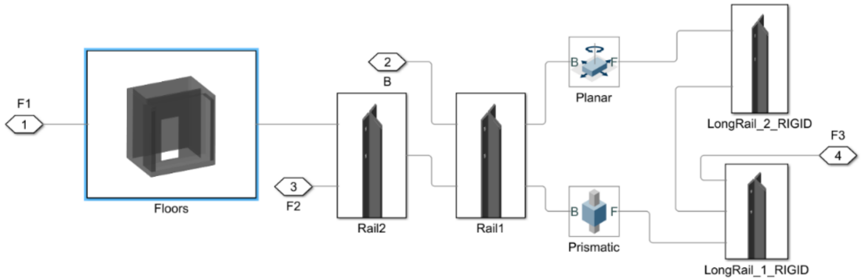


Elevator system simulation configuration composed of Simscape Multibody

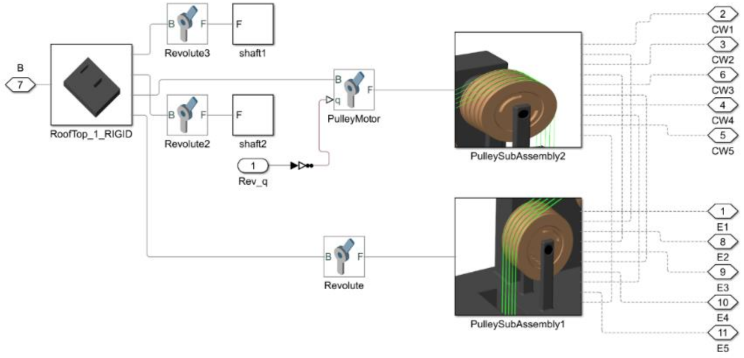


Building, MotorPully, ElevatorCabin, CounterWeight configuration diagram

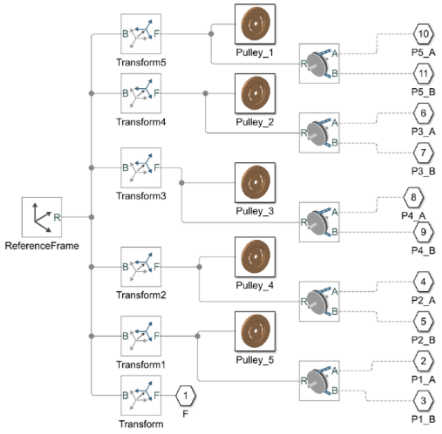
2. Elevator Simulation using Simscape Multibody



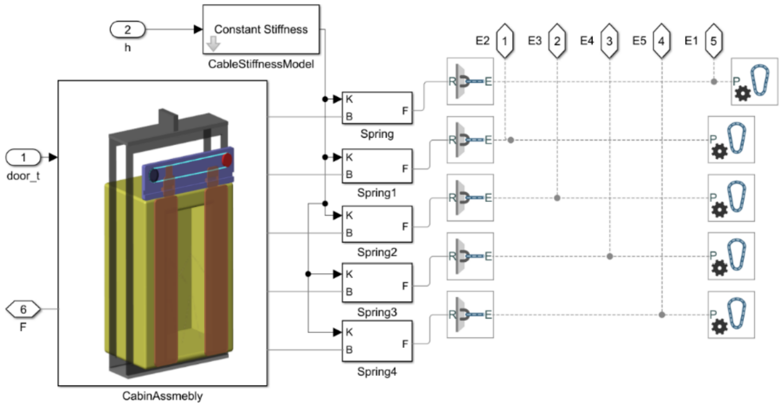
Structure of floors and rails inside the building



RoofTop, PullyMotor, PullySubAssembly2, and PullySubAssembly1 configuration diagram inside MotorPully

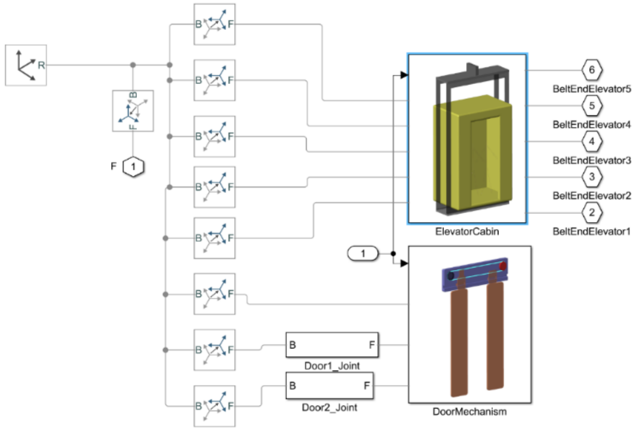


Pully configuration diagram of PullySubAssembly2

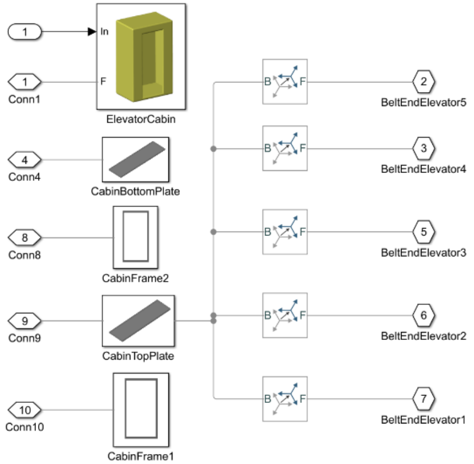


Stiffness Model and belt cable angle and characteristics of the rope connected to the CabinAssembly

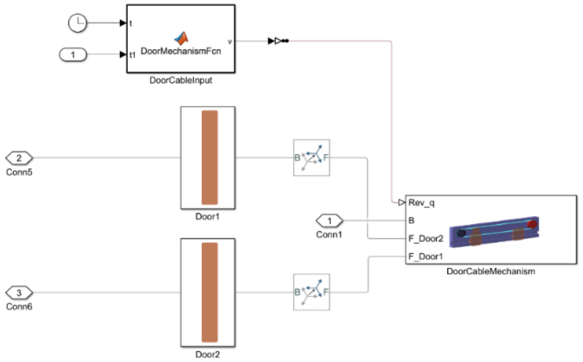
2. Elevator Simulation using Simscape Multibody



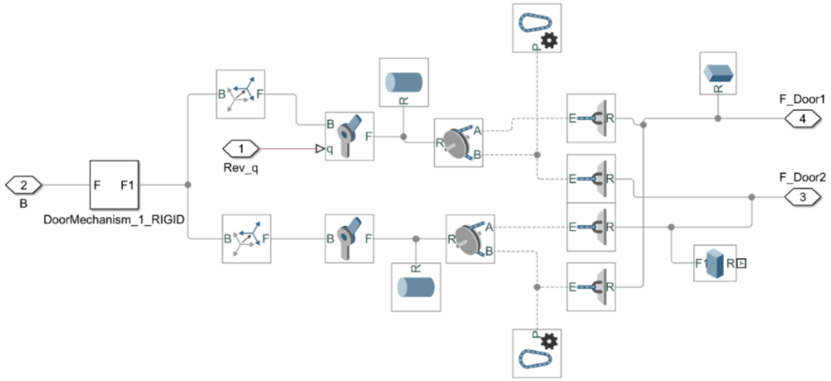
ElevatorCabin and DoorMechanism configuration diagram inside CabinAssembly



ElevatorCabin, CabinBottomPlate, CabinTopPlate, CabinFrame1, 2. Configuration diagram inside ElevatorCabin



Cardoa speed profile function and door configuration diagram inside DoorMechanism



DoorMechanism internal RevoluteJoint, Pully, BeltCableEnd configuration diagram

2. Elevator Simulation using Simscape Multibody

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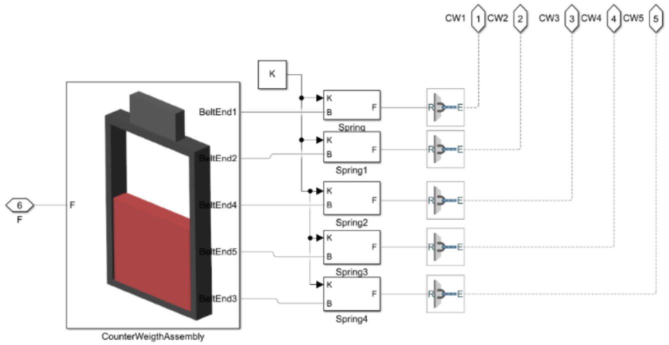
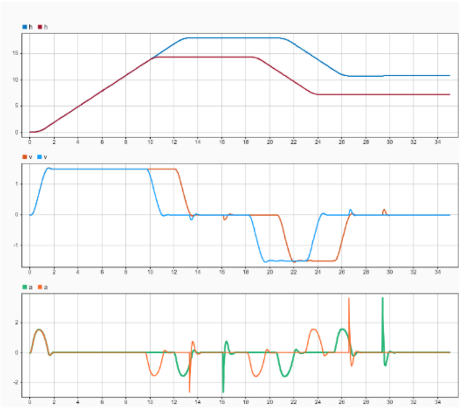
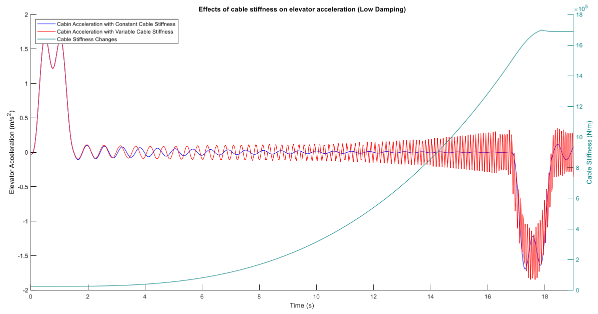


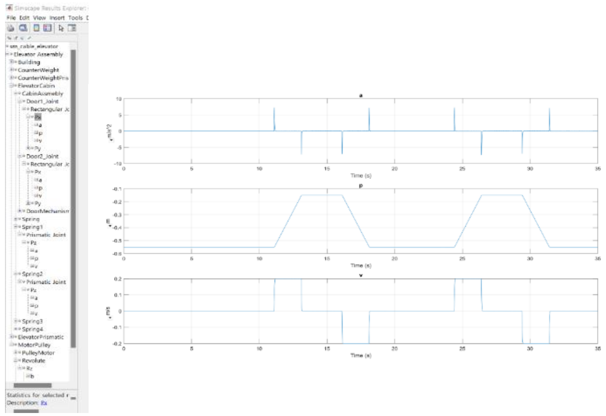
CounterWeight internal CounterWeightAssembly, RopeSpring, BeltCableEnd configuration diagram



Graph logging speed and acceleration by elevator travel distance



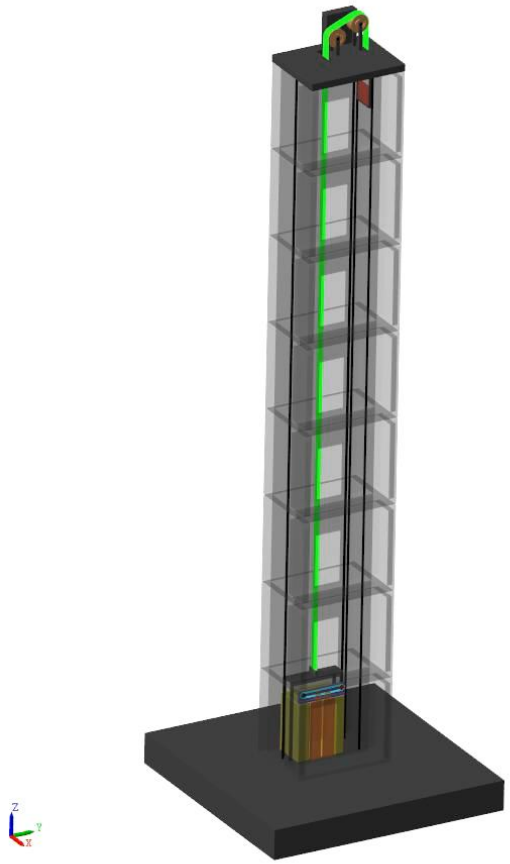
Cable stiffness effect graph on elevator acceleration



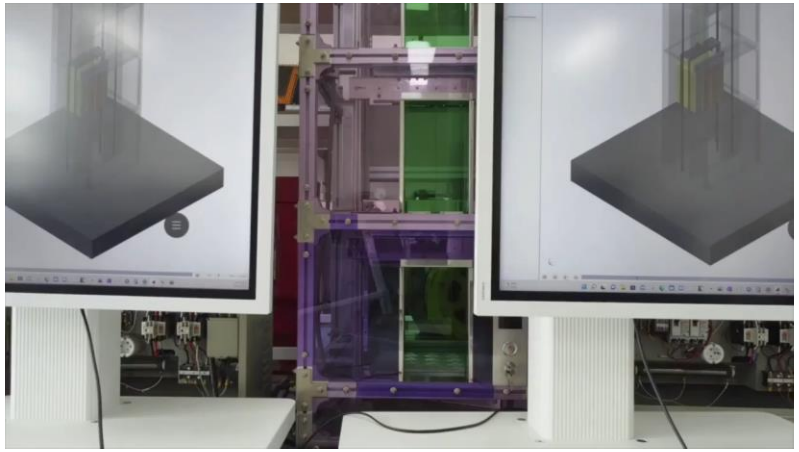
Acceleration, distance, and speed graph of Door1 Joint of car door

2. Elevator Simulation using Simscape Multibody

- **Mechanical Explorer (3D Animation)**



- **Digital Twin Elevator**



3. Safety assessment of mechanical components of digital twin elevator door system

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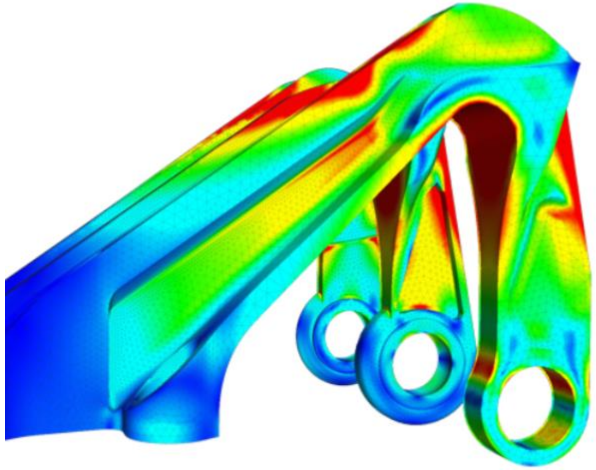
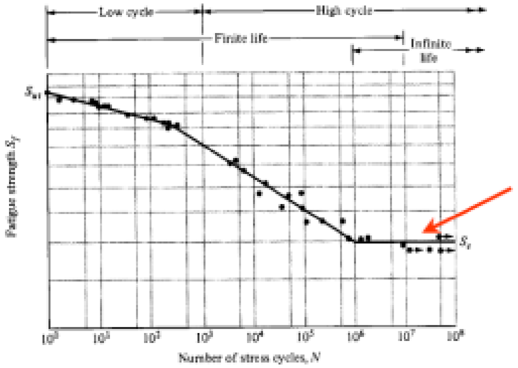
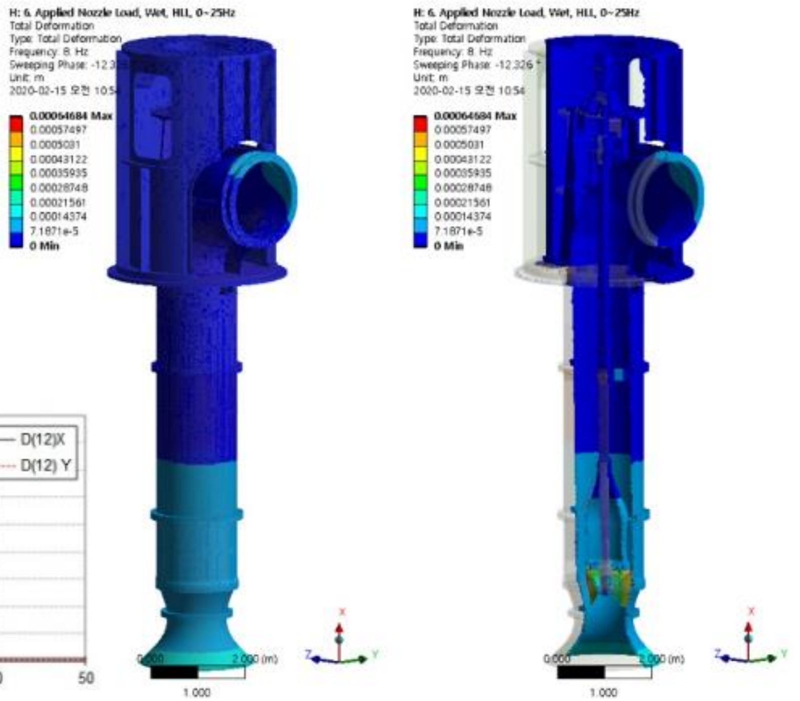
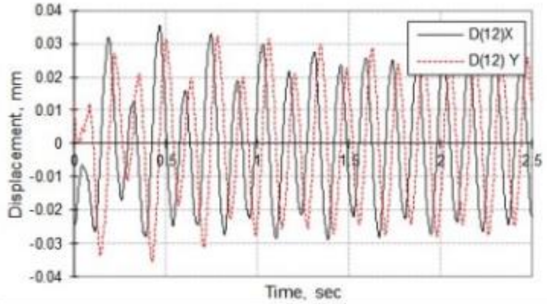
1. Safety evaluation: structural analysis, life evaluation, damage analysis, etc.
2. Machinery parts/product testing: Machinery environmental resistance testing (vibration, temperature-humidity, salt water, etc.), machinery noise/vibration measurement and analysis, etc.

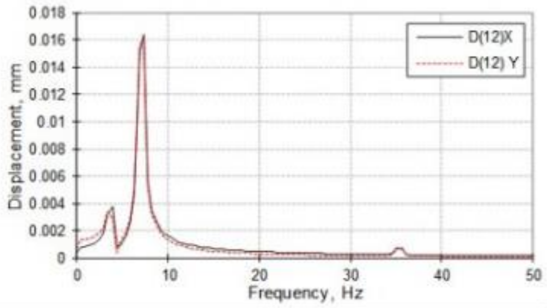




The Endurance Limit is observed as a horizontal line on the S-N curve.



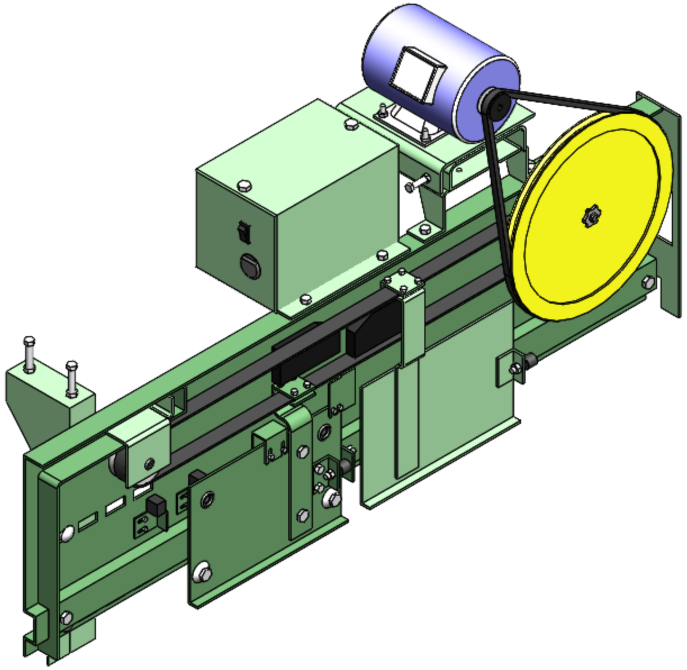


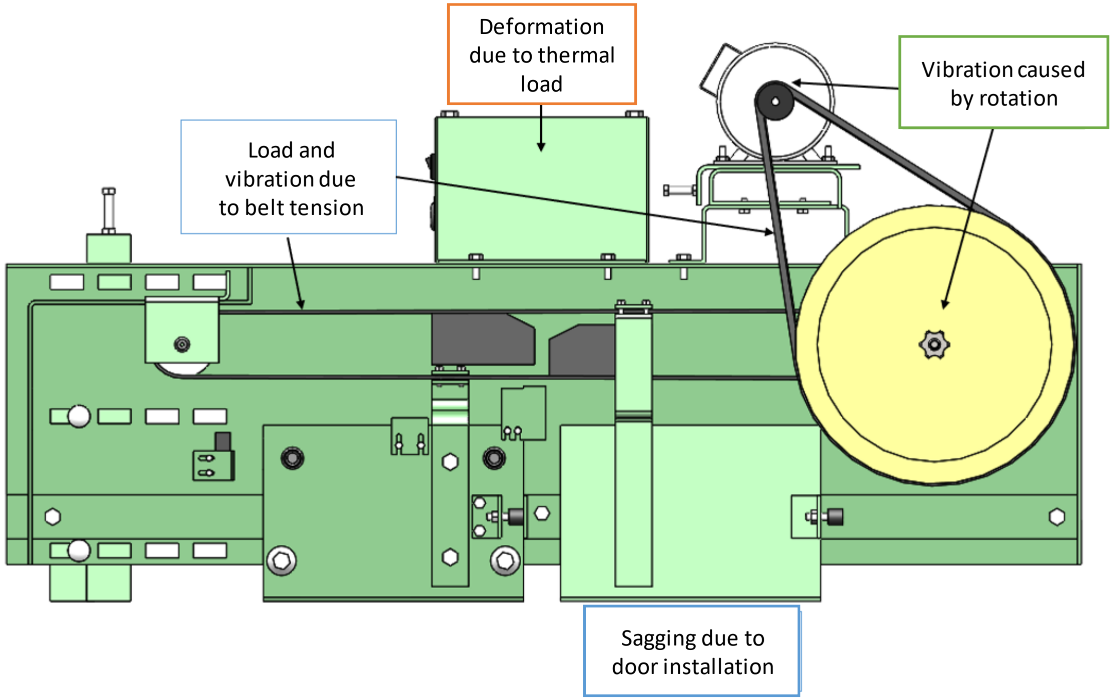


3. Safety assessment of mechanical components of digital twin elevator door system

- Considerations when verifying safety

- Independence of loads acting on each part
- Differences from actual conditions of expected load or vibration
- Changes in elastic and damping properties transmitted in the assembly

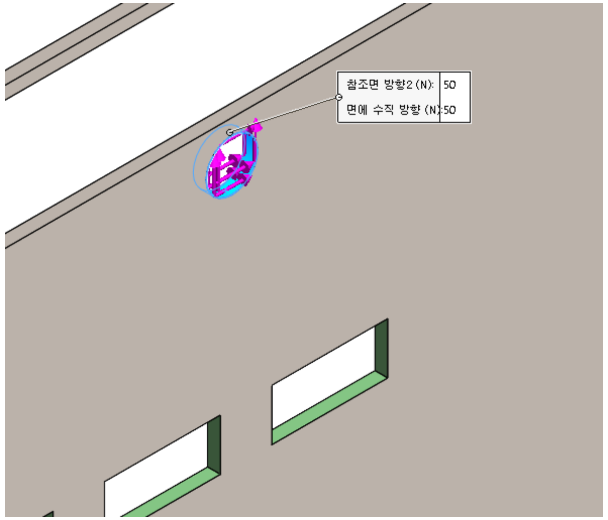


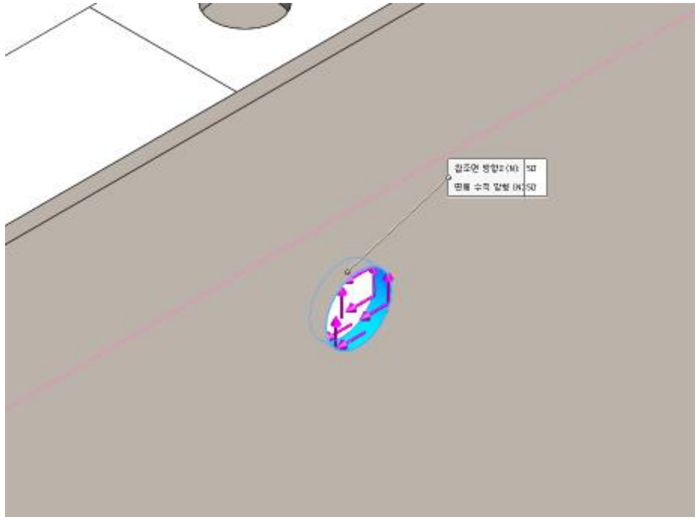


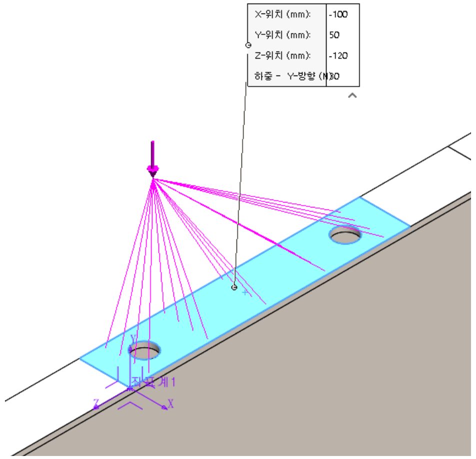
3. Safety assessment of mechanical components of digital twin elevator door system

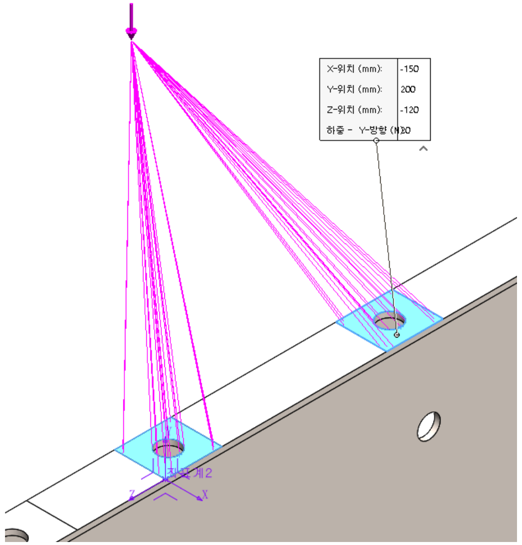
- Utilize load information of major components

- Structural analysis considering loads applied to major components
- Belt tension and load due to self-weight of peripheral devices, etc.









3. Safety assessment of mechanical components of digital twin elevator door system

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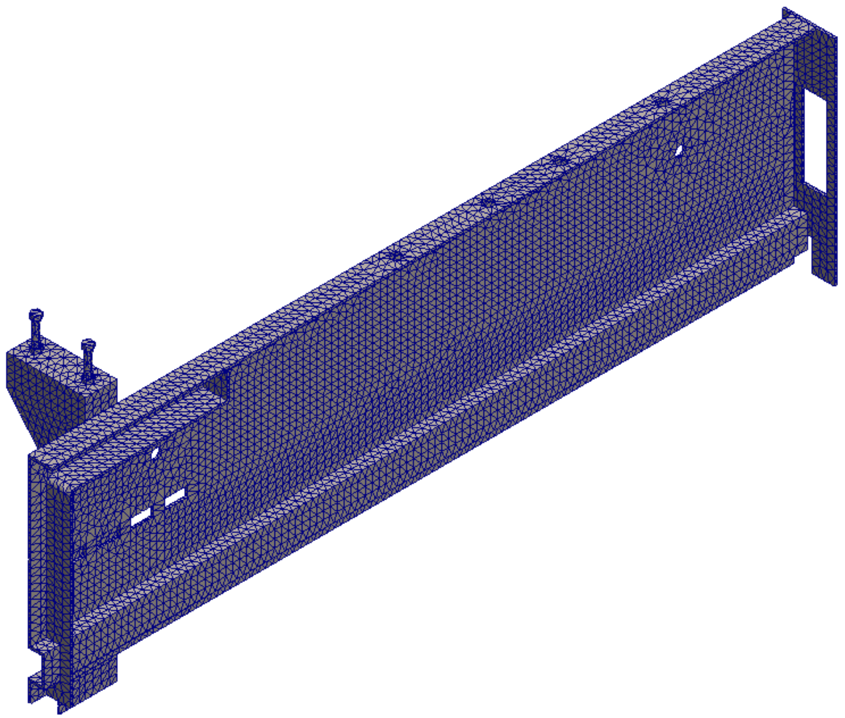
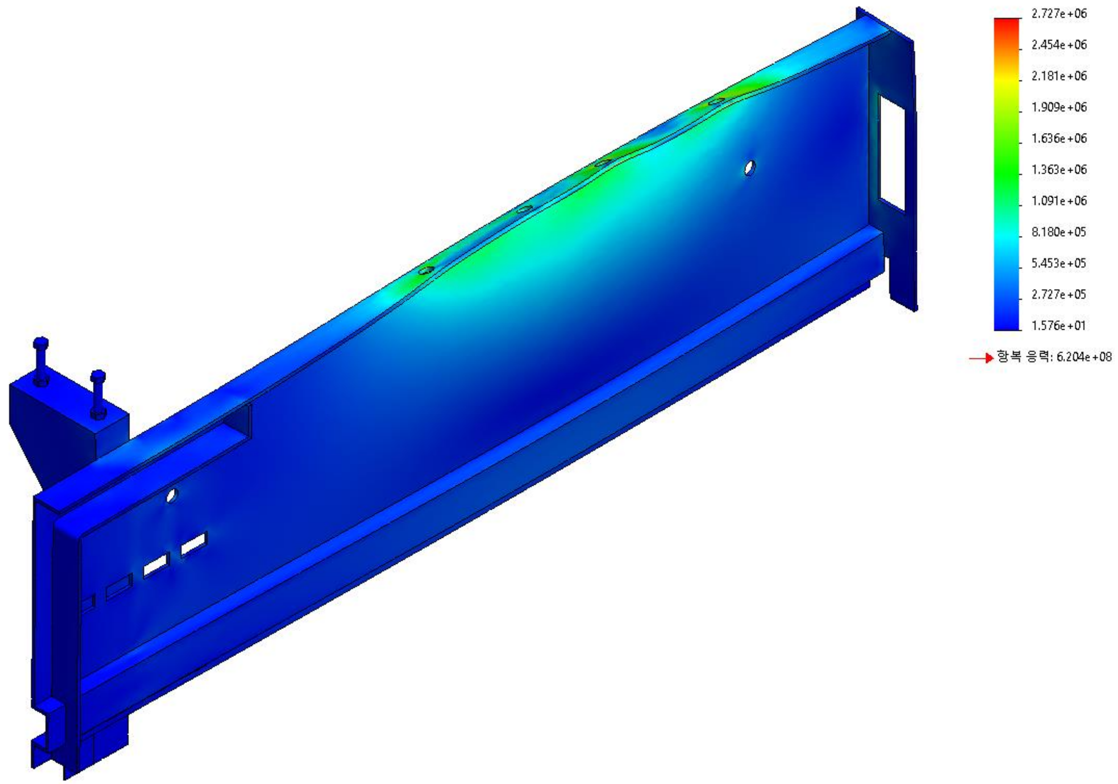
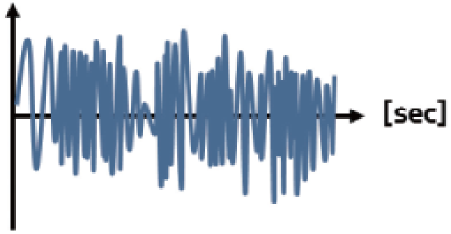
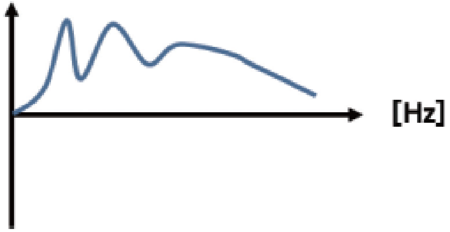


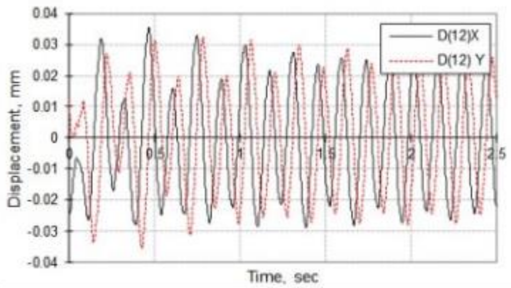


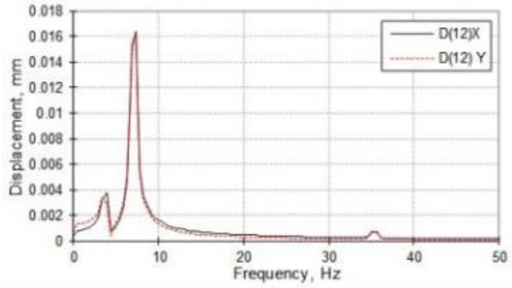
3. Safety assessment of mechanical components of digital twin elevator door system

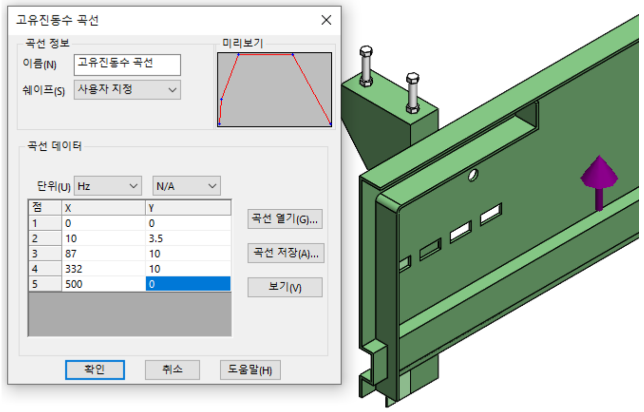
- Utilize Realtime Sensing Data
- Structural analysis using real-time data of major components
- Convert time domain loads collected from each part into frequency domain loads and apply them

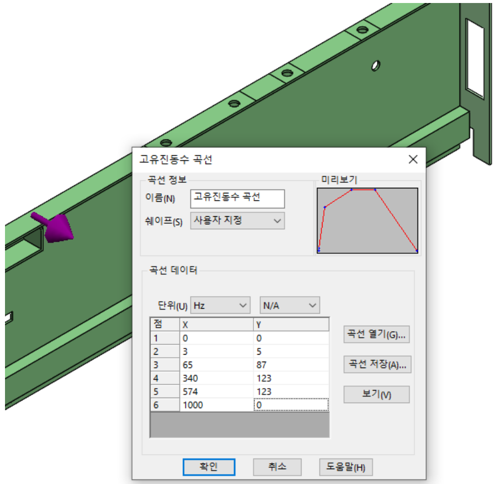


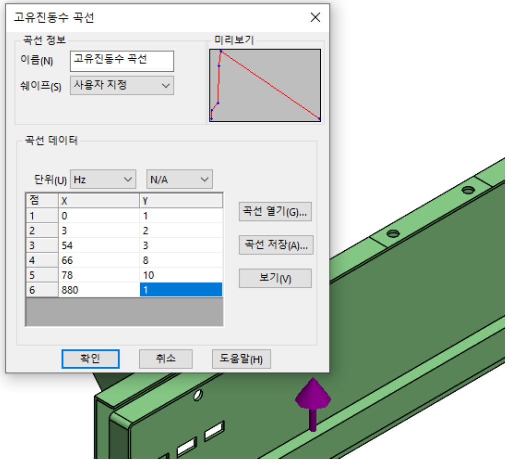


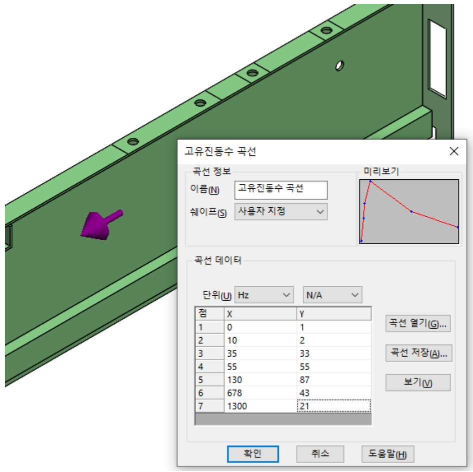






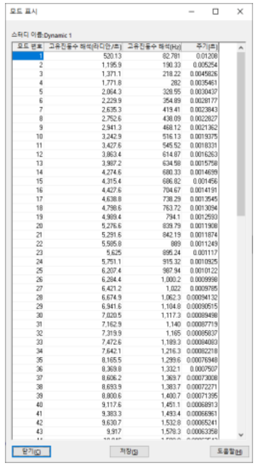






3. Safety assessment of mechanical components of digital twin elevator door system

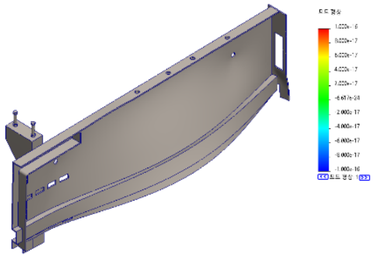
- Utilize Realtime Sensng Data

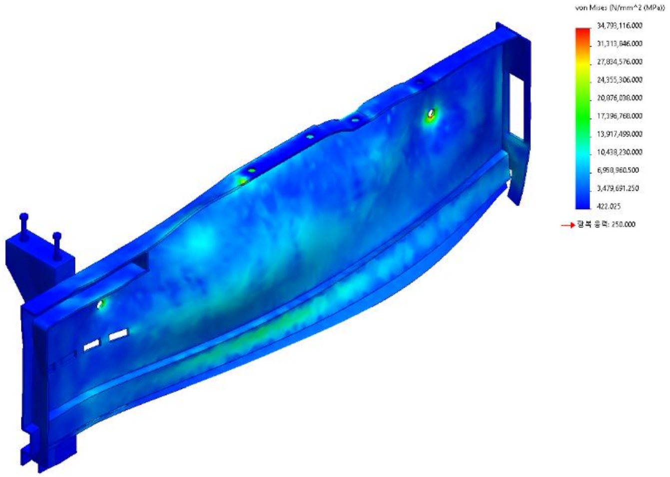

모드 표시

스터디 이름:Dynamic 1

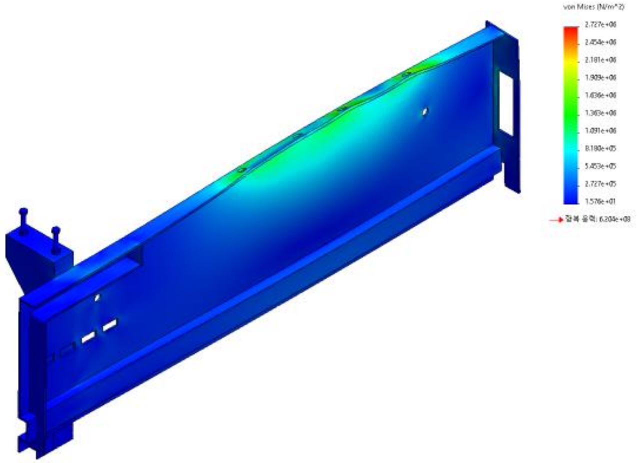
모드 번호	고유진동수 해석(라디안/초)	고유진동수 해석(Hz)	주기(초)
1	520.13	82.781	0.01208
2	1,195.9	190.33	0.005254
3	1,371.1	218.22	0.0045826
4	1,771.8	282	0.0035461
5	2,064.3	328.55	0.0030437
6	2,229.9	354.89	0.0028177
7	2,635.3	419.41	0.0023843
8	2,752.6	438.09	0.0022827
9	2,941.3	468.12	0.0021362
10	3,242.9	516.13	0.0019375
11	3,427.6	545.52	0.0018331
12	3,863.4	614.87	0.0016263
13	3,987.2	634.58	0.0015758
14	4,274.6	680.33	0.0014699
15	4,315.4	686.82	0.001456
16	4,427.6	704.67	0.0014191
17	4,638.8	738.29	0.0013545
18	4,798.6	763.72	0.0013094
19	4,989.4	794.1	0.0012593
20	5,276.6	839.79	0.0011908
21	5,291.6	842.19	0.0011874
22	5,585.8	889	0.0011249
23	5,625	895.24	0.001117
24	5,751.1	915.32	0.0010925
25	6,207.4	987.94	0.0010122
26	6,284.4	1,000.2	0.0009998
27	6,421.2	1,022	0.0009785
28	6,674.9	1,062.3	0.00094132
29	6,941.6	1,104.8	0.00090515
30	7,020.5	1,117.3	0.00089498
31	7,162.9	1,140	0.00087719
32	7,319.9	1,165	0.00085837
33	7,472.6	1,189.3	0.00084083
34	7,642.1	1,216.3	0.00082218
35	8,165.5	1,299.6	0.00076948
36	8,369.8	1,332.1	0.0007507
37	8,606.2	1,369.7	0.00073008
38	8,693.9	1,383.7	0.00072271
39	8,800.6	1,400.7	0.00071395
40	9,117.6	1,451.1	0.00068913
41	9,383.3	1,493.4	0.00066961
42	9,630.7	1,532.8	0.00065241
43	9,917	1,578.3	0.00063358

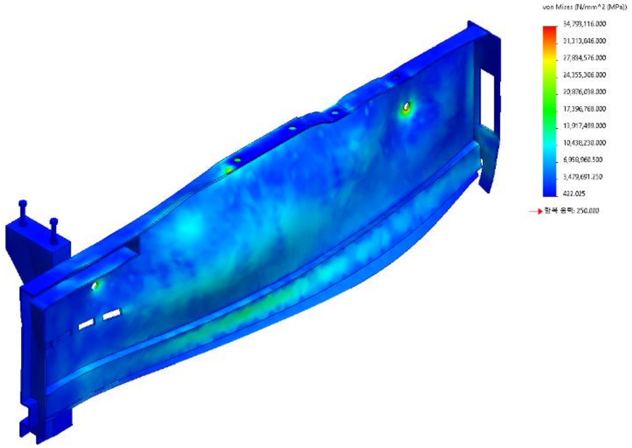
닫기(C) 저장(S) 도움말(H)





- Compare results



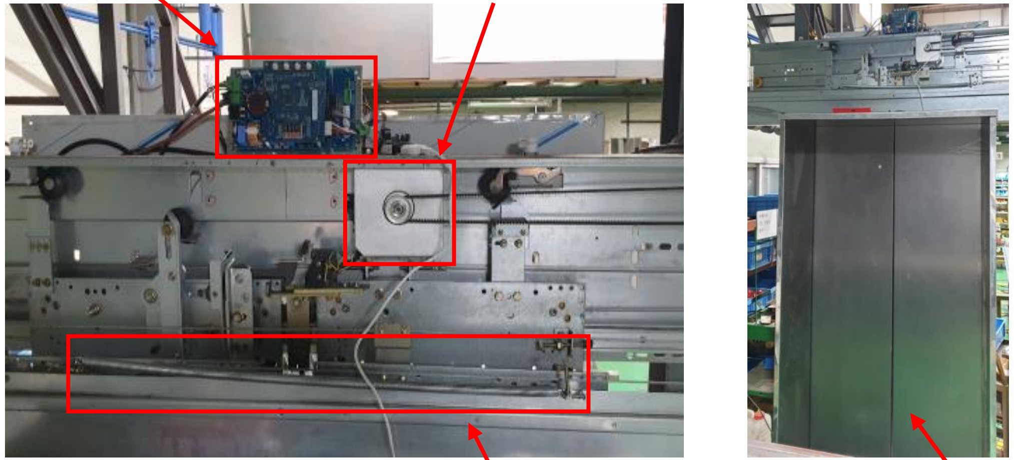


4. Implementation of a digital twin model of an elevator door device using MATLAB

- Configuration of elevator door device

Controller (speed + vector control + inverter)

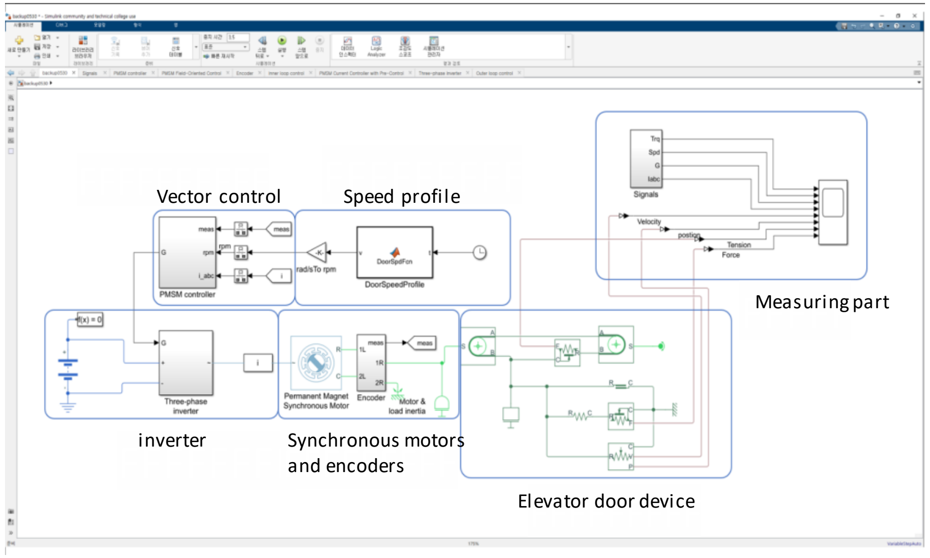
Motor & Belt & Pully



spring

door panel

- Implementation of digital twin model of elevator door device



4. Implementation of a digital twin model of an elevator door device using MATLAB

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- Driving speed profile of elevator doors

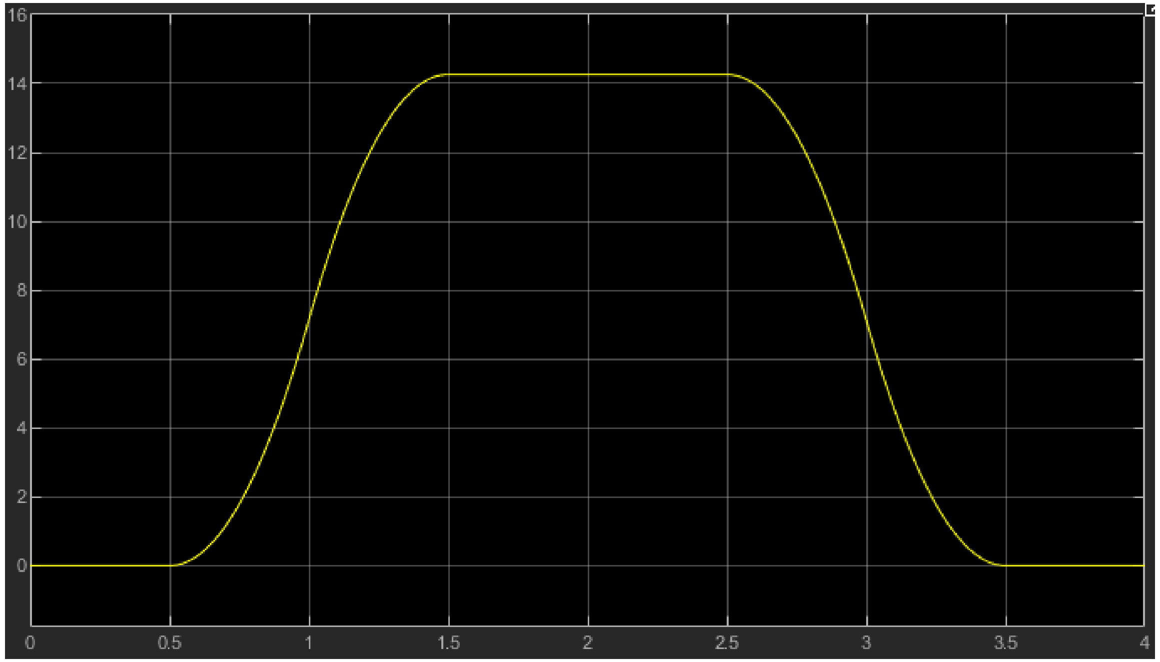
- Simplified into three sections: acceleration + constant speed + deceleration for easy observation.

- Acceleration/Deceleration part is S pattern

$$v(t) = \frac{\triangle w}{2\triangle t^2} t^2 \qquad (0 \le t \le \triangle t)$$

$$v(t) = -\frac{\triangle w}{2\triangle t^2}(t - \triangle t)^2 + \frac{\triangle w}{\triangle t}(t - \triangle t) + \frac{\triangle w}{2} \qquad (\triangle t \le t < T)$$

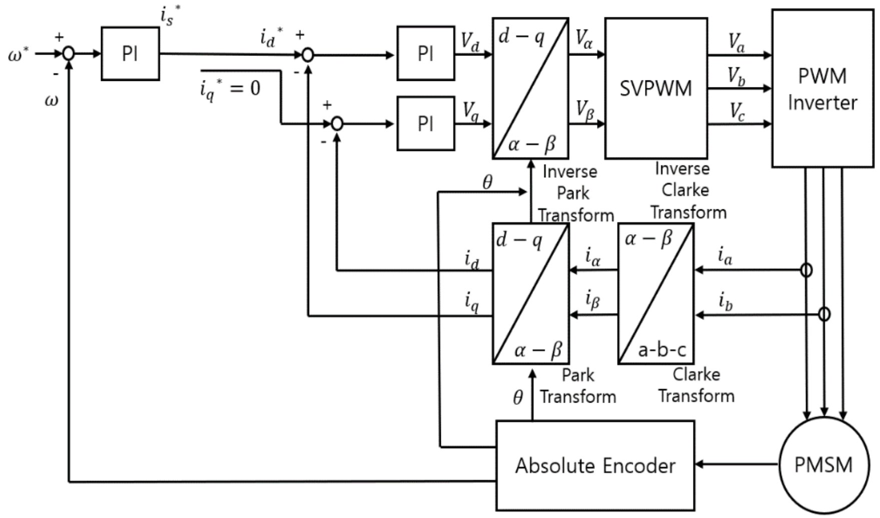
```
%parameter
wRef = 14.26;         % top speed
fwdTime = 0.5;        % Door opening start time
revTime = 4;          % door closing start time
opWaitTime = 1;       % acceleration time
opAccTime = 1;        % constant speed time
clAccTime = 1;        % deceleration time
```



- Opening 1000mm, Center open

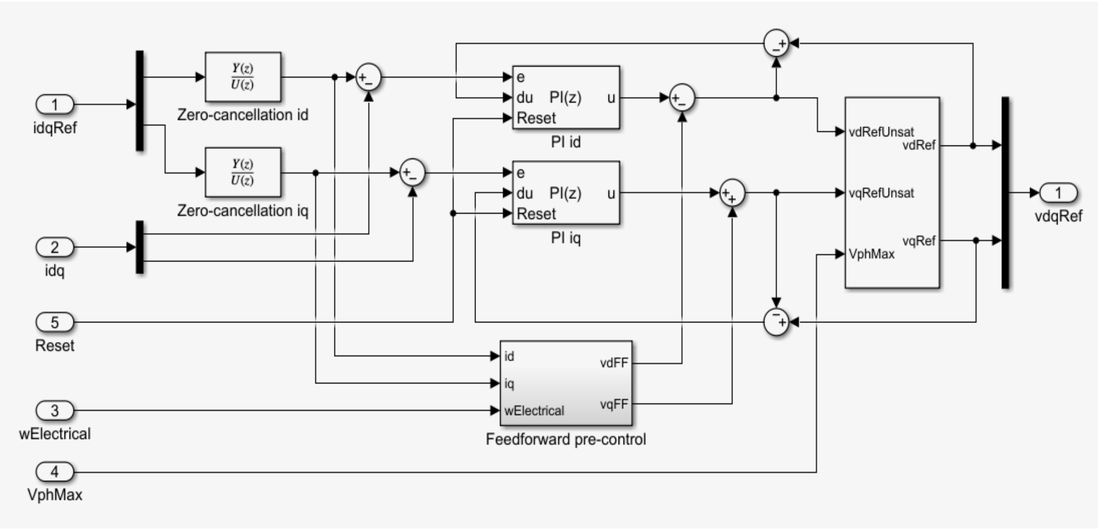
4. Implementation of a digital twin model of an elevator door device using MATLAB

- SPMSM (synchronous motor) vector control of actual model



- The three-phase alternating current flowing in the motor is controlled by two direct currents on the d and q axes.

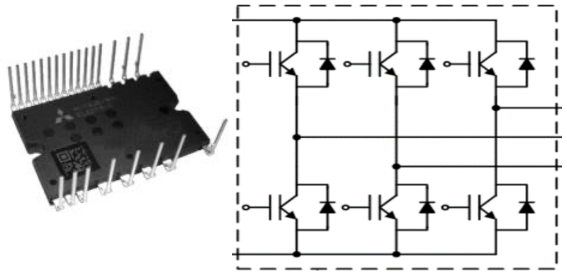
- SPMSM (synchronous motor) vector control of digital twin model

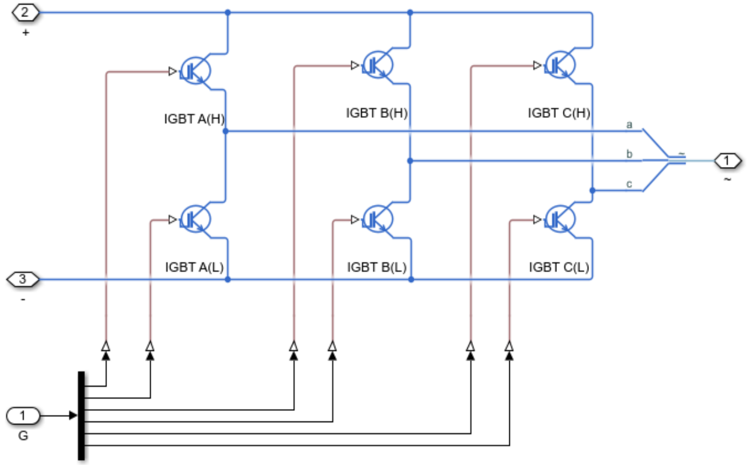


4. Implementation of a digital twin model of an elevator door device using MATLAB

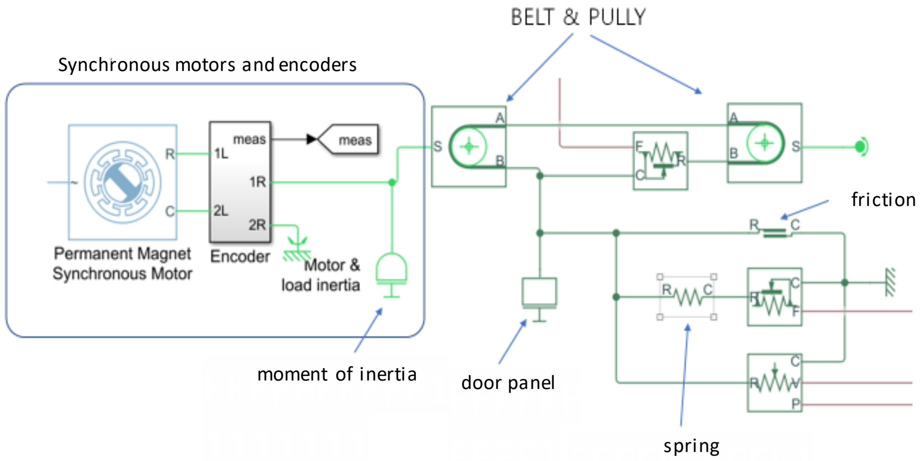
- Inverter circuit configuration

- The actual model uses Mitsubishi's IPM semiconductor.
- Implementation of IPM digital twin model with 6 IGBTs



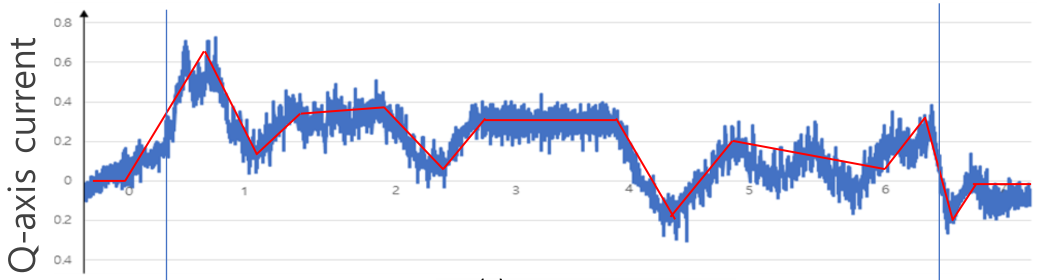


- Digital twin model of mechanical elements of the door device

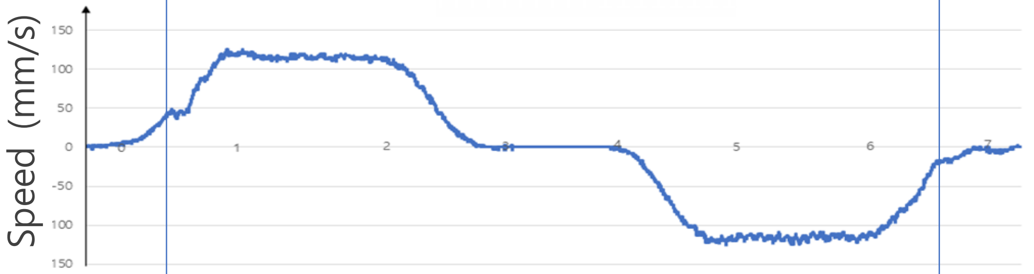


4. Implementation of a digital twin model of an elevator door device using MATLAB

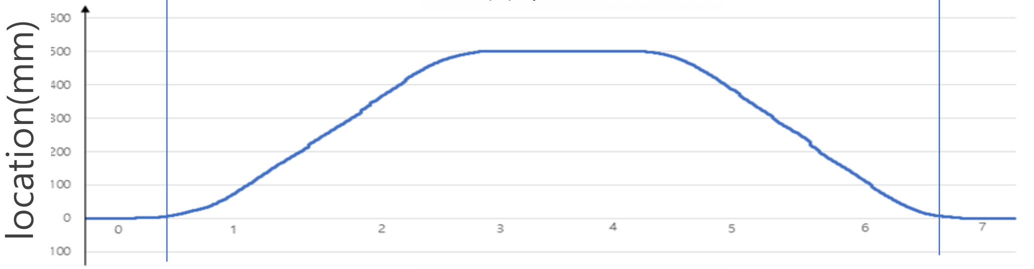
- Experiment result



(a) Current

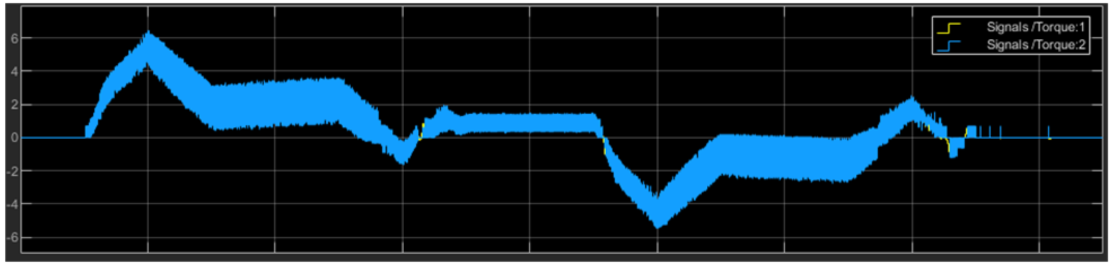


(b) speed

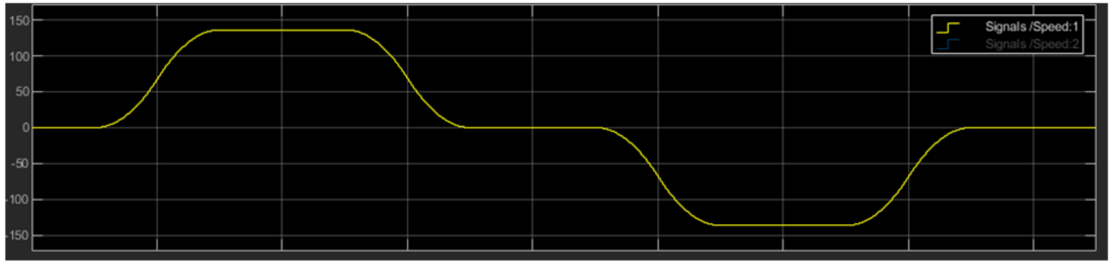


(c) Travel distance

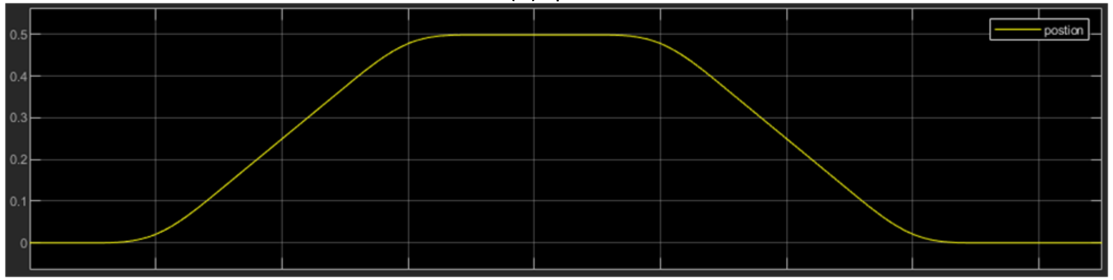
real model



(a) Current



(b) speed



(c) Travel distance

digital twin model

5. Digital twin model-based design workflow for elevator safety certification

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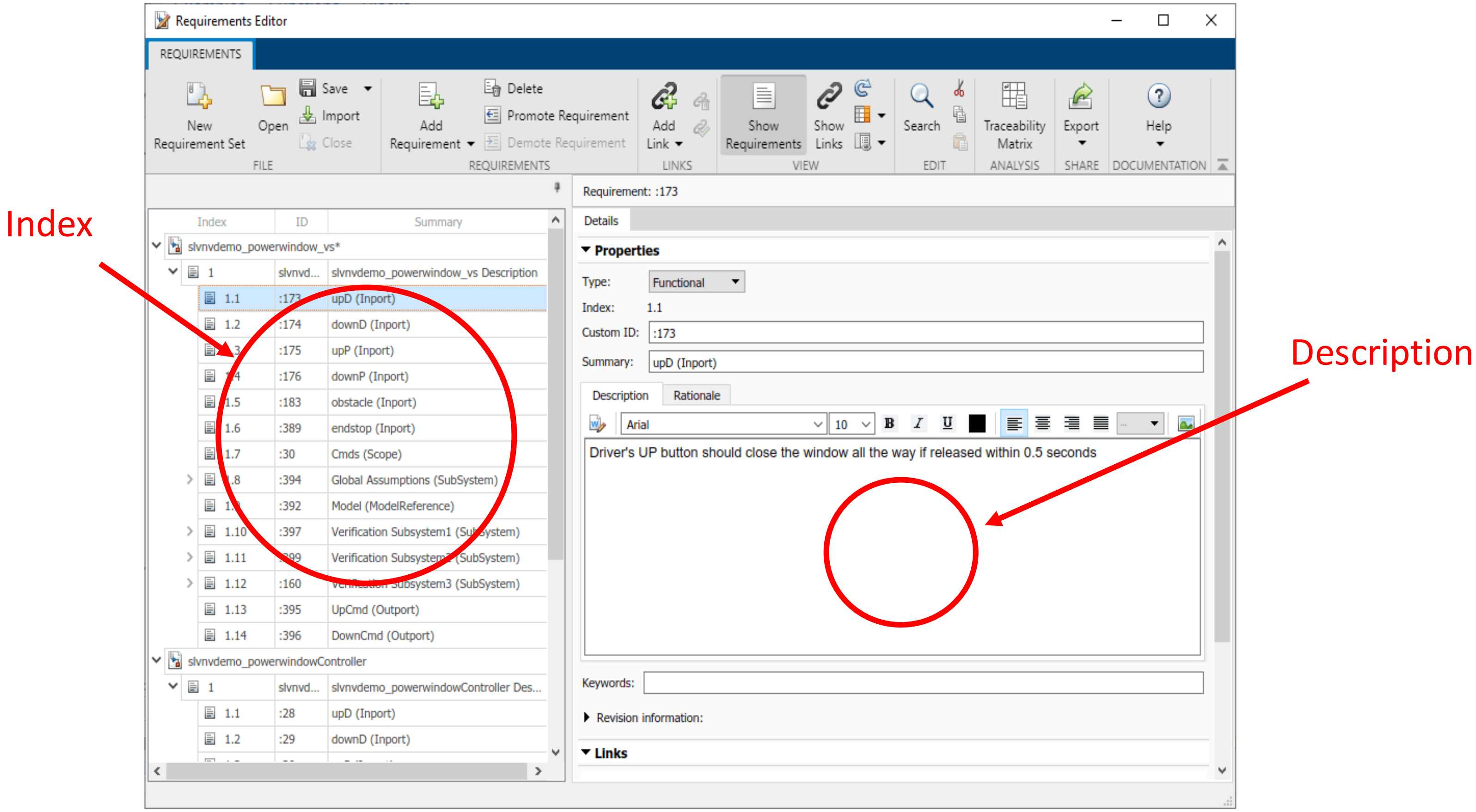
1. Create requirements

Create requirements using Requirements Editor

Create a development “specification” that specifies all requirements for development as well as safety-related matters

Two-way compatible with Microsoft's Word and Excel



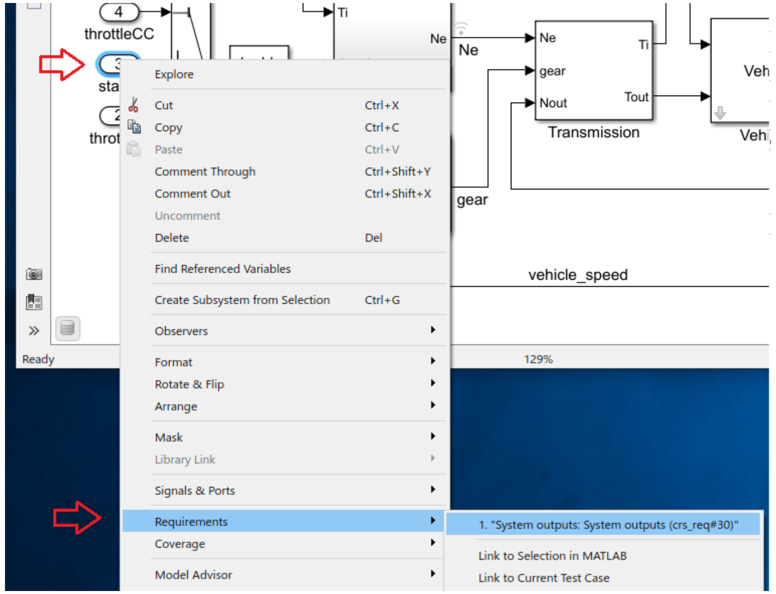
5. Digital twin model-based design workflow for elevator safety certification

2. Connect requirements traceability

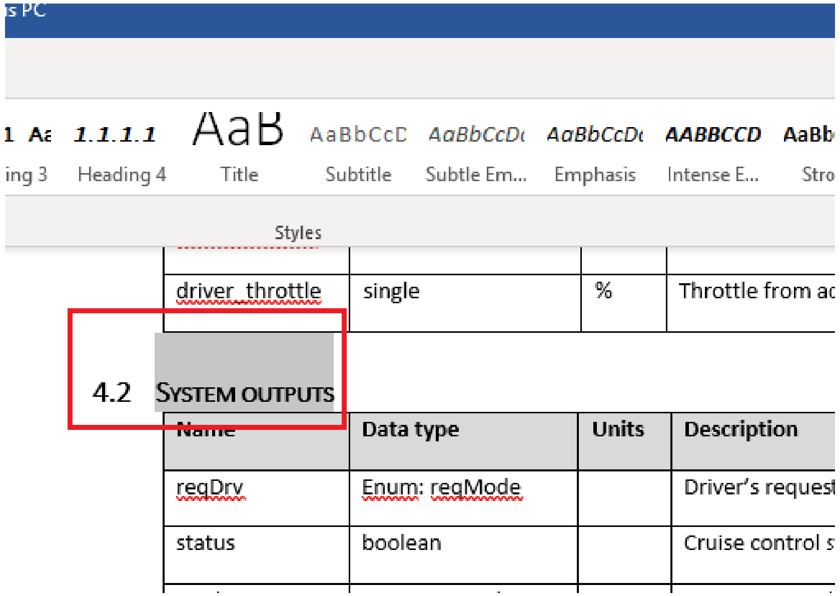
After creating a model based on written requirements, connectivity and traceability between requirements and model

Linking to requirements enables bi-directional dynamic referencing

Requirements or one requirement can be linked to multiple models



Link requirements for traceability in models



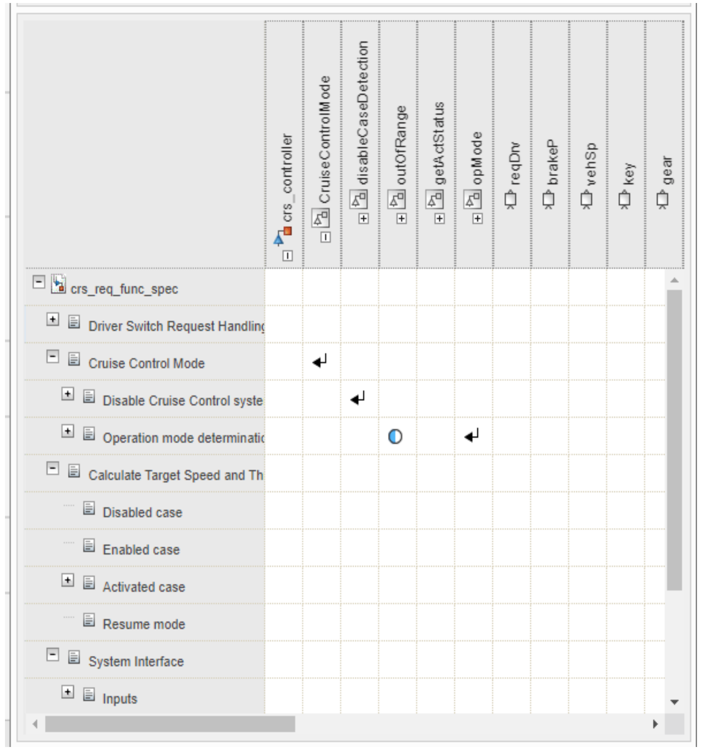
Check connected requirements

5. Digital twin model-based design workflow for elevator safety certification

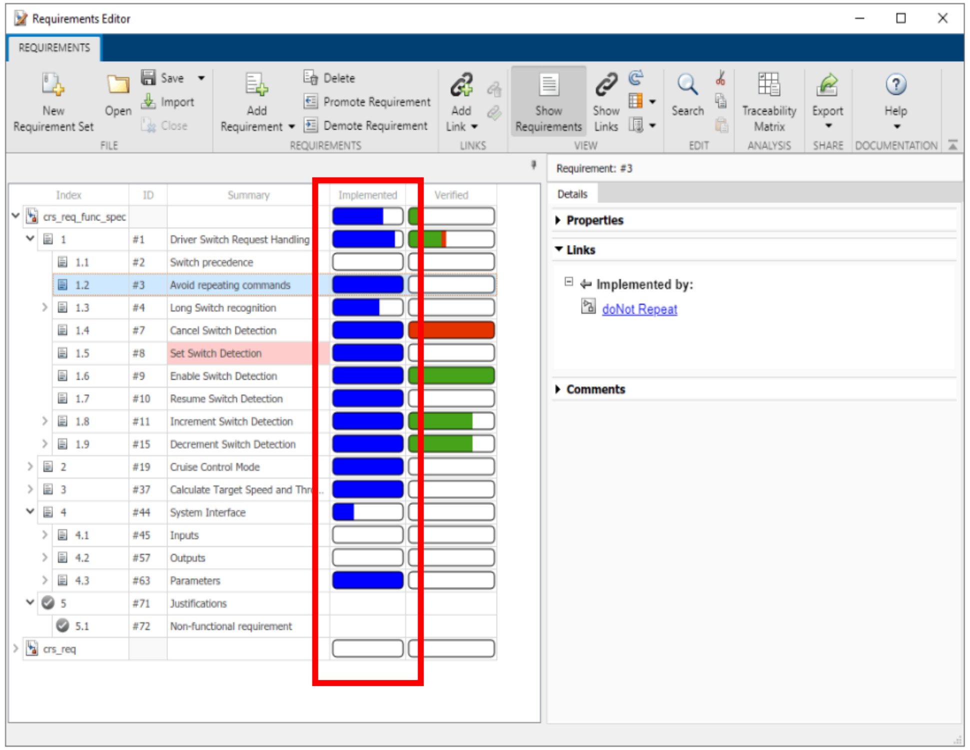
2. Connect requirements traceability

In case of multiple connections between requirements and model, it can be easily confirmed using the requirements matrix.

Progress for each requirement can be checked graphically



Requirements Matrix



Implemented (blue)
Justified (light blue)
None (colorless)

Requirements Connection Status Graph

5. Digital twin model-based design workflow for elevator safety certification

3. Requirements-based testing

Verify and confirm that the model is properly implemented in accordance with the connected requirements

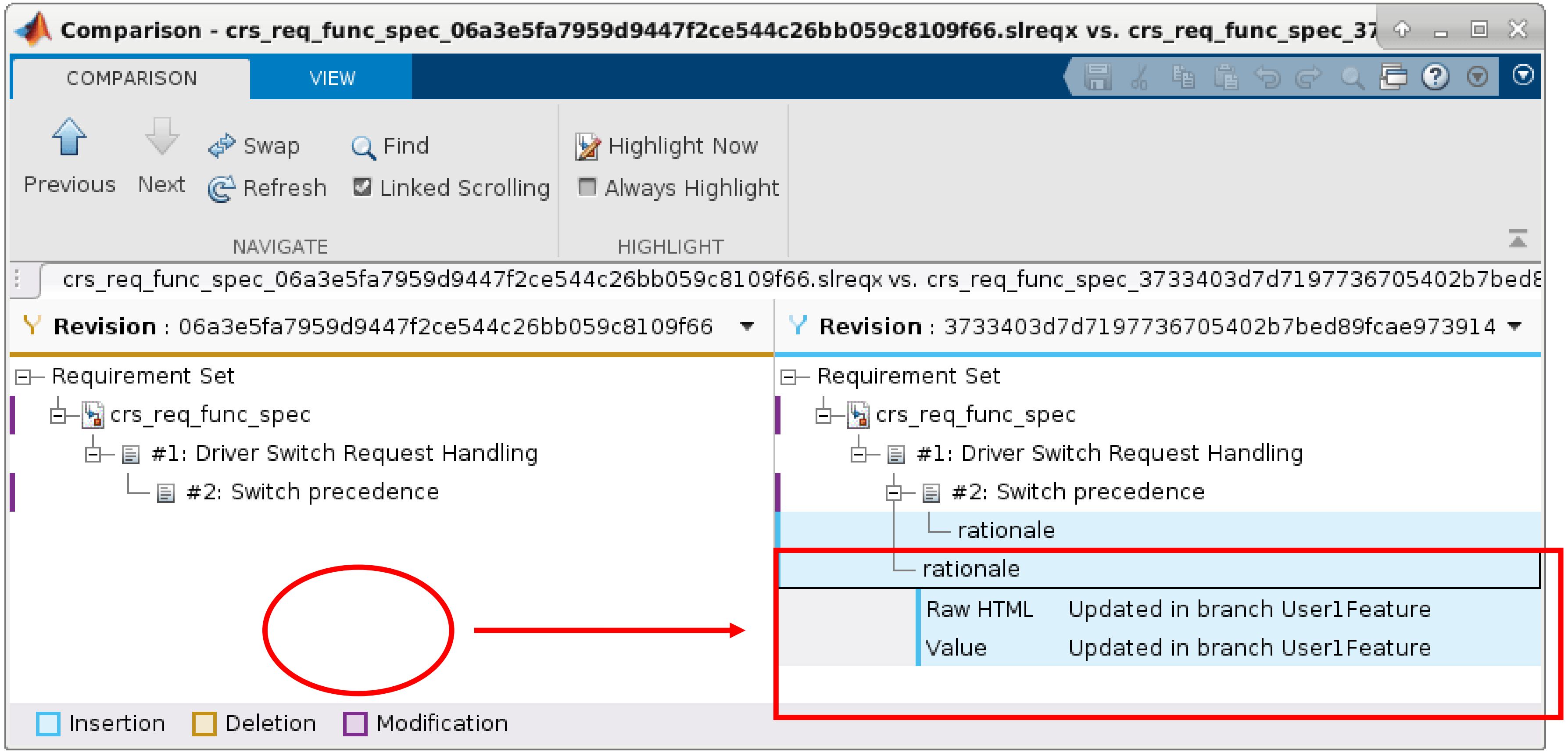
Passed (green)
Failed (red)
Justified (light blue)
Unexecuted: (yellow)
None (colorless)

Show test status

5. Digital twin model-based design workflow for elevator safety certification

4. Compare requirements and track changes

Changes due to team and individual requirements activities can be compared and tracked



5. Digital twin model-based design workflow for elevator safety certification

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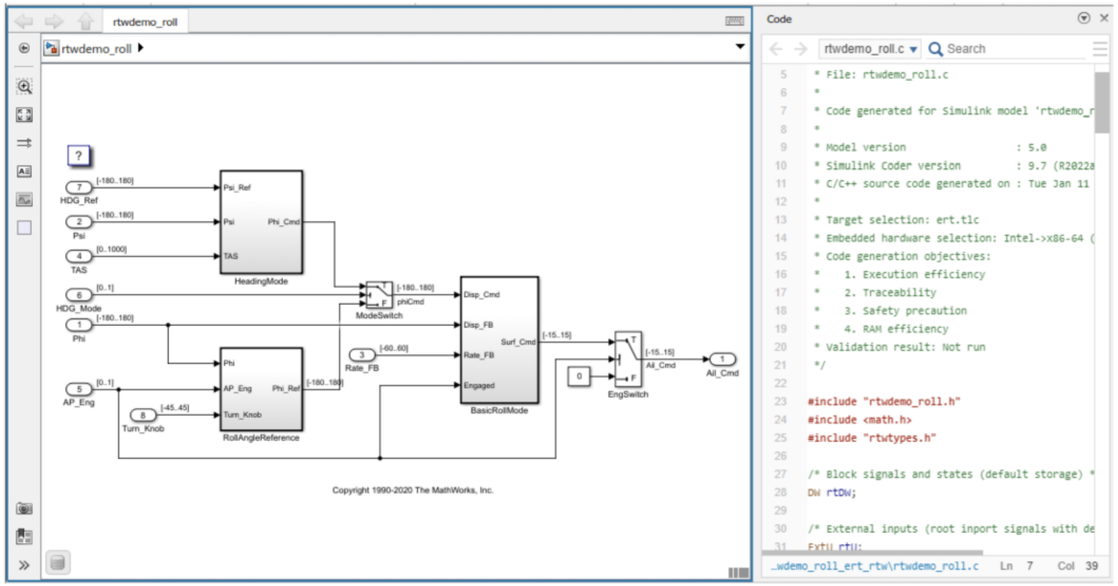
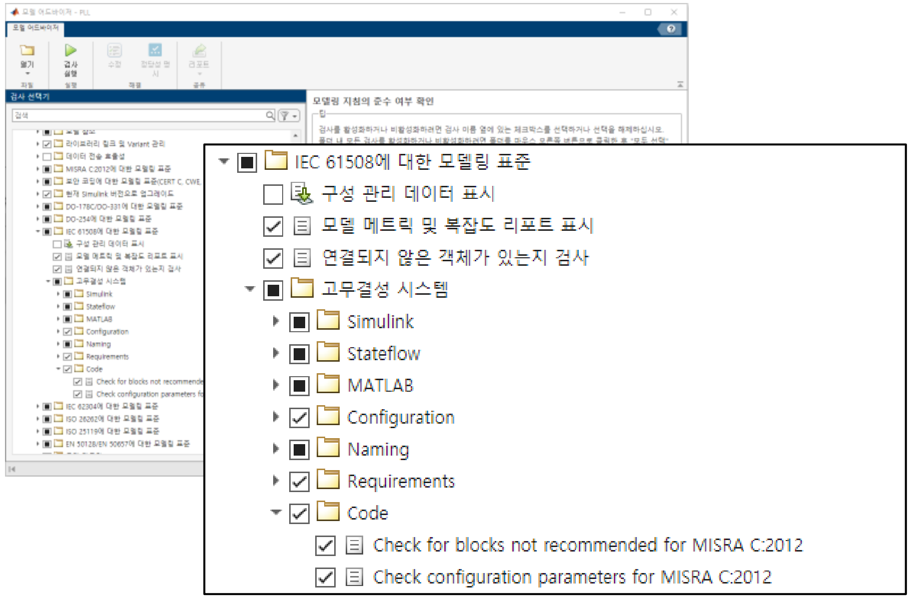
5. Code generation and IEC61508 verification

Generate code based on the model

Generate model and generated code IEC61508 verification report (TUV certified)



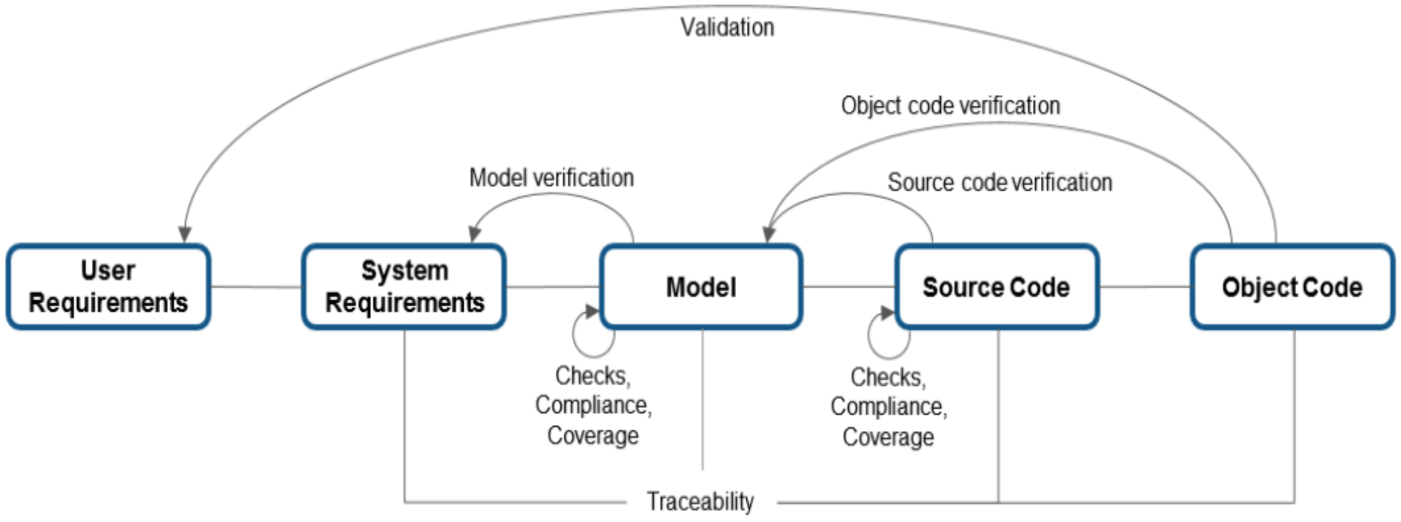
Code generation



IEC61508 model verification

5. Digital twin model-based design workflow for elevator safety certification

5. Verification



Conclusion

- Using PSIM's EMI Design Suite, one of the elevator DT processes, we constructed EMI Filter modeling of the control panel and analyzed the correlation between control panel components and EMI Filter.
- The elevator system is modeled as a third-order multibody, and the rope stiffness relationship is analyzed according to the elevator's speed, acceleration, and acceleration.
- Examining the safety of the elevator door system using the Digital Twin concept.
- Design and validation of a digital twin model of an elevator door device.
- The cause of the failure can be identified through data analysis of the digital twin model and the actual model.
- Presenting software development techniques using the Digital Twin Model-Based Design tool using MATLAB.
- Ensures mutual traceability at each stage of the requirements writing, modeling, source code generation, and verification procedures and reduces problems that may arise through the verification process.

Thank you