Research on the Key Technology of the Automatic Piping Layout Design for the Launch Vehicle

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Abstract. For the low design efficiency and poor design quality in the piping layout design of the launch vehicle, the article raises a piping automatic layout method which is based on the geometry. In order to realize the piping automatic layout design, the method need the position coordinates and direction vector for both of the initial point and termination point. The article verifies the feasibility of the method by developing the piping automatic layout design system for the launch vehicle.

1. Introduction
Pipe system is an important part of the pressurized transportation system for the launch vehicle, which is worked by the gas or liquid as working medium for transmission power to control the system operation normally. The traditional piping layout is based on the human-computer interaction design relying on the experience of the designer or the improved design on the original model, which is the low accuracy, the high labor intensity and the poor design quality. It is meaningful to research the piping automatic design method which is aimed to improve the piping design quality and relieve the burden of the piping designer.

The piping system of the complex electromechanical products around the world can be divided into two types. The first type is abstracted the piping layout to a pure mathematical optimization problem, which takes the shortest pipeline length or the optimal pipeline dynamic performance as the optimization target. They seek the best design path by various optimization algorithms, such as the Bai Xiaolan[1] of the Northeastern University, she solves the single pipeline and the branch pipeline layout by the intelligent optimization algorithm in 2013. Liu Jianhua[2] realizes the piping automatic layout which is bases on the design knowledge in 2014. The second type is recover the designer’s experience as the leading, which is mainly on the advanced design tool such as the virtual reality technology to complete the piping layout. Such as Holt[3] in the university of Heriot-Watt of England raised the piping layout method based on the immersive virtual reality devices in 2004. Ning Ruxin[4] realizes the flexible conduit model’s piping layout in the virtual environment. Whereas the amount of influence factors in the launch vehicle piping layout design, the current optimization design theory cannot give a better scheme immediately. The advanced design technology such as the virtual reality is expensive for the current design of launch vehicle. There are abundant of rapid design requirements for the two endpoints of single pipe. The article researches the rapid design of the two endpoints of the single pipe layout, at the end of the work raising the module of the piping automatic layout[5][6][7].
2. Theory of the piping automatic layout for the launch vehicle

According to the condition of the launch vehicle piping layout, the piping layout can be divided into two cases. The first case is the two-dimensional layout design of the pipe. The second case is the three-dimensional layout design of the pipe.

The two-dimensional layout design of the pipe means the coordinates and the direction vector of the two endpoints are in the same plane. This moment the piping layout design equals to two straight line in the same plane which is in the parallel or the vertical position. At this point, the solution to complete the piping layout design is adding a pipe and selecting the bending radius.

The three-dimensional layout design of the pipe means the coordinates and the direction vector of the two endpoints are not in the same plane. This moment the piping layout design equals to the intersecting method design of the two straight line in a heterophedral relationship.

Suppose the coordinates of the starting point for the launch vehicle pipeline system is,

\[ P_0 = (p_{0x}, p_{0y}, p_{0z}) \]

The pipeline from the starting point is \( L_0 \), the direction vector of the starting point is,

\[ V_0 = (v_{0x}, v_{0y}, v_{0z}) \]

The coordinates of the termination point is,

\[ P_1 = (p_{1x}, p_{1y}, p_{1z}) \]

The pipeline from the termination point is \( L_1 \), the direction vector of the termination point is,

\[ V_1 = (v_{1x}, v_{1y}, v_{1z}) \]

As shown in figure 1. At this point the piping layout equals to the judgment and solution of position relation for the two straight line in the space.

\[ \hat{r}_0 \times \hat{r}_1 = \begin{vmatrix} i & j & k \\ v_{0x} & v_{0y} & v_{0z} \\ v_{1x} & v_{1y} & v_{1z} \end{vmatrix} = \begin{vmatrix} i \ (a_y b_z - a_z b_y) & j \ (a_z b_x - a_x b_z) & k \ (a_x b_y - a_y b_x) \end{vmatrix} \]  \hfill (1)

If the formula (1) equals to 0, it means the pipe is in the same plane. If the direction vector’s intersection angle of the initial point and the terminal point is 0, the scheme is to design a semicircular arc-shaped joint pipe. If the angle is 180 degree, the scheme is to design the joint pipe depending on the location of the two endpoints and the bending radius value.

If the formula (1) is not equals to 0, it means the pipe is overlapping relation in the same plane or in a heterophedral relationship. Assumed as follows,

\[ \hat{r}_0 \hat{r}_1 = \hat{d}_0 \hat{d}_1 = (p_{1x} - p_{0x}, p_{1y} - p_{0y}, p_{1z} - p_{0z}) \]  \hfill (2)
Given the conditions to compute the (2)(3)(4), then judge if the vector $M$ and $N$ is parallel, if the vector $M$ and $N$ is parallel, the pipe is overlapping relation in the same plane, the scheme is design the pipe by selecting the bending radius. If the vector $M$ and $N$ is not parallel, the pipe is in a heterophedral relationship, we can get the following formula according to the heterophedral relationship. Assumed as follows,

$$\left( \left( \left( \vec{P}_1 + L_1 \vec{V}_1 \right) - \left( \vec{P}_0 + L_0 \vec{V}_0 \right) \right) \cdot \vec{V}_0 \right) = 0$$

$$\left( \left( \left( \vec{P}_1 + L_1 \vec{V}_1 \right) - \left( \vec{P}_0 + L_0 \vec{V}_0 \right) \right) \cdot \vec{V}_1 \right) = 0$$

Simultaneous equations (5) and (6) we can get the value as following,

$$L_1 = \frac{\left( \left( \vec{P}_1 - \vec{P}_0 \right) \cdot \vec{V}_0 \right) \left| \left( \vec{V}_0 \right) \right|^2 - \left( \left( \vec{P}_1 - \vec{P}_0 \right) \cdot \vec{V}_1 \right) \left| \left( \vec{V}_1 \right) \right|^2}{\left| \left( \vec{V}_0 \right) \right|^2 - \left( \vec{V}_0 \right) \left( \vec{V}_1 \right) \left| \left( \vec{V}_1 \right) \right|^2}$$

$$L_0 = \frac{\left( \vec{P}_1 - \vec{P}_0 \right) \cdot \vec{V}_0 + L_1 \vec{V}_1 \cdot \vec{V}_0}{\left| \left( \vec{V}_0 \right) \right|^2}$$

Now it is the shortest pipeline of the heterophedral pipe. The next step is to select the bending radius to finish the piping automatic layout.

### 3. System development of the Launch vehicle piping automatic layout

The launch vehicle piping automatic layout system is consisted by four modules. The four modules are the pipeline information input module, the pipeline spatial relationship interpretation module, the pipeline design visualization module and the pipeline design information output module respectively. As shown in figure 2. The development flow chart of the launch vehicle piping automatic layout system is as figure 3.

![Automatic Piping Layout Design System for Launch Vehicle](image)

Figure 2. Schematic diagram of the launch vehicle piping automatic layout system
4. Example verification

4.1. The pipeline information input module

The pipeline information input module is based on the XML file, which described the pipeline basic information. Just as figure 4(a) and (b). The file path selection interface is based on the MFC, just as figure 5.
4.2. The pipeline spatial relationship interpretation module
By the basic pipeline information and the interpretation algorithm of the straight line in space, the module realize the pipeline judgment of the straight line in space. The design parameter of the pipeline for the relationship is as figure 6.

![Figure 6. The interface of the parameters selection of the pipe](image)

4.3. The pipeline design visualization module
The module realize the pipeline visualization based on the OpenCascade, just as the figure 7abcd shows the paralleled pipe and the angle is 0, the paralleled pipe and the angle is 180, the coplanar and intersecting pipe, and the heterophedral pipe respectively.

![Figure 7. The visualization of the piping layout](image)

4.4. The pipeline design information output module
The key information during the piping layout design include the coordinates of the key points on the route of pipe, the length of the pipe, the overall length of the pipe, the bending radius, the wall
thickness of the pipe, the outer radius of the cross section, the inner radius of the cross section. The output mode is as figure 8.

![Figure 8](image_url)

**Figure 8.** The file description of the key information in piping layout

5. Conclusion

By researching the typical problem in the piping layout, the article raises an automatic layout algorithm based on the geometry. A piping automatic layout system is developed by the algorithm and the OpenCascade, which verifies the feasibility of the algorithm, raises the efficiency of the designer, shortens the product development cycle.

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