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Research of Spacecraft Assembly Simulation with Ground Mechanical Equipments

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Abstract. In order to overcome the shortcomings of the physical test conditions, research and development of the spacecraft container simulation verification platform to enhance the level of digital development of the spacecraft container. Based on the theory of rigid-flexible coupling dynamics, the dynamic model of the box system is established. The dynamic external excitation is determined by obtaining the track spectrum and identifying the condition of the line. Based on the computational fluid dynamics, the thermal model of the spacecraft container is established, and the container is realized by simulating the natural convection and air conditioning control spacecraft container thermal simulation. Using modular design, C/S architecture and navigation process to achieve the simulation platform architecture versatility, ease of maintenance and scalability and other needs. Finally, the mechanics and thermal performance verification of the spacecraft container and physical test are carried out. The results show that the simulation results of the box dynamic system and the thermal system are in good agreement with the experimental results.

1 Introduction

The spacecraft container is the electro-mechanical equipment to realize the function such as spacecraft ferry transport, made up of multiple subsystems, in the process of designing and using process, involving many professional departments such as force, heat, electricity, which need to be used in structural design and perform a large number of analysis and simulation work when planning formulation. Limited to the limitations of the physical tests, the current sports car test can not meet the requirements of the increasing security requirement of spacecraft. To overcome the limited physical sports car test conditions and defection of measuring point are little, based on the demand of improving digital level of container, simulation verification platform for spacecraft container is urgently needed for research and development.

There are a number of research on aircraft container dynamics and thermal in the domestic. Bai Qiaofeng, et al[1] built the physics model of the container suspension system and built the model using the dynamic energy method . Tan Dekun, et al[2-3] developed spacecraft container vibration test system by using virtual instrument, and analyzed the spectral analysis, key point highlight and extremum retrieval of the collected data. Hu Yupeng,et al[4] put forward BWBZX-1 heat preservation container design scheme, and then through the numerical simulation research structure of thermal physical parameters on the container material and the influence of the temperature field and heat

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transfer characteristics of the final pass environmental test for validation. Through the whole modeling of the spacecraft and the container, Su Xinming, et al[5] used the numerical simulation of the passive thermal insulation performance of the container in different working conditions. Xiao gang ,et al[6]introduced the design and development features of the container cases and the results of the airlift test results based on a certain type of spacecraft airlift container, and the results showed that the container design was reasonable.

Nowadays, in the process of the container design and simulation, the container mechanics, thermal analysis model lacked unified management in the simulation data and the simulation project is single and insufficient. A simulation analysis method for the optimization and use of the working condition environment of the container is lacked. In addition, the design of the spacecraft container should be evaluated through the commissioning to evaluate the performance of the container, and decide whether it meets the required quality requirements .It is necessary to develop the simulation and verification platform for spacecraft transport container based on the demand of digital level. According to the container and the spacecraft, container digital mechanics simulation model and the thermal simulation model is established respectively, which can realize ,in the process of railway transport ,the simulation analysis of spacecraft container by simulation of the stress and temperature conditions.

2 SIMULATION MODEL OF THE CONTAINER SYSTEM

The spacecraft transport container system consists of several subsystems, including box, bracket, shock absorber, satellite and railway transport vehicles. The dynamics and thermal model of the container system are described as follows:

2.1 Dynamic modeling of container system

Because of the complexity of the container system and the large difference of stiffness of different parts, such as the structure stiffness of the container and other structures is large, and the stiffness of the bracket and astral structure is low, therefore, the dynamics modeling for stiffness large parts adopt equivalent rigid body, the structure of low stiffness and elastic deformation is large equivalent for the flexible body, container system eventually formed a coupled multi-body system, the complete system equations [7] as follows:

$$\dot{\boldsymbol{p}} = \boldsymbol{T}(\boldsymbol{p})\boldsymbol{v} \tag{1}$$

$$\boldsymbol{M}(\boldsymbol{p})\dot{\boldsymbol{v}} = \boldsymbol{F}(\boldsymbol{p},\boldsymbol{v},\boldsymbol{c},\boldsymbol{s},t,\boldsymbol{u},\boldsymbol{\lambda}) - \boldsymbol{G}^{\mathrm{T}}(\boldsymbol{p},\boldsymbol{c},\boldsymbol{s},t,\boldsymbol{u})\boldsymbol{\lambda} \tag{2}$$

$$\dot{\boldsymbol{c}} = \boldsymbol{F}_c(\boldsymbol{p},\boldsymbol{v},\boldsymbol{c},\boldsymbol{s},t,\boldsymbol{u},\boldsymbol{\lambda}) \tag{3}$$

$$0 = \boldsymbol{g}(\boldsymbol{p},\boldsymbol{c},\boldsymbol{s},t,\boldsymbol{u}) \tag{4}$$

$$0 = \boldsymbol{b}(\boldsymbol{p},\boldsymbol{v},\boldsymbol{c},\boldsymbol{s},t,\boldsymbol{u},\boldsymbol{\lambda}) \tag{5}$$

Among them: p is the position vector of the hinge position; T is the angular transformation matrix; V is the state vector of hinge velocity; M is the mass matrix; F is the force and torque vector generated by the element; c is the dynamic state vector of the control unit and the control unit; s is the algebraic state of displacement and acceleration; t is for time; u is the external input of displacement and velocity level; λ is the binding force and torque; G is the jacobian matrix for the constraint equation ;Fc is dynamic state equation of the force and control unit; g is the constrained algebraic equation of constraint; b is the constraint algebraic equation related to the algebraic state quantity.

2.2 Thermal modeling of container system

Due to differences in container inside and outside temperature and the container system internal air flow with heat transfer, the container internal flow field can be approximately treated as the three dimensional incompressible turbulent flow. The control equation of the transport equation as follows:

$$\frac{\partial(\rho\boldsymbol{\varphi})}{\partial t}+div(\rho\boldsymbol{u}\boldsymbol{\varphi})=div\left(\Gamma grad\boldsymbol{\varphi}\right)+\boldsymbol{S} \tag{6}$$

Among them: t is the time; ρ is the air density; u is the velocity vector; $\boldsymbol{\varphi}$ is the flow field flux; $\boldsymbol{S}$ is the source term; Γ is the diffusion coefficient.

In addition, the state equation of association pressure, temperature and density should be added, and the expression is as follows:

$$p=\rho RT \tag{7}$$

Among them: p is time; R is the molar gas constant; T is the temperature.

3 DEVELOPMENT OF BOXED SIMULATION PLATFORM

3.1 Platform architecture design

Since the simulation platform application involved spacecraft container the whole life cycle, including the spacecraft container design, analysis, manufacture, application and so on. At present, it is necessary to fully consider the extension requirements of various functional modules in the framework design of the platform. Therefore, module division, call relation, data link need to be applied in the design, simulation, optimization, manufacturing, test and other aspects of the basic flow. Aiming at the general usability, maintainability and extensibility of the simulation platform architecture, the following solutions are used in architecture design:

(1) The system adopts the concept of modular design, and adopts the matching management of the user - role - permission - function module to establish the mapping relationship between the user and the function module.

(2) Because of the complexity and diversity, the whole platform uses C/S architecture in which the client application deployment aims at different user groups and the centralized management of data is conducted by the server. This architecture can solve the problem of localization of complex commercial software applications. What’s more, software license management can adopt the floating management pattern to increase effective utilization of software;

(3) Considering the user's ease of use, the design fully adopts the navigational process, organization of the structure tree and the Tab page to make users easier to understand and master the operating process.

The design, optimization, manufacturing and other modules in the diagram provide the interface for the simulation of the whole process platform simulation.

3.1.1 The function module of the front end

The front function module includes four modules: project, working condition simulation, test data and user information. The working condition simulation is the most core business module and it is also the user's main application interface. Considering the late scalability requirements, the front business module can be configured in the background where the role is associated with each business module, and the user is associated with role again. And then they achieve good expansion function of the system.

The simulation module is divided into dynamic simulation and thermal simulation module. The simulation module includes three parts: simulation calculation, historical working condition query and working condition library management. "Simulation calculation" is a simulation analysis of a module according to the process. The "historical working condition query" is a query for all working conditions of the user's history simulation, and it can check the setting parameters of each working condition and corresponding simulation results. "Working condition library management" is to modify and delete all the conditions of management which were simulated by users.

The experimental data module is also divided into dynamic simulation and thermal simulation submodule. The test module mainly provides functions of viewing and downloading the test data. " viewing Test data " means to select a project to display the test data with the table and curve; “Downloading test data” refers to that test data are segmented and recombined according to the selected project and processing requirements of the data, and then the test data are output and downloaded to the required location according to requirements.

User information module is mainly to change passwords for users.

3.1.2 The function module of the background

The background function module includes four modules:the project database management, working condition bank management, test library management and user management. The project library management module is the creation, modification and deletion of the project. Working condition bank management module is divided into dynamic simulation bank, and each thermal simulation bank, each module contains the function of three parts: the simulation template bank management, simulation model bank management and simulation working condition library management. Test library management module is divided into dynamic simulation and thermal simulation, and the function of each module consists of three parts: test data entry, test data modification and test data deletion; The "user management" module includes the functions of adding, modifying, and deleting users.

3.2 Platform data management

The diversified design data of the container includes model data, working condition of dynamic simulation, dynamic simulation results data and dynamic test data, working condition of the thermal simulation data, the thermal simulation results and the thermal test data. How to realize the different stages of heterogeneous data management and quick retrieve, how to make a reasonable correlation of different types of application data, how to extend product instance data, and how to design the data structure and data relations are based on platform build experience to analysis and design for specific applications.

4 THE SIMULATION PLATFORM OF THE CONTAINER

To verify the accuracy of the dynamic model of the container system and considering the total transportation, dynamic modeling of the container system was carried out, and the simulation results were compared with the test data. The whole container model included container body, L bracket, satellite and the model of vibration damping.

Figure1and Figure 2 are the comparison between the acceleration curves and the spectral curves of the container pedestal and the satellite certain location. The dynamic simulation outputs the acceleration of the selected measurement points and compares the results of 1700s to 2500s. The comparison results were showed that the simulation and test results have good consistency, and the error of container and satellitic acceleration were small. Container station within 15 Hz consistency is very good. But the satellitic points could be seen that the frequency of the test data between 12-15Hz is abundant. From the comparison of the frequency domain, the low frequency part consistency is better, and the high - frequency part experiment of 20Hz was slightly larger than the simulation.

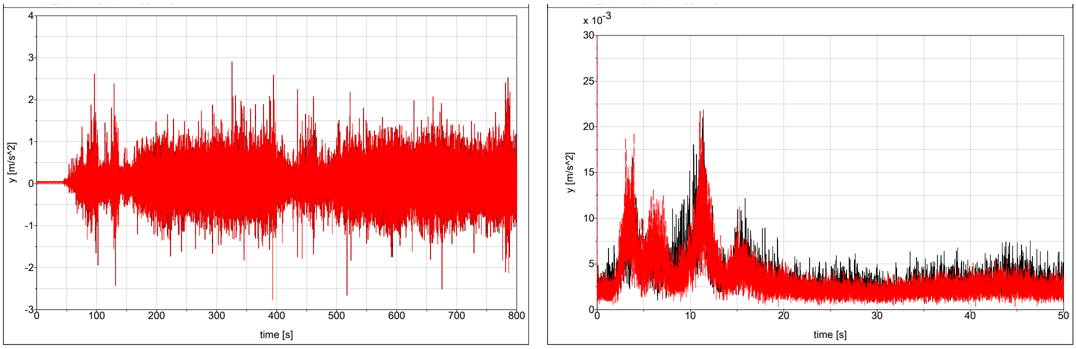

Figure 1. transverse acceleration and spectrum comparison of the container pedestal

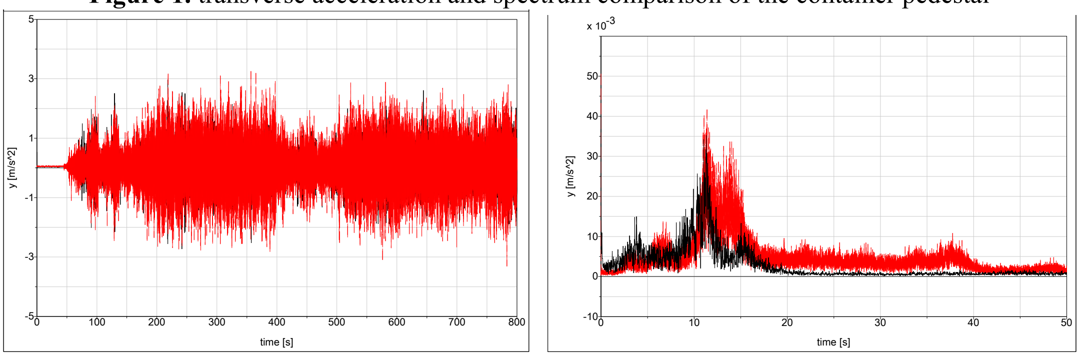

Figure 2. transverse acceleration and spectrum comparison of a satellite certain location

5 CONCLUSION

Spacecraft transport container multi-functional platform aims to the business process of container design, modifying the existing design methods, introducing advanced digital simulation analysis and management, comprehensive covering container structure design, manufacturing process planning, and working condition analysis of simulation requirements, significantly improving the level of digital development of the container. As a multi-functional platform, the container simulation platform is the most important part of the container, in order to realize the virtual commissioning based on the container of the fixed condition of railway transportation experiment as the core, through the platform design and research, the function of the following are realized:

(1) Establish the digital mechanical simulation model and thermal simulation model of the container, according to the container and spacecraft product structure, materials and transportation methods;

(2) The dynamic and thermal-environment excitation of the actual railway physics commissioning test is applied to these simulation models, using the results of simulation analysis to verify the design of the container quality, carrying out the simulation analysis of the force and temperature of the railway transportation in the container cases;

(3) Manage the data of mechanics and temperature conditions in the actual transportation of railway transport vehicles, and conduct data analysis.

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