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# Research on Complex Products based on Digital Layout Design and Simulation Modeling

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***Abstract***

*From the point of view of digital product development, this paper makes a deep discussion and research on the key technologies of pipeline layout design, pipeline layout optimization, and assembly simulation in the process of complex product development. We introduce an automatic pipe layout techniques based on improved rapidly exploring random tree, it could able to quickly establish the framework model of pipeline system, on this basis are discussed a pipeline of the simulated annealing algorithm based on automatic optimization algorithm, and interactive pipeline layout method, using computer artificial intelligence and design personnel manual intervention method to improve the quality of pipe layout. Also, we make the system realization of automatic layout of pipe line, and put forward related Suggestions.*

***Keywords**: Computer artificial intelligence, simulation modeling, complex product, piping system*

## 1. Introduction

Pipeline system in automobile, shipbuilding, chemical, aerospace, aviation and other mechanical equipment widely used the pipeline system with gas and liquid as working medium, to achieve operation of mechanical and electrical products, control and manipulation. With the development of aerospace and aviation complex products to miniaturization, lightweight, precision and optical, mechanical and electrical integration direction and also increases the complexity of the pipeline [1]. The performance and reliability of the pipeline system performance is directly related to the product, and sometimes can become the key to the success of the influence on the product development. The United States GE Corp has carried on the summary to the failure of previous aircraft engines in the process of using, the real cause of the air parking incident, 50% because of damage to external pipes, wires, sensors or caused by the failure of the United States Navy; the annual cost of about 1 million 800 thousand people in the pipeline and cable troubleshooting or repairs [2-3]. A monthly average of two flight pipeline system fault; the United States Air Force Flight 43% is estimated with the piping system in accidents related to abnormal quality problems in statistics; Academy of China aerospace research product analysis report pointed out that the failure of piping system for a total failure more than 20%. The three-dimensional digital design and manufacturing technology has been widely used by three-dimensional digital design and manufacturing technology for complex products in the pipeline layout Design and optimization to provide new ideas and tools. Software vendors and research institutions from the point of view of various applications put forward different pipeline digital design and manufacturing tools, but generally speaking, this research is still in development stage, existing software packages are only partially satisfied the requirement of practical engineering application [4].

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A lot of researches have been carried out in the field of computer aided piping layout design. Research on the interactive computer aided layout system of the United States P&W company in the end of 1970s. The system mainly carries on the design of the pipe parts, the final output conduit engineering drawing and the data set up for the manufacture of the pipe, and the interference detection can be carried out. People, machines, computer and closely linked to the pipe layout system organically, its main characteristics is realizing the creation computer aided piping, 3D catheter measurement, CNC bending formation of a series of related businesses, saving 50% of the cost of the design, saving 50% of the pipe laying work time. GE Company in the United States before and after 80 years the use of Geomod's SDRC software DDM (Design, Drafting, Manufacturing) module will be the introduction of the electronic model of the aircraft engine to the external pipeline layout[5]. DDM is oriented to the line box modeling CAD software, can be designed to draw and control the output value of the figure. This system is an interactive system, which allows designers to observe the engine electronic model from different angles. Geomod is a solid modeling software, can be given according to the coordinates of the pipeline layout, and can avoid such as accessories or other obstacles, can also be inserted into a certain bending radius of the elbow [6]. In the process of layout, the Geomod can also be automatically carried out to check the gap. This system has been applied in the development of CF-80C2 engine, and has achieved good results. British R.R Company developed a three-dimensional layout of the external pipeline system Trent800. Based on the experiences of designing R. R Company, established in 1990 BMW kind of company for CADDS software, for the br700 engine series development of the specialized extensions, using numerical preassembled DPA (digital Preassembly) on a dedicated workstation, developed engine external pipe layout system [7-8]. At present, developed countries in Europe and the United States aviation engine company in external pipeline design are used CAD / CAM / CAE software of pipeline effect is very good. For example, all the external pipes of the V2500 engine on the computer layout is complete, directly to pipeline data transmission to the CNC bending machine, 90% of the pipeline can be a successful processing, only a small amount of pipeline in the actual manufacturing need to adjust.

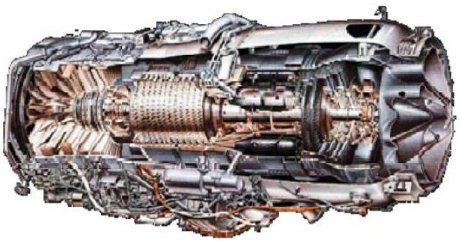

**Figure 1. Pipeline System in Aviation and Space Engine**

Reasonable distribution and optimization of pipeline is the premise to ensure the reliable operation of complex mechanical and electrical products, as shown in Figure 1. As in the complex products and system piping layout design stage and need comprehensive consideration of the pipeline can manufacturing, stability, strength and flow resistance of a series of inter professional problem, engineering often due to consider the impact of complex factors, resulting in how the relationship pipeline system layout design time under the protection of layout design quality has become a difficult problem in engineering. The to improve the problem of complex products in the pipeline layout design efficiency and quality, a complex product pipeline digital layout design and Simulation of related theory, method and implementation techniques were studied, so as to provide theoretical basis, method and digital tools to improve the system piping layout design efficiency and quality.

## 2. Digital Layout Technology of Pipeline

Digital expression of product information is a prerequisite for the realization of digital manufacturing. In complex product development and wide application of 3D CAD system for product design and 3D digital definition, and based on this, simulation processing components, products of CAE analysis, part or whole of the digital pre assembly. For products in the pipeline system, at present the mainstream CAD system provides pipeline system layout module, for implementing based on 3D scene pipeline layout and generate corresponding pipeline layout data in product design. However, these tools are used to regard the pipe as a common rigid part. After the central line of the pipe is determined, the solid model of the duct is established by the method of scanning. And due to the pipeline system in most of the lines appear in groups, and a large number of branch pipe and the catheter with similar functions, work environment similar, cannot carry out the unified management of a large number of catheter parts by using this method, it is difficult to make a for optimization.

### 2.1. Piping Accessories Parts Modeling

Unlike catheter digital expression model, piping accessories parts because the structure is relatively complex, and the current CAD software has the ability of modeling of complex parts, so the pipeline accessory parts of virtual entity model direct reference to other CAD software, the modeling results, patches of virtual entities using B-rep format to establish the geometric model geometric information structure model as shown in Figure 2. Based on the geometric model, the corresponding collision model is generated by the collision detection algorithm. At last, through the addition of relevant engineering information, the information model of pipe accessory is generated.

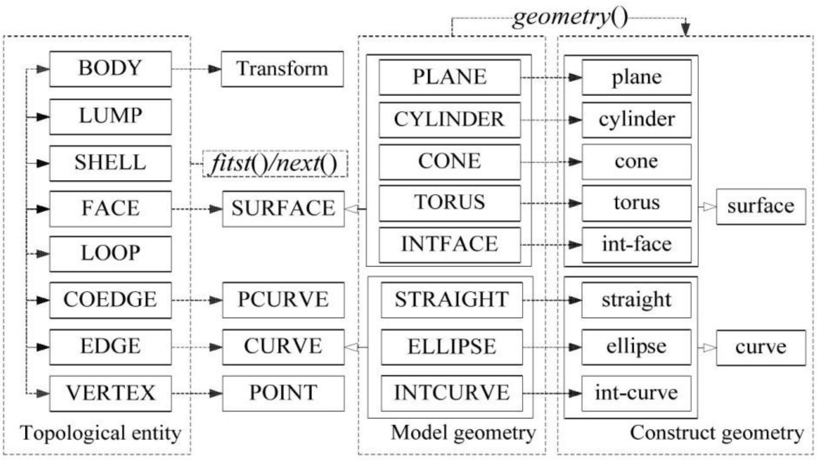


**Figure 2. B-Rep Representation**

### 2.2. Overall Process of Digital Layout of Pipelines

Pipeline digital layout design that, in computer software and hardware platform, based on digital prototype of the product, use digital tools for the layout and design of complex products in the pipeline system, pipeline parts in the process by a digital model of the pipeline for definition and description. On the basis of the digital layout design of pipeline system, this step is divided into three functional modules, which are automatic layout of pipelines, pipeline layout results optimization and pipeline interactive layout design. The automatic pipeline layout module is obtained according to the constraint space structure of pipe layout digital prototype of the product at the same time, according to the function requirements of automatic connecting piping system will have a connection opening connected to the preliminary results of the pipeline layout; layout optimization is the result according to the specific engineering constraints, the layout of the this module needs improvement, follow-up results provide layout verification phase optimization; pipeline layout design is to improve the method of interactive digital pipeline layout flexibility, you can manually in the layout process to adjust the layout of the results, to maximize the advantage of experience design personnel, improve the layout efficiency.

After the completion of the layout, the layout results are verified by the layout knowledge and rules, including the rules of machinability, the rules of assembly, the rules of strength characteristics, and the rules of vibration characteristics and so on. If the verification results meet the requirements, the output result of layout, including the 3D model of the digital pipeline layout, BOM and other file archiving and so, if the verification results do not meet the requirements returns on a step on the layout results are further optimized and re layout.

### 2.3. Pipeline Layout Result Optimization Goal Modeling

In the process of optimizing the pipeline layout results, it is needed to specify a target function. In this paper, based on simulated annealing algorithm, the results of pipeline layout optimization method, there are two kinds of optimization objectives, one for the standard optimization objectives, and the other for the additional optimization objectives. The standard optimization objective refers to the optimization goal that has been played in the process of layout optimization, which ensures that the optimized pipeline can meet the basic requirements of engineering constraints. These optimization objectives are obtained from the industry standard, and the mathematical model is relatively simple. Standard optimization mainly includes the following parts: the principle of economy; as far as possible along the edges of the installation layout rules; bending pipe layout rules; pipe layout minimum clearance rules; avoid equipment in the machinery and equipment, is connected with a given the check point; try to avoid the heat source. According to the above principles, the mathematical model of the optimization of the pipeline is established:

$$\begin{cases} \min\{N_{bend}\} \\ \min\{f(d_1,\ldots d_i,\ldots d_n)\} = \min\left\{\sum_{i=1}^{n} d_i\right\} \\ bend_i > 2.5D \\ angle \geq 0.5\pi \\ Length > L_1 \\ d_s < L_2 \\ d_f > L_3 \end{cases}$$

In the formula, $N_{bend}$ is pipe bending number and $d_i$ for catheter of the i-th segment length, $bend_i$ pipeline of the i-th corner radius, $angle_i$ for pipeline in the ith a bending angle of the bending angle, length of pipeline in the first paragraph and terminal degree,$d_s$ to support the distance of the pipeline,$d_f$ the distance between the pipeline and the mechanical equipment parts,$L_1$, $L_2$, $L_3$, respectively, for the industry regulations in the pipeline system.In addition, to consider some of the restrictions on the layout of the multi tube road, described as follows:

 

$$\begin{cases} \min\left(\sum_{i=1}^{n} N_{bi}\right) \\ \min\left(\sum_{i=1}^{n} f_i\right) \\ \min\left(\sum_{i=1}^{n,m} d_{ij}\right) \\ d_p > L_4 \end{cases}$$

Additional optimization objectives, at present, the standard optimization objective described above is the most commonly considered evaluation index in pipeline route optimization, which is simple and easy to calculate. Additional optimization objectives including the pipeline flow resistance loss, the strength of pipeline and engineering constraints, following detailed description of several types of additional optimization objective mathematical modeling method and other additional target optimization model can analogies drawn. Flow resistance loss: to make the layout of the pipeline to meet the system requirements for the loss of flow resistance. Pipeline is a straight curve segment and segment, and the fluid after the pipeline straight section and a bending section is respectively will produce along the side resistance loss and the local resistance loss, resulting in pipeline of fluid in the fluid reaches the end of the flow resistance loss, fluid drag losses in the pipeline should satisfy formula:

$$F_l = \frac{1}{\sum f \frac{l_i}{d} \frac{\rho v^2}{2} + \sum \xi \frac{\rho v^2}{2}}$$

Among them, f and ξ representing along the friction factor and the coefficient of local resistance, $l_i$ means the length of each straight section, ρ means the ductal fluid density, v represents an intraductal fluid velocity, d means the catheter diameter.

## 3. Automatic Evaluation Technology of Pipeline System

ASP is the answer set programming, research source of ASP in the intersection of two areas of logic programming and no monotonic reasoning and logic programming based is knowledge of the first-order predicate logic expression and non-monotonic reasoning is that with the increase of information inference, will lead to modifications in the inference. In recent years, with the improvement of the efficiency of the ASP solver, it has more and more applications in the field of artificial intelligence. An ordinary logic program is a finite combination of general rules, an ordinary rule has the following form:

$$H \leftarrow \alpha_1, \ldots \alpha_m, not\alpha_{m+1}, \ldots not\alpha_n$$

Using ASP to problem solving needs will be the code structure of ASP programming language, ASP language is declarative language it with C / C + + process of different languages, declarative language only need to describe what the problem is, and process of the language need detailed characterizations algorithm how to solve the problem. Because the complexity of the answer set of the computational logic program is NP-complete, it is generally required to find the answer set through the search method. The existing common logic programs of the ASP solver mainly include: smodels, cmodels, clasp, ASSAT and DLV, these solvers are mainly divided into two categories:

- Based on DPLL algorithm, Including: smodels, DLV, clasp.
- Based on SAT solver, Including: cmodels, ASSAT.

 

The ASP solver used in this study is clasp, which is one of the current mainstream ASP solvers. The basic structure of the DPLL algorithm pseudo code is as follows:

```
B is a clause set of SAT, If it's satisfied return TRUE, else return FALSE
l is the unique literal of the clause set
while (l)
   if (unit clause C exist in B)
       l = C;
       use l to simply B;
       if (B == Ø)
          return TRUE;
    else if (!variable_decide())
      return TRUE;
    end if
    while (!bcp_deduce())
       if (conflict())
            select the nearest non-reversal decision variable v;
            if (v == NULL)
                 return FALSE;
            else
                 reversal the value of v and mark it as a reversed variable ;
                 cancel the valid implication of the last bcp_deduce();
       end if
    end while
end while
```

# 4. Simulation Technology of Assembly and Disassembly of Piping System

## 4.1. Task and Process of Assembly and Disassembly Simulation of Piping System

The pipeline system is an important part of the product, which is represented by the product of the spacecraft. Pipeline system is responsible for the transmission of gas or liquid media, to ensure the normal operation of the whole. Therefore, the assembly quality directly affects the performance and reliability of the product. The characteristics of pipeline system disassembly and assembly task is: first, piping system parts generally after the completion of the complex product structures of other parts manufacturing and assembly to assembly, the assembly sequence is generally in the last step of the product; the second, a complex product pipeline parts belong to the vulnerable parts, disassembly and maintenance of frequency to higher than other structures; third, pipeline system in the tube part most is long and narrow, and complex products in the assembly and disassembly of the space is small, so assembly and disassembly path get very difficult. In particular, the implementation of assembly and disassembly operation of pipeline system parts in complex products has the following difficulties:

*1)* the assembly density of complex products is high, and the assembly and disassembly operation space is limited;

*2)* complexity, assembly and disassembly of the catheter;

 

*3)* the assembly flexibility is poor after the assembly operation of the pipeline system parts;

*4)* to ensure the reliability of the installation, fixed and other aspects;

*5)* The removal rate of the parts of the piping system is high, and the disassembly process needs to be as little as possible.

Current production at the scene of complex products, mainly to the physical prototype trial installed in the form of making assembly process, time-consuming, low precision and relies on people's experience and information to analog transmission; and in the link for pipeline layout for disassembly simulation research rarely, the complex product maintenance and maintenance consumes a lot of cost. This paper on the digital prototyping of complex product based, according to the digital model of the pipeline, the pipeline system parts of complex product of assembly and disassembly simulation, verify the product assembly and maintenance, and to develop process, to the scene to guide the production assembly and remove unloading operation implementation.

In the assembling process, for example, a complex product pipeline assembly simulation system is with the aid of the computer and other equipment to simulate the real operating environment, in this environment, conduit and pipe accessories assembled to the device, and the process of assembly path planning and assembly sequence planning. This process is a simulation of the assembly process. In the process of simulation, it is necessary to consider the virtual reality of the simulation process, reduce the gap between the actual assembly operation and the use of tools and fixtures.

### 4.2. Fast Extended Random Tree Algorithm

Because the disassembly operation can be realized with the aid of the related tools, it is needed to determine the accessibility of the tool and whether the operating space is. Simplify the equipment, bulkhead and other obstacles to the wall, the distance between the pipeline and the obstacle is simplified as the distance between the flange and the wall. So the problem is translated into the flange and the wall of the shortest distance $L_{min}$, to ensure that the pipe is removed when the wrench has enough room for movement. If the flange radius is $d_f$, the wrench length is $L_w$, θ is spanner dismantling process once in a maximum rotation angle. Wrench main function is the screw nuts, bolts and other rotating parts assembly, wrench around parts of the rotating shaft to rotate, wrench and general requirements for minimum rotation angle of 60 degrees, and for the special parts such as the four hexagon nut, wrench rotation angle of at least 90 degrees, θ = 60. The relative position of the flange and the wall can be divided into the following two conditions, as shown in Figure 3.

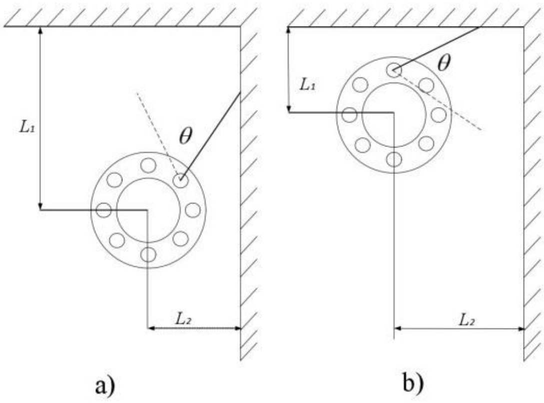


**Figure 3. The Relative Position of Flange with Obstacles**

Figure 3 shows two cases represent only the flange on the walls in the upper right corner of the, in fact flange on the wall in the upper left corner, the left corner, in the lower right corner and equipment with the relative position between are similar. I

$$L_{\min} = \min(L_1, L_2) = \begin{cases} L_2, L_1 \geq L_2, L_w \leq L_1 \\ L_1, L_2 \geq L_1, L_w \leq L_2 \end{cases}$$

Taking (a) as an example, the expression of $L_{min}$ is:

$$L_{\min} = d_f + l_w \sin\left[\theta - \arctan\left(\sqrt{2} - 1\right)\right]$$

In the process of removing the operation, the distance between the flange and the product structure is less than $L_{min}$, then the tool does not have the maneuverability, otherwise the tool can complete the disassembly operation.

### 4.3. Automatic Generation Technology of Pipeline Disassembly Sequence

Traditional disassembly sequence planning algorithm to determine the component disassembly, often only judgment in parts to connect the orthogonal directions (x, y) whether local degrees of freedom, that is to judge in the disassembly process, target parts is able to out of the assembly becomes a movable parts. In actual operation, as in parts of disassembly path may be interference of other components, the condition is not enough to judge the parts can be removed, the section describing the rapid expansion of random tree algorithm to judge whether the parts can achieve the global free space and for judging the disassembly constraint relationship of parts in an assembly provides the basic arithmetic. On the basis of the application of motion planning technology to the disassembly path analysis of parts, the construction of disassembly constraint relation diagram is constructed. Due to the selection of parts for disassembly sequence planning, the need to clear the assembly of all parts of the disassembly constraints, it is necessary to carry out the assembly of all parts of the assembly of the constraint analysis.

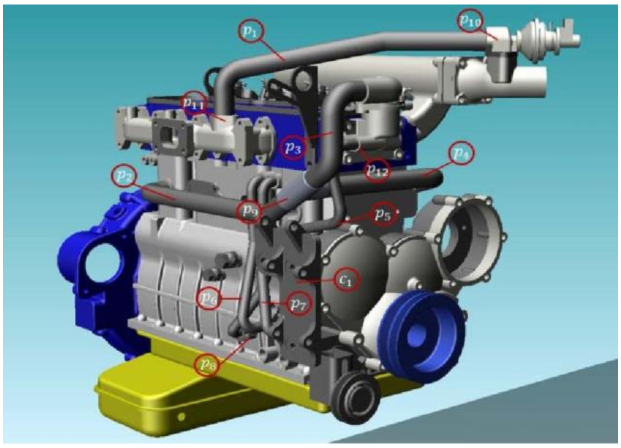

**Figure 4. Automatic Generation of Pipeline Disassembly Sequence**

(1) Layered structure of the assembly: as shown in Figure 4, the pipeline system in an automobile engine is an example, set up:

$$\Omega = \{p_i, i = 1, 2 \ldots n\}$$

Means all parts of the assembly line, G= $\varnothing$ for processed parts. The initial value is null. First the set $\Omega$ elements do traversal, using section describes the rapid expansion of random tree algorithm to solve pipe parts disassembly path, to determine the component disassembly. In the process of determining the disassembly of the target line part, a collection of obstacles $O=\{P_i, P_i \in \Omega, P_i \neq P_{tar}\}$ .That is, all the parts of the assembly body which are not removed except for oneself.

(2) The establishment of the disassembly constraint relation diagram of zero parts: in the process of slicing the parts in the assembly body, it is required to analyze the disassembly constraint relations between different levels.

```
GENERATE_DISASSEMBLY_CONSTRAINS(pt)
pt←target part, N←Layer index of pt;
A←Assembly with N and N+ Layers;
A0←parts in N- Layers;
S.Init(pt, N);
while(N!=1) do
        path←preserved escape path of pt;
   Ω←parts in Layer N-1 and in A0
   C=Get_Collision_Parts(pt,path, Ω);
   Ωt←Generate_Combinations(C );
   Rearrange_From_More_To_Less(Ωt);
   for c in Ωt do
     A.add(c);
     if(MotionPlanning(pt, A) == succeed)
       S.add(Ωt-c);
       A0= A0-Precedence_Conditions(Ωt-c);
       pt.path.Update();
       N=N-1;
       break;
return S;
```

As shown in Figure 5, if you want to remove the catheter $p_5$, according to the initial disassembly path (path 1), the parts will be in collision with $P_3$, $P_6$, $P_7$. If these three parts are removed, the $p_5$ is bound to be removed. But the shape of the parts analysis shows that, if only the removal of part $P_3$, you can produce a new path (path 2) touch the catheter $p_5$ removed, therefore in every time to remove parts again after disassembly path search, you can find minimum cost of disassembly scheme.

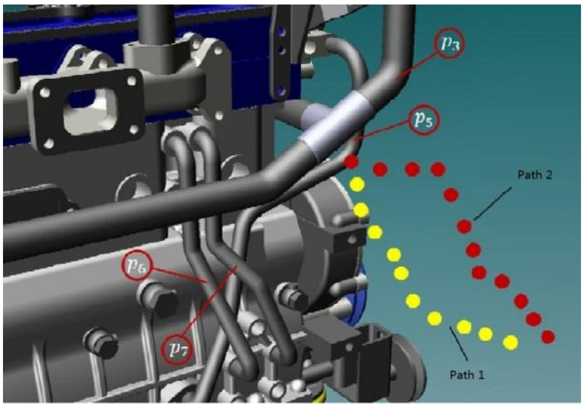


**Figure 5. Disassembly Constraint Analysis Example**

### 4.4. System Implementation

The product design model (such as Pro/E model) was transformed by the model conversion interface program, and the main program platform was introduced to build the digital prototype and build the assembly. As shown in Figure 6. Through the pipeline function connection information can get the pipeline system contains 6 paths, the digital prototype of the structure of the pipeline connection position label, as shown in Figure 7.

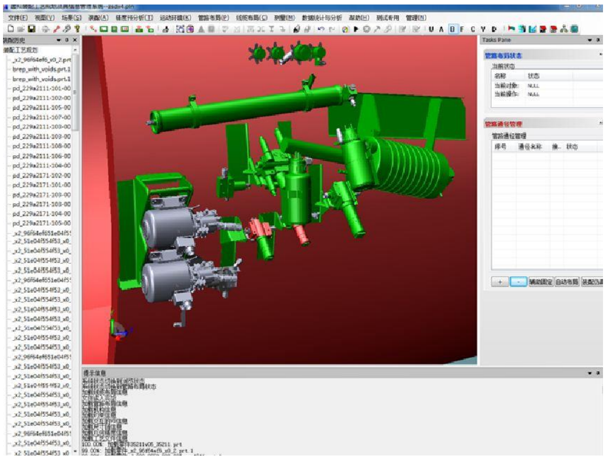

**Figure 6. Introduction of Product Model and Construction of Digital Prototype**

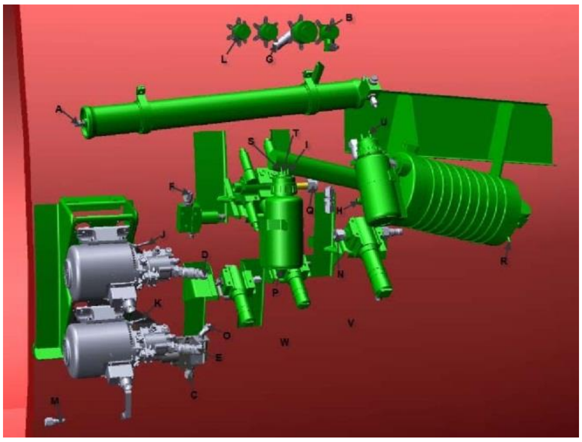

**Figure 7. Path Connection label**

 

After on pipe size definition, call system has the function of the automatic layout module for automatic layout, the pipe size in the module, need sizing of automatic layout, the size can be automatic layout, you can also specify the starting point and end point, single line for automatic layout, at the same time also need to set algorithm parameters. After completion of the automatic layout, can be seen in the interface below layout result list, on the above-mentioned six pipe size automatic layout, the result is shown in Figure 8.

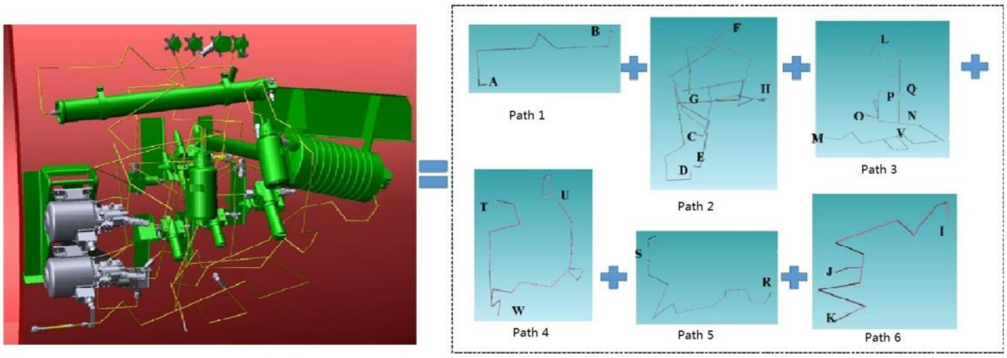


**Figure 8. Pipeline Automatic Layout Result**

## 5. Conclusions

Pipeline system is an important part of complex products, is responsible for the delivery of gas, liquid and other fluid medium, pipeline system to a large extent affect the performance and reliability of complex products. The layout design of pipeline system needs to consider its structure, manufacturing, assembly, strength, flow resistance characteristics and a series of engineering constraints, the process is very complex. At present our country's complex product manufacturing enterprises in the pipeline system research and development process, technical means and auxiliary tools are more backward. From the point of view of digital product development, this paper makes a deep discussion and Research on the key technologies of pipeline layout design, pipeline layout optimization, and assembly and disassembly simulation in the process of complex product development. The main tasks of pipeline layout design are analyzed, and the process of digital layout design is presented, and the key technologies are studied. Introduces a based on improved rapidly exploring random tree automatic pipe layout techniques, able to quickly establish the framework model of pipeline system, on this basis are discussed a pipeline of the simulated annealing algorithm based on automatic optimization algorithm, and interactive pipeline layout method, using computer artificial intelligence and design personnel manual intervention method to improve the quality of pipe layout. The output mode and implementation technology of digital layout design are introduced.

In this paper, a digital model of pipeline is proposed, which is based on the path of the path. The method to pipe through diameter as the core will function similar, working environment and transmission medium of the same interconnected piping system components as a whole through the digital modeling, change the traditional single catheter modeling method for the core, more conducive to the realization of pipeline digital layout and simulation related business. Based on the modeling method in pipe parts basic elements of the establishment of basic elements contains the relationships and connections between topology information, and then taking the topological structure as a skeleton, association pipeline system the and so on Information Engineering, pipe parts information unified and comprehensive expression, and the engineering information retrieval. The digital expression model has the characteristics of generality and extensibility, and can be used as a unified data source for the business of pipeline layout, optimization, assembly and disassembly simulation.

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