Research and Application of Spacecraft Pipeline Digital Development Mode Based on MBD Technology

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Abstract. With the increasingly complex types, functions and structures of spacecraft, the requirements for the quality and cycle of spacecraft pipeline design are becoming higher and higher. By summarizing and analyzing the shortcomings of the traditional development mode of relying on drawings and documents as the carrier, and fully combining with the advanced technology of Model-Based Definition (MBD), the digital development mode of spacecraft pipeline based on MBD technology is proposed. Through the built-in pipeline design rules, the construction of standard parts database and CNC elbow, etc., and relying on the Virtual Product Management (VPM) management platform, with a set of pipeline digital model as the information carrier, runs through the design, process and welding work, shorten the spacecraft pipeline development cycle, improves the design quality, and significantly improves the quality control level.

1. Introduction

In recent years, in view of the characteristics of long life, short development cycle and high reliability of spacecraft, higher requirements are put forward for the development quality, development cycle, development cost and system reliability of pipeline system as the power source of spacecraft.

The traditional spacecraft pipeline development mode is that the designer carries out the three-dimensional design of pipeline direction according to the propulsion schematic diagram and equipment layout, and finally abstracts it into a two-dimensional pipeline welding drawing; the welding personnel complete the manual sampling and welding work of the pipeline under the guidance of the pipeline welding drawing. The design, manufacturing and assembly of this development mode are not based on the same data source [1], which can not guarantee the consistency of design data. At the same time, the conversion of three-dimensional and two-dimensional drawings increases the workload of design changes, which can no longer meet the requirements of high-quality and high-efficiency of spacecraft development.

In view of the above problems, domestic and foreign research on pipeline digital layout design, automatic layout and digital design system has been carried out. Liu Jianhua et al. [2] proposed an integrated method of pipeline digital layout design, manufacturing and detection, and gave the technical framework and business process of the integrated system; Zhang Liang et al. [3] proposed a system oriented design based on Pro / E software The digital design system of spacecraft pipeline is constructed. The above pipeline digital design methods proposed solutions from the technical framework,
system and manufacturing technology, but the solution of pipeline digital development based on the same data source has not been given in the pipeline design process assembly welding for whole business process.

Based on CATIA software and virtual product management (ENOVIA VPM) platform, fully combined with spacecraft pipeline development business process and MBD technology, this paper puts forward the spacecraft pipeline digital development mode, in order to improve the quality and efficiency of spacecraft development.

2. Pipeline development system based on MBD Technology

The digital development mode of spacecraft pipeline based on MBD technology is supported by CATIA software and virtual product management (ENOVIA VPM) platform. It includes the following contents:

① According to the constraints of spacecraft piping design, the design specifications and rules are customized, and the design constraints are built into the CATIA software to form a design environment suitable for spacecraft pipelines, so as to adapt to the fast piping design;

② Construct the resource library of pipeline design, including pipe valve, cylinder, thruster, connector and support with pipeline attributes and precise geometric features;

③ According to the requirements of spacecraft pipeline digital development mode, the MBD information set applied to spacecraft pipeline development mode is formulated, and the auxiliary functions of MBD information set are customized and developed;

④ According to the schematic diagram of the propulsion system, the 3D layout of the pipe valves, connectors and supports is carried out by CATIA software, and the 3D direction design of the pipeline is completed;

⑤ According to the three-dimensional direction of the pipeline, the pipeline design parameters are extracted, and the pipe bending machine is used for digital control bending;

⑥ According to the MBD information in the 3D pipeline model, the 3D pipeline lightweight welding model is formed, which can directly guide the process planning, pipe valve parts, support parts installation and pipeline welding work.

Figure 1. MBD based digital development model framework for spacecraft pipeline
3. Digital design of spacecraft pipeline

3.1. Three dimensional layout and design of pipeline
According to the principle of the propulsion system and taking full account of the design constraints and principle of pipeline layout, the pipe valve parts, support parts and connectors of the standard parts library of the pipeline can be obtained from the ENOVIA VPM platform for three-dimensional layout. After completing the three-dimensional layout of the pipe and valve parts, the three-dimensional design of the pipeline can be carried out according to the original plan, and the appropriate Line can be selected. After ID, the run function is used to route the pipeline. After selecting the nozzle of two pipe valves, the system will automatically create the pipeline route between the two pipe valves, and finally complete the overall layout and direction design of the pipeline.

![Image 1](image1.png)

**Figure 2.** 3D design of pipeline

3.2. NC machining of pipeline
In order to guide the subsequent production of pipeline components, it is necessary to extract weld information and pipeline geometry information from 3D pipeline model. Among them, the weld information can be expressed in the form of annotation; for the geometric information of the pipeline, such as the number of pipe segments, the center point of each section, the length of each straight line segment, the inner and outer diameter of the conduit, and the bending radius of each circular segment are all expressed through the 3D model of the pipeline [4].

The NC pipe bender can bend the pipe continuously according to the NC instruction. There is a certain amount of springback after bending, that is, the bending angle is less than the angle required by the numerical control command. The CNC pipe bender supports the springback correction method, which inputs the angle and springback relationship curve of each specification of pipeline into the bending machine. The bending machine can modify the NC instruction to ensure that the actual processing angle is consistent with the NC requirements.

![Image 2](image2.png)

**Figure 3.** Comparison between pipeline model and real object
3.3. Pipeline welding model based on MBD

In the early stage of pipeline design, MBD technology has been used to write the relevant basic information of pipe valves, connectors, supports and other basic information into the model in advance, that is to say, all design information has been introduced into the model in advance. At the same time, the pipeline design specifications and direction rules have been solidified in CATIA software in advance to help and constrain designers to meet the design specifications in the design process.

After that, the pipeline design process is only based on the pipeline schematic diagram, and references different pipe valve parts, connectors and support parts models from the pipeline standard parts resource library to design a pipeline system that meets the requirements.

After completing the pipeline schematic diagram, layout trend and 3D model, the process and welding personnel are required to prepare process documents and pipeline welding according to the welding model, and at the same time, the three-dimensional pipe model is bent by CNC pipe bending machine to make the actual pipeline.

![Figure 4. Model information transfer based on MBD](image)

Due to the cancellation of two-dimensional engineering drawings, three-dimensional model becomes the only carrier of design and process information. However, CATIA software information used in this paper is built-in and has no display expression. In addition, the information required by the welding department is only a subset of the design information. If CATIA software needs to be installed in the welding workshop, a certain amount of software and hardware resources will be wasted, and excessive design information sent to the welding workshop will also bring unnecessary interference to the welding personnel [5].

Therefore, in order to show the pipeline welding information more clearly, the pipeline design form and trend are directly reflected to the process planning personnel and pipeline welding personnel. The MBD information built in the model is automatically extracted by using lightweight software, and the annotation is displayed in the form of lightweight. At the same time, the performance requirements of the computer are reduced, so as to realize the lightweight of 3D welding The model replaces the traditional two-dimensional welding drawing to avoid the waste of resources caused by the huge amount of data of 3D design model. Figure 10 shows the lightweight welding mode of pipe valve.
4. Application and verification

At present, the spacecraft pipeline digital development mode based on MBD has been successfully applied to many spacecraft models. Through summarizing the pipeline specifications and pipeline design rules, the design constraints are built into CATIA design environment, and the design specifications are guaranteed by tools.

The pipeline standard parts resource library suitable for multiple types and models is gradually improved, and the design library is constantly improved and expanded to meet the requirements of fast, efficient and high-quality design of multiple models.

At the same time, according to the design parameters of the three-dimensional model of the pipeline, the numerical control bending machine can be used for bending and forming, which avoids the error caused by manual sampling, and saves the cycle of production and assembly of sampling tooling, and saves the cost.

In addition, the first mock exam model of spacecraft pipeline based on MBD eliminates the transfer and conversion links between design intent and production objects, enables technicians and welding personnel to visually navigate the pipeline path form complex space, and relies on the MBD 3D model as the only information carrier, and the design, process and operation refer to the same model at the same time, and realizes the unified design based on the same model. A set of model of data source is used in the whole cycle from design, process to welding work. Fig. 6 shows the comparison between pipeline design model and physical welding model. It can be seen that the precision degree of pipeline is close to 100% and the design state is restored.

Figure 5. 3D model of pipeline lightweight welding display

Figure 6. Comparison between pipeline design model and physical welding model
5. Conclusion
The digital development mode of spacecraft pipeline based on MBD technology realizes the full three-dimensional development from design to process, assembly and welding. MBD technology, pipeline design rules built-in and standard parts resource library are used as technical support, relying on ENOVIA as a collaborative design environment, VPM platform uses a set of 3D pipeline model as the only data source to directly guide the process, processing and welding, which reduces the workload of designer's 3D model and 2D drawing conversion, cancels the unnecessary work of designer's 2D drawing drawing and manual sampling, and avoids the risk of pipeline welding from 2D to 3D. It improves the efficiency and simplifies the pipeline development process.

Through the in-depth application in the process of spacecraft model development, it is further confirmed that the full three-dimensional digital development mode not only improves the accuracy of pipeline direction, but also simplifies the original development process and reduces the development cost. At the same time, it greatly improves the quality and efficiency of spacecraft pipeline design, which has reference significance for the promotion of pipeline digital development mode in related industries.

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