AN OVERVIEW ON SIMULATION BASED DIGITAL TWIN MODEL

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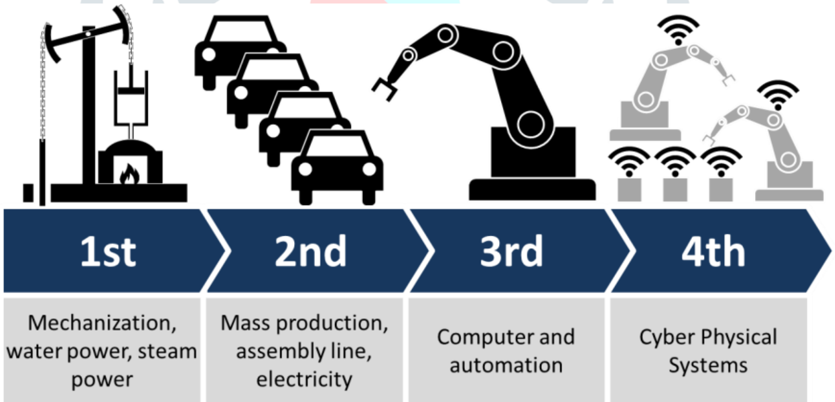
Abstract : Today numerous organizations are investing their time and resources on adopting industry 4.0 concept for better production & warranty and least maintenance. Digital Twin is one of the ongoing concepts to provide the same feature. Digitalization has become a need in the highly competitive environment. Digitalization helps to log continuous data from real product for further analysis using several techniques and software. Digital Twin requires the integration between physical model and digitalized model which can be either CAD model or block diagram. In the current paper, it is aimed to explore the recent trend of Industry 4.0 as digital twin simulation based model.

***IndexTerms* – Digital Twin, Simulation, Real Time Data, ANSYS.**

I. INTRODUCTION

The world of industrial automation is undergoing a major transformation. Advanced computation and communications technologies have reached such a level of maturity that machine manufacturers are making dramatic changes in the way they design their products. Indeed, the evolution and convergence of many new technologies - mechatronic systems, controllers, on-board computation, Big Data, machine learning and the Industrial Internet of Things (IIoT) – are driving thought-leaders to talk about The Next Industrial Revolution, or Industry 4.0. In simple words it is called as "smart factory".



Source: Wikipedia – Industry 4.0

Figure 1.1: Industrial revolutions and future view

The concept of the Digital Twin dates back to a University of Michigan presentation to industry in 2002 for the formation of a Product Lifecycle Management (PLM) center. The Digital Twin has been adopted as a conceptual basis in the astronautics and aerospace area in recent years. NASA has used it in their technology roadmaps and proposals for sustainable space exploration. The concept has been proposed for next generation fighter aircraft and NASA vehicles, along with a description of the challenges and implementation of as-builts.

Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin. The digital twin is able to leverage multi-fidelity simulations from detailed 3-D physics to reduced order models (ROMs) to compress simulation times and demonstrate key product performance aspects.

Real-time data is information that is collected through sensors and delivered immediately after collection. There is no delay in the timeliness of the information provided to analysis. Real-time data is enormously valuable in things like traffic GPS systems, climate conditions, earthquakes information, water condition, flood condition and other natural disaster information. It is helpful for all sorts of analytics projects and for keeping people informed about their natural environment through the power of instant data delivery. During the early days of computing, the model was to capture any data for storage. Now, with the proliferation of mobile devices and other advancements in technology, it is becoming more common for software to simply port collected data directly to an end user.

II. Simulation Platforms

There are various simulation platforms are available for developing system level model for implementing digital twin concept.

1. ANSYS SIMPLORER enables engineers to accurately and quickly design complex power electronic and electrically controlled systems. It is an intuitive, multi-domain, multi-technology simulation program used to simulate, analyze, and optimize complex systems, including electromechanical, electromagnetic, power and other mechatronic designs. In industries such as automotive, aerospace and industrial automation, organizations use SIMPLORER to identify problems in the early design stages that other simulation or build-and-test methods cannot detect.
2. SCADE Suite is a product line in the ANSYS embedded software family that provides you with a model-based development environment for critical embedded software. With native integration of the formally defined SCADE language, SCADE Suite is the integrated design environment for critical applications including requirements management, model-based design, simulation, verification, qualified / certified code generation and interoperability with other development tools and platforms.
3. SIMULINK enables engineers to model systems in multiple domains (such as mechanical, electrical, hydraulic, and other physical domains) through its interactive graphical modeling environment. Simulation, design, and code generation are all performed in a single environment, allowing engineers to focus more on engineering tasks and less on maintaining their corporate simulation platform. SIMULINK has been used for over 20 years to help design the world's most complex engineering systems.

III. Digital Twin Simulation Modeling

Digital twin modeling can be done on a complex structure as well as on a simple system. To demonstrate how digital twin works, a simple spring-mass system is considered. Details of system, simulation and results are listed as below:

A. System Details

A system containing two masses, m1 and m2, and two springs of stiffness k1 and k2 is subjected to load F(t) on mass 1. Loads are described in detail in section B. The objective of simulation is to determine the displacement response of the system for the load history shown.

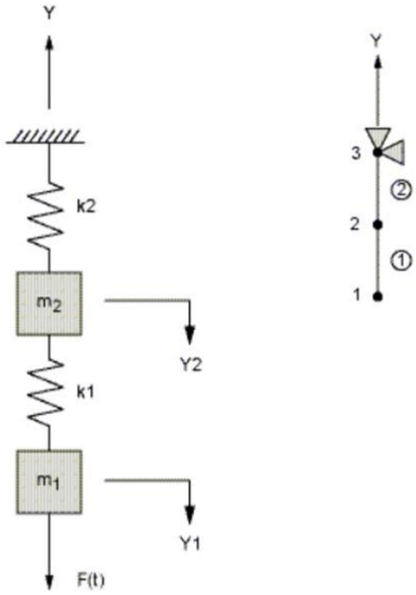


Figure 3.1: Spring-mass System Problem Sketch & Representative Finite Element Model

B. Material Properties

Mass of each block	m1 = m2 = 50 Kg		
Spring stiffness	k1 = 100 N/m	and	k2 = 300 N/m

C. Analysis Assumptions

1. COMBIN40 combination elements are selected to represent the springs and masses.
2. Node locations are random.
3. Spring lengths are also random.
4. Mode-frequency Analysis is performed which is followed by Transient Dynamic Mode Superposition Analysis.

D. Loading Details

For spring-mass system, following loads are considered. Each load history is simulated as a separate case.

1. *Steady State load history:* Load is constant though out the time period. Hence no variation in load with respect to time.

Table 3.1: Steady State Load table

Time (Sec)	0	3	6	9	12	15	18	21	24	27	30
Load (N)	50	50	50	50	50	50	50	50	50	50	50

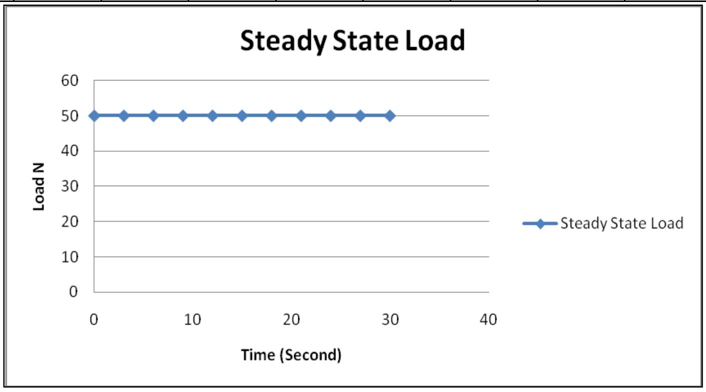


Figure 3.2: Steady State Load Graph

2. *Ramping Up load history:* Load is increasing continuously and rate of increment would be constant. Hence in graph, it will be a line 45 degree inclined with X axis.

Table 3.2: Ramping Up Load table

Time (Sec)	0	3	6	9	12	15	18	21	24	27	30
Load (N)	0	10	20	30	40	50	60	70	80	90	100

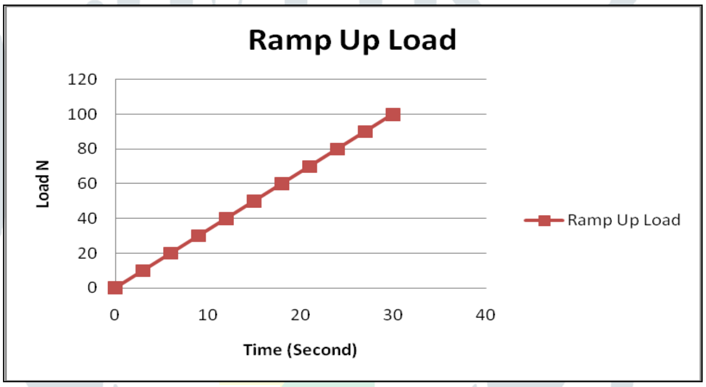


Figure 3.3: Ramping Up Load Graph

3. *Impulse load history:* There is a sudden application of load at a certain point of time. Hence a single pulse can be seen in load graph.

Table 3.3: Impulse Load table

Time (Sec)	0	3	6	9	12	15	18	21	24	27	30
Load (N)	0	0	0	0	0	100	0	0	0	0	0

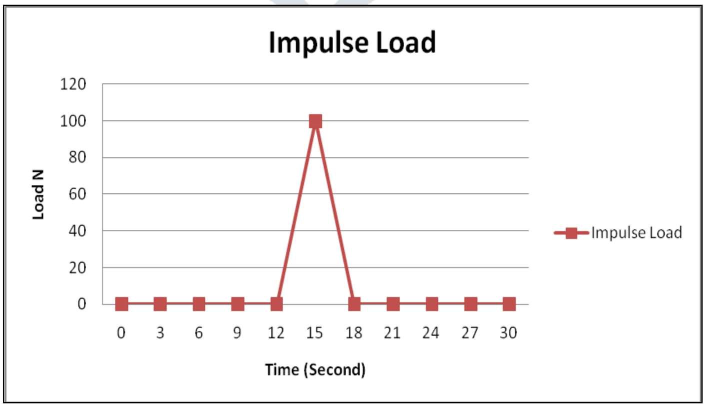


Figure 3.4: Impulse Load Graph

4. *Duty Cycle load history:* A certain pattern of load history is repeated continuously which is known as duty cycle. It acts like a small window where load history is captured. It is commonly seen in engines.

Table 3.4: Duty Cycle Load table

Time (Sec)	0	3	6	9	12	15	18	21	24	27	30
Load (N)	0	50	50	100	100	100	100	100	50	50	0

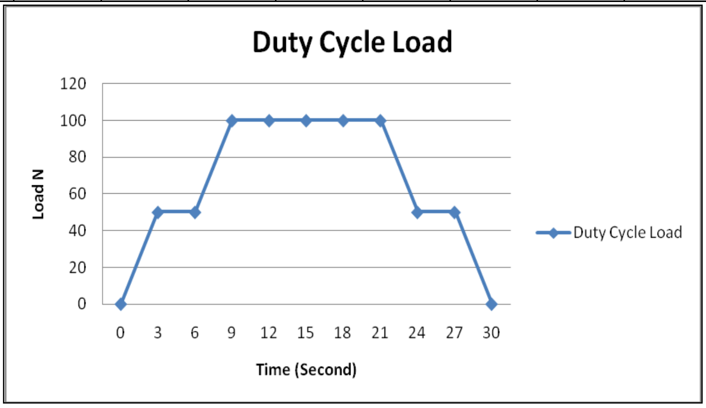


Figure 3.5: Duty Cycle Load Graph

5. *Random load history:* It is irregular and not providing any kind of load pattern.

Table 3.5: Random Load table

Time (Sec)	0	3	6	9	12	15	18	21	24	27	30
Load (N)	0	100	50	80	90	10	60	40	20	30	0

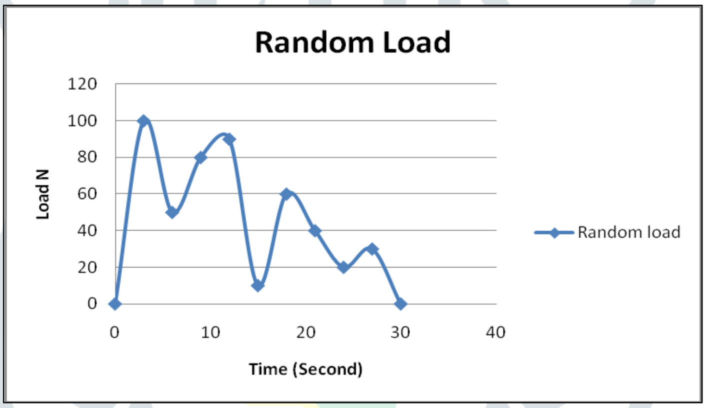


Figure 3.6: Random Load Graph

6. *Step load history:* A step load function is a piecewise constant function having only finitely many pieces. Loads are represented as step in pattern. Step value may be same, increased or decreased.

Table 3.6: Step Load table

Time (Sec)	0.00	3.00	3.01	6.00	6.01	9.00	9.01	12.00	12.01	15.00	15.01
Load (N)	10	10	20	20	30	30	40	40	50	50	60

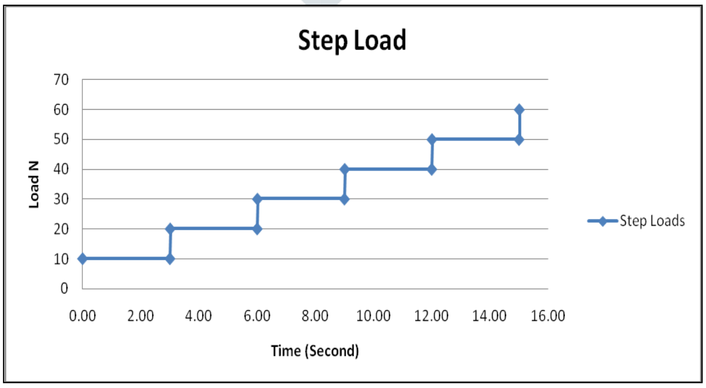


Figure 3.7: Step Load Graph

E. ANSYS SCRIPT

Following ANSYS script is used to model the spring-mass system in ANSYS APDL, apply material, load cases and boundary conditions and solve a transient response analysis. Later the results are post processed and displacement Vs time graph is drawn.

```
/PREP7
/TITLE, TRANSIENT RESPONSE OF A SPRING-MASS SYSTEM
ANTYPE,MODAL                    ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,2,,,                ! PRINT TWO REDUCED MODE SHAPES
ET,1,COMBIN40,,,2               ! UY DOF
R,1,100,,50                     ! K1=6 N/M     M1=2 KG
R,2,300,,50                     ! K2=16 N/M    M2=2 KG
N,1
N,2,0,1
N,3,0,2
REAL,1
E,1,2
REAL,2
E,2,3
D,3,ALL
OUTPR,,ALL
/SOLU
SOLVE
FINISH
/SOLU
ANTYPE,TRANS                    ! TRANSIENT DYNAMIC ANALYSIS
TRNOPT,MSUP,2                   ! MODE SUPERPOSITION, BOTH MODES
DELTIM,0.01                     ! INTEGRATION TIME STEP = .01
OUTPR,,NONE
OUTRES,,1
KBC,1                           ! STEP BOUNDARY CONDITIONS
*DIM,EXT_FORCE,TABLE,11,1,1,TIME,
*TREAD,EXT_FORCE,TABLE,INP
F,1,FY,%EXT_FORCE%
*DO,I,0,30,3
TIME,I
SOLVE
*ENDDO
FINISH
/POST26
FILE,,RDSP                      ! REDUCED DISPLACEMENTS FILE
NSOL,2,1,U,Y,UY1
NSOL,3,2,U,Y,UY2
/GRID,1
/AXLAB,Y,DISP
PLVAR,2,3                       ! DISPLAY DISPLACEMENT RESPONSE VS. TIME
PRVAR,2,3
```

F. RESULTS AND DISCUSSION

ANSYS script is used to perform the transient analysis on spring mass system and following results are generated.

1. *For Steady State load history:* For constant loading, displacement would also be constant as shown in below graph.

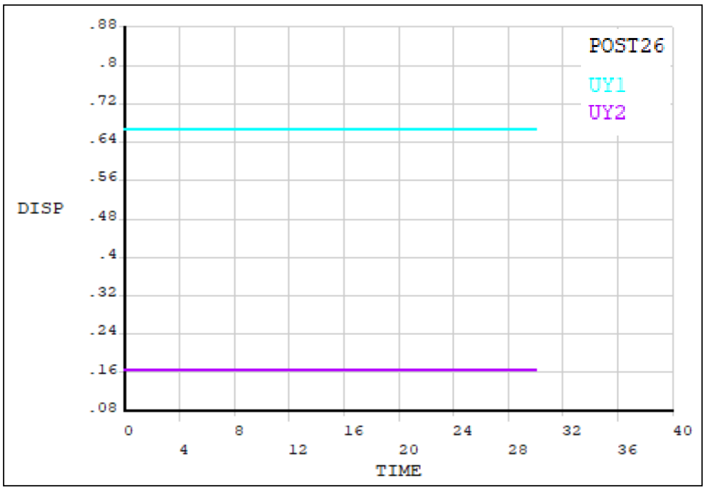


Figure 3.8: Steady State load - Displacement Vs Time Graph

2. *For Ramping Up load history:* As loading is increasing continuously, displacements of masses are also increasing continuously as shown in below graph.

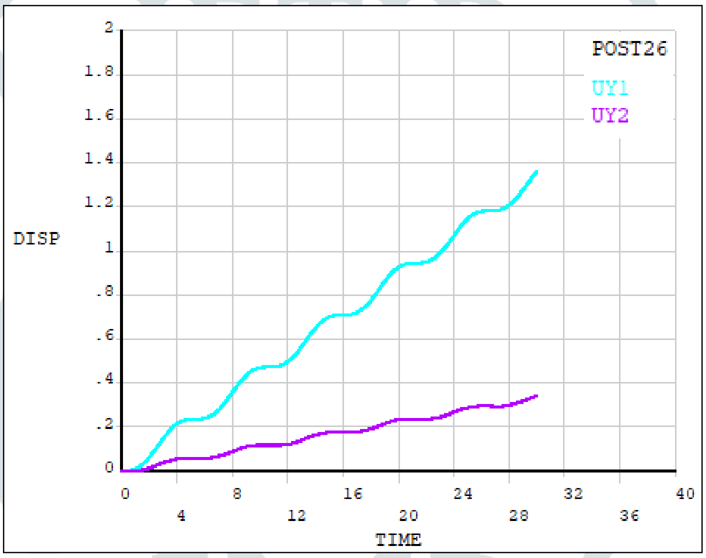


Figure 3.9: Ramping Up load - Displacement Vs Time Graph

3. *For Impulse load history:* As it can be seen that initially load was zero so displacement of masses are also zero. When masses are disturbed by an impulse loading and released, displacement is continuing for rest of the time period.

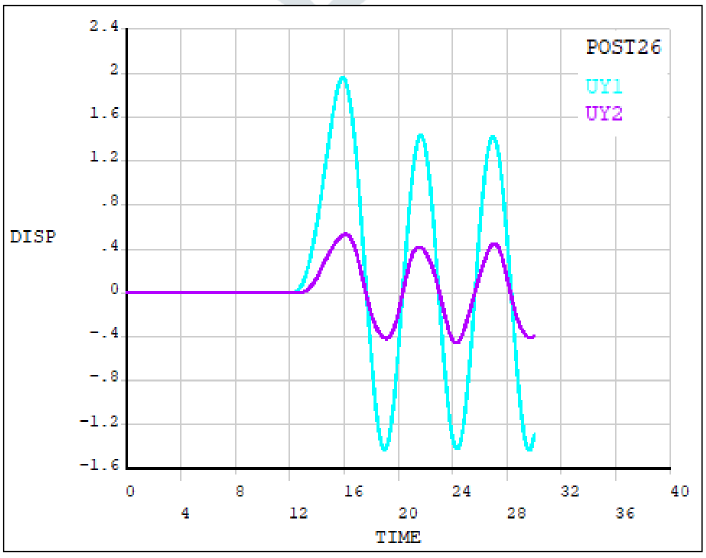


Figure 3.10: Impulse load - Displacement Vs Time Graph

4. *For Duty Cycle load history:* It follows a certain pattern of inputs and the same pattern can be seen in output graphs.

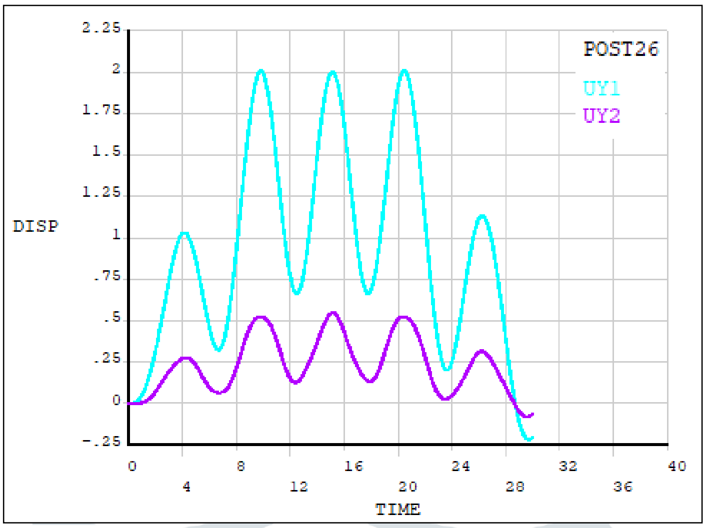


Figure 3.11: Duty Cycle load - Displacement Vs Time Graph

5. *For Random load history:* Whenever a random load signal is applied on system, a random output is expected. Below graph is showing the same.

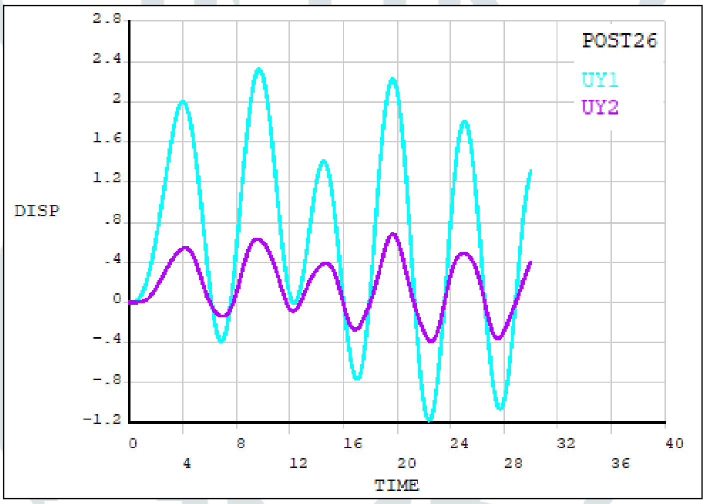


Figure 3.12: Random load - Displacement Vs Time Graph

6. *For Step load history:* Initially load is constant for first step and later increased in stepwise. Similar pattern can be seen in displacement graph.

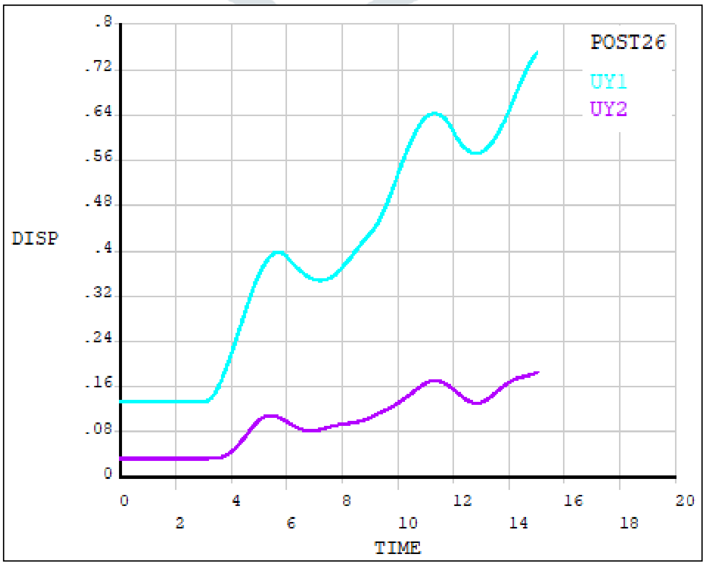


Figure 3.13: Step Load - Displacement Vs Time Graph

G. Spring Mass System from Digital Twin perspective

It is seen that there are various load signals which can be applied on spring mass system individually and each of them will provide a unique displacement output signal. From digital twin perspective, if any load signal is applied on physical system which is sensed by a load sensor, the load signal can be accumulated using transient recording system and can be published as a real time data. Later published real time data is used in FE model as an input to simulate the output as displacement. The displacement from FE model should be matched with displacement from physical system. This is called the Digital Twin model.

IV. Acknowledgment

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