Research and Application of Top-down Design Method for High Precision Metering Pump

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Abstract

This paper aimed to developing a high precision metering pump structure so that to solve the problem of traditional reciprocating metering pump. The method of concurrent design system engineering is used to design the metering pump from top to bottom. The module of UG/WAVE product design is called to realize the modeling technology of related parts and to ensure the interrelation of different parts in the same assembly. In order to realize the automatic optimization of assembly relationship between related parts.

Keywords

Metering pump, top-down,system engineering.

1. Introduction

Metering pump is a kind of special volumetric pump which can satisfy all kinds of strict process requirements. The flow rate can be adjusted steplessly in the range of 0-100%.Widely used in petroleum, chemical, water treatment, food, pharmaceutical, environmental protection, medical devices and other industries of fluid quantitative and proportional addition, metering pump is the heart and engine of the process industry .The metering pump can be used to measure the conveying medium at the same time in order to achieve the purpose of transportation and adjustment, thus refining the technological process of production and processing. The structure of metering pump includes three parts: power drive device, hydraulic end and power end.At present, the common structure of metering pump power end mostly uses crank and connecting rod mechanism to realize reciprocating movement, which mainly drives the connecting rod and piston movement through the crank rotation, thus drives the metering device to work, the driving end temperature is too high, vibration and noise, to some extent, affect the metering accuracy of the metering pump.In addition, due to the limitation of principle error, transmission system error, structural design and matching between the performance curve of measuring device and the characteristic curve of pipeline system, it is difficult to realize real-time flow control, and the measurement accuracy is low. We can not reach the best operating point of the pipeline system and achieve real-time monitoring, real-time adjustment etc. In this article, the structure of the general metering pump is improved with the aim of improving the measuring accuracy, and the digitized design of the metering pump is completed with the top-down strategy[1-5].

2. Theoretical Analysis and Key Parameter Design of Metering pump

2.1 Structure and performance index of metering pump

In view of the problems of crank and connecting rod mechanism commonly used in metering pump, this structure is cancelled. The energy of the prime mover is transferred directly to the hydraulic end by meshing the wire rod with the nut, as shown in fig.1. The structure consists of the hydraulic end and the power end, the hydraulic end is a single cylinder dual action pump, which completes the continuous suction and discharge of the liquid, and the power end is composed of wire rod nut and step motor, which are used to transfer the energy of the prime mover to the hydraulic end. The expected performance parameters for completion are shown in Table 1.

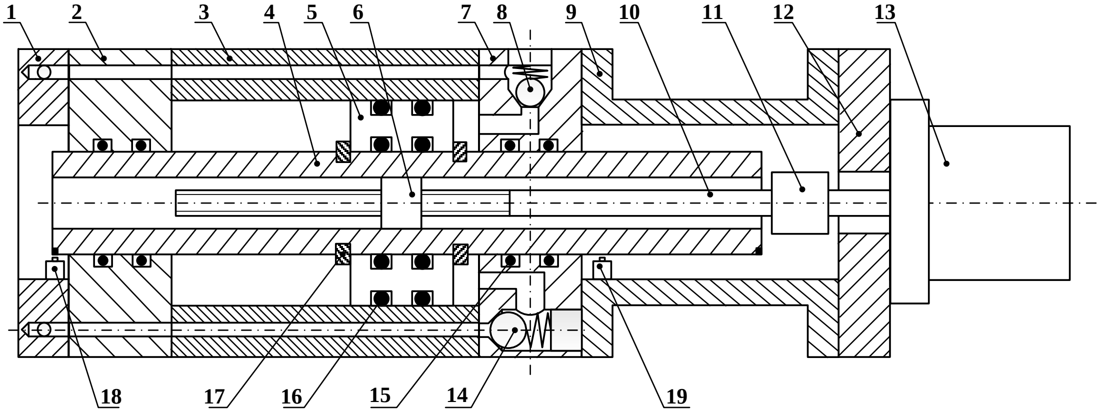

Fig.1 Structure diagram of metering pump

1 Liquid plate,2 Left end cover,3 Cylinder,4 Piston rod,5 Piston,6 Nut,7 Right end cover,8 Right outlet one-way valve,9 Connecting plate,10 Lead screw,11 Clutch,12 Connecting plate,13 Stepper motor,14 Right liquid one-way valve,15 End cover seal,16 Piston seal,17 Spring ring,18 Left position induction switch,19 Right position induction switch

Tab1 Main performance parameters of metering pump

Numble	Index content	Index parameter
1	medium	Corrosive or non-corrosive liquid
2	Liquid viscosity	0.5CP≤viscosity at 20℃≤40CP
3	Flow rate	0-5L/min
4	Medium maximum temperature	60℃
5	Maximum pressure at the output end	0-2MPa
6	work environment	Indoor, room temperature, normal pressure

2.2 Theoretical Analysis of Metering pump and determination of parameters of key parts

Metering pump belongs to one kind of piston pump, its working principle is: when the actuator is driven, the plunger moves back and forth in the cavity. The volume of the closed cavity composed of plunger and cavity is changed to complete the process of suction and drainage. The efficiency of piston pump is high, its volume efficiency is generally about 95%, the total efficiency is above 90%.

2.2.1 Flow rate and Precision Design of Metering pump

The theoretical flow Q of metering pump mainly depends on the structural parameters of reciprocating pump, calculated by formula (1)

$$Q = \frac{ASn}{60} KZ\tau K_V = \frac{D^3 \psi n}{240} \pi KZ\tau K_V \qquad (1)$$

Where:

D —diameter of piston

K_V—volumetric coefficient

V_m—average speed of piston

Ψ—Ration of stroke to diameter of piston

The accuracy of metering pump is to measure the flow rate of the same flow indication value several times independently under the rated external condition, and the degree of repetition of each measurement value, that is, the discrete degree of each measurement value. Numerically, it can be expressed by limit relative error. The smaller the value is, the better the degree of repetition is, the smaller the degree of dispersion is, and the higher the measurement accuracy is. The formula of accuracy E of metering pump can be calculated by formula (2).

$$E = \pm t_{\alpha} \cdot \frac{\sqrt{\sum_{i=1}^{n} \frac{(Q_i - Q)^2}{(n-1)}}}{Q} \times 100\% \quad (2)$$

Where:

Q_i—Flow value measured at the “*i*” time(L/min)

Q—The mean value of the flow value measured for n times(L/min)

t_{α}—coefficient

n—Measuring coefficient, normally is ten

2.2.2 Structure and key parameters of One-way Valve

The inlet and outlet valves in metering pumps are one-way valves, and the time of opening and closing directly affects the real time of measurement accuracy. According to the main performance indexes, the flow velocity of liquid outlet media is 1 m / s, and calculated by the relation (3) between flow rate and area .

$$Q = \upsilon \cdot A_0 \quad (3)$$

Where:

υ —Medium velocity,

A_o—Outlet sectional area.

Can be calculated according to the performance index

$$A_0 = 8.3 \times 10^{-6} m^2, R = 5.15mm, d = 10.3mm$$

2.3 Page Numbers.

The average speed of piston. If the average speed is too high, the wear of the friction pair will be accelerated, at the same time the leakage will increase and the flow rate will decrease, and the life of the easily damaged parts will be reduced, which will also have a great influence on the working reliability of the pump.At the same time, it will increase the inertial water head in the suction tube, and the suction will become bad. In terms of Fomula (1), the greater the average speed of the piston is. When the effective power of the metering pump increases, the piston resistance increases. In order to reduce the piston resistance effectively, it is necessary to reduce the piston diameter, but it will increase the piston stroke S or the piston reciprocating times n. The average speed of the metering pump is 0.025 to 0.3 m / s, and the average piston speed is 0.1 m / s according to the demand.

Determining piston stroke S.After the determination of the average speed of the piston, the diameter D of the piston can also be determined, but when designing and calculating the main parameters of the reciprocating pump, it is necessary to determine the stroke S of the piston or the reciprocating number n of the metering pump. When the flow rate of the metering pump is fixed, the piston stroke volume can be reduced and the piston diameter can be reduced by increasing the reciprocating number n. In this way, not only the radial dimension of the hydraulic end can be reduced, but also the piston force can be reduced. The load on the transmission end is reduced, thereby reducing the structural size of the transmission end.

Determining the number of reciprocations n. When the number of times of reciprocation is increased, the wear of the corresponding parts will increase, especially the suction valve of the pump and the discharge valve with the number of times of reciprocation. When the number of times of reciprocation increases, the inertial force also increases, which makes the impact produce and the valve closure lag seriously. The service life of the valve is shortened. At the same time, the pump volume coefficient and the flow rate are reduced. N value ranging from 10 to 180 times· $\min^{-1}$ of plunger type metering pump is suggested. 20 times· $\min^{-1}$.

Ratio of length to diameter of piston Ψ. To a certain extent, Ψ reflects the relationship between total length and width. If the ratio of length to diameter is larger or smaller, the total size and mass of reciprocating pump will be increased. The reasonable ratio of length to diameter can make the structure dimension more harmonious and obtain the optimum value in length, width and high comprehensive size. When the average speed of piston is selected, the stroke S will decrease and the ratio of length to diameter will be smaller when the reciprocating times N are increased. The range of ψ is 1.0~3.5. The transmission end of metering pump is mostly regulating mechanism, according to the characteristics of different mechanism, the value vary between $\psi = 0.1 \sim 10$.

2.4 The Design of Piston Assembly

The selection of piston rod diameter d of double acting reciprocating pump is related to the extrusion coefficient τ. The smaller the extrusion coefficientτis, the more obvious the double action effect is, and the more uniform the flow is, the bigger the extrusion coefficient τ is, the worse the double action effect is.

Calculation of piston diameter:

$$D = \sqrt{\frac{8Q_r}{v_m \pi Z K \tau K_v}} = 125mm$$

piston stroke:

$$S = \frac{30 v_m}{n} = 150mm$$

Piston width:

$$B = 0.6D = 75mm$$

Path to diameter ratio:

$$\psi = \frac{S}{D} = 1.2$$

Piston rod diameter:

$$\mathrm{d} = \mathrm{D}\sqrt{\frac{\psi - 1}{\psi}} = 63mm$$

2.5 Design of suction pipe and exhaust pipe diameter

The diameter of the suction and discharge lines is determined mainly by the average velocity v_1 、 v_2 of the fluid medium in the pipeline. If the average velocity is too large, the hydraulic loss is large, the power consumption is also large, the suction performance of the pump is poor, and the average velocity is low, which makes the structural size of the pipe and hydraulic end larger. Formula (4) is for the calculation of diameter.

$$d_1 = \sqrt{\frac{4Q_r}{\pi v_1}} \ \& \ d_2 = \sqrt{\frac{4Q_r}{\pi v_2}} \tag{4}$$

2.6 Cylinder routine design

2.6.1 Strength design

$$\delta_0 \geq \frac{p_{max}D}{2\sigma_p} \;\&\; \delta_0 \geq \frac{p_{max}D}{2.3\sigma_p - 3p_{max}} \tag{5}$$

Where:

δ_0—Minimum required value for cylinder material strength

p_{max}—Maximum working pressure in cylinder

σ_p—Allowable stress of cylinder material

n—Safety coefficient,Usually is 5.

2.6.2 Cylinder bottom thickness

When the bottom of the cylinder is flat, its thickness can be calculated according to the formula of disk strength constrained by the periphery.

$$\delta_1 \geq 0.433D_2\sqrt{\frac{p}{\delta_p}} \tag{6}$$

Where:

δ—Cylinder bottom thickness

D_2—Outer diameter of Calculation thickness

2.7 Transmission Mechanism and parameters of Wire Rod Nut

The piston is connected to the piston rod through the thread rod nut mechanism, that is, the motion of the thread rod nut should be synchronized with the piston, and the ball screw of the series DCT series with a large lead is temporarily selected, the type is 2010-2.5, the nominal diameter of the lead screw is d_0=20mm, the nominal lead range is P_h=10mm, and the nominal dynamic load is C_a=11.494KN. Rated static load C_oa=23.545KN. The ball screw rod should be fixed to the piston rod, and the total stroke of the piston is short, so the ball screw pair is fixed at one end and free at other end.

3. Top-down Development Design Based on UG/WAVE

The development and design of new products is a complex process, which is the process of mapping product market requirements into product functional requirements and product functional requirements into geometric structures. In order to realize this process, first of all, we should analyze the functional requirements of the product, design the preliminary scheme and the sketch of the assembly structure, obtain the function concept model of the product, and transmit the design information through the assembly body model. Then each design team under the unified control of the assembly model completes the detailed design of each sub-assembly namely parts in parallel. Finally, we should analyse the design product and return to modify the unsatisfactory, until we obtain the functional requirements of the product . In the above implementation process, the key lies in: firstly, the result of product analysis is reflected in the overall control structure, the main control parameters of the product, the shape and position information of the main components should be included in the control structure[7-8]. The second is to select useful information from the total control structure to control the subsystem in order to realize the data transmission from top to bottom and the coordination and unification among the subsystems. In addition, after detailed design and completion of product assembly, all aspects of the product are inspected and modified and updated at the overall control structure level, although the control structure of the product and the assembly model of the product are separate documents. But they relate to each other, so changes to the master control structure are automatically reflected in the product model.

3.1 Establishment of Top level structure and Subsystem Division

The main structural parameters obtained from the design of the metering pump can determine the relative spatial position of the main components of the hydraulic end of the metering pump and the assembly constraints between them. After simplification, some reference planes representing each component can be used. The datum axis is used to represent the position of each component in space, which is the basis of the detailed design in the future, for example, the axis parts are represented only by the center of rotation, and so on, which is obtained by adding the parameter relation and constraints. In this way, a number of benchmark features form the prototype of the global conceptual model of the product, thus expressing the overall design scheme of the product. The shape of assembly model can be changed and the design scheme can be improved by modifying the position of each datum and the relationship between them.

The calculated parameters are input into the "expression" function provided by UG to facilitate the later parameterized design.In order to reflect the function of the user-defined control structure, the main structural parameters of the metering pump are not taken as the known driving parameters directly, but as the main driving sources such as flow rate, pressure, material, etc. Then the relationship between the product size and the relationship is established to realize the drive of the product.

The dimensions of the metering pump are highly correlated, and the accuracy range of the assembly must be taken into account. The expressions to be used are all listed in the control structure and associated with the sub-components. And export files in "exp" format to facilitate the call and editing of other assemblies. The contents are as follows:

```
[mm]DO_barrel=Di_barrel+2*t_barrel                    //Cylinder external diameter
[mm]D_ball=d_passageway*1.2                           // Ball diameter
[mm]Di_barrel=do_piston+tolerance_piston_barrel       //Cylinder internal diameter
F=150                                                 //Material allowable stress
L_barrel=s_piston+t_piston                            //Cylinder length
[mm]L_rod=(L_barrel-t_piston)*2+t_cover*3             // Piston rod length
[mm]L_screw=L_rod/1.5                                 // Wire rod length
P=2                                                   //Maximum pressure
[mm]Ph=10                                             //Wire rod lead
Q=5                                                   //Maximum flow rate
V=1                                                   //Velocity of flow
[mm]d_hole_rod=d_piston_rod/2                         //Piston rod inner diameter
d_passageway=2*1000*sqrt(Q*0.001/60/pi())             //Flow path diameter
[mm]d_piston_rod=do_piston/2                          //Piston rod diameter
[mm]d_screw1=db_screw-d_screw_ball                    //Wire rod thread diameter
[mm]d_screw_ball=0.15*d_hole_rod                      //Ball diameter
[mm]db_screw=d_hole_rod/2                             //Wire rod diameter
[mm]di_cover=d_piston_rod+tolerance_cover_rod         //End blank inner diameter
[mm]di_piston=d_piston_rod+tolerance_piston_rod       //Piston inner diameter
do_piston=1000*sqrt((8*Q*0.001*60)/(3600*0.025*pi()*1.75*0.95))
//Piston outer diameter
........
[mm]p58=p33+d_passageway/2-(p33-d_passageway/2)
```

[mm]s_piston=2*do_piston //Piston stroke

[mm]t_barrel=2*(P*do_piston/(F*1-P*10)+5)+d_passageway //Cylinder body thickness

[mm]t_cover=t_piston //End cover thickness

[mm]t_liquld=t_barrel //Liquid plate thickness

[mm]t_piston=do_piston/2 //Piston thickness

[mm]tolerance_cover_rod=if((d_piston_rod>30)&&(d_piston_rod<50))(0.059)else(tolerance_cover_rod_a) //Tolerance between piston rod and end cover)

[mm]tolerance_cover_rod_a=if((d_piston_rod>50)&&(d_piston_rod<80))(0.069)else(tolerance_cover_rod_b) //1

[mm]tolerance_cover_rod_b=if((d_piston_rod>80)&&(d_piston_rod<120))(0.081)else(tolerance_cover_rod_c) // 1

[mm]tolerance_cover_rod_c=0.093 //1

[mm]tolerance_piston_barrel=if((50<do_piston)&&(do_piston<80))(0.069)else(tolerance_piston_barrel_a) //Piston and cylinder tolerance)

[mm]tolerance_piston_barrel_a=if((80<do_piston)&&(do_piston<120))(0.081)else(tolerance_piston_barrel_b) //2

[mm]tolerance_piston_barrel_b=if((120<do_piston)&&(do_piston<180))(0.093)else(tolerance_piston_barrel_c) // 2

[mm]tolerance_piston_barrel_c=0.105 //2

[mm]tolerance_piston_rod=if((d_piston_rod<50)&&(d_piston_rod>30))(0.041)else(tolerance_piston_rod_a) //Tolerance between piston and piston rod)

tolerance_piston_rod_a=if((d_piston_rod>50)&&(d_piston_rod<80))(0.049)else(tolerance_piston_rod_b) //3

tolerance_piston_rod_b=if((d_piston_rod<120)&&(d_piston_rod>80))(0.057)else(tolerance_piston_rod_c) //3

tolerance_piston_rod_c=0.065 //3

v_piston=0.025 //Piston speed

The center of the cylinder block of the metering pump is taken as the datum of the whole model. On this basis, the datum level and reference shaft are arranged to determine the position of each component, and the top-level structure of the model is established. Here we use the above formula to determine the relative position between the planes and the axes. As shown in fig. 2.

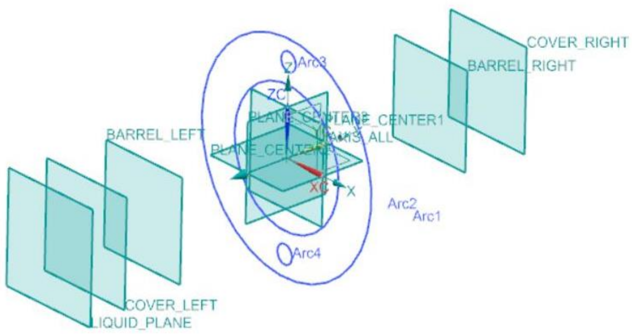

Fig.2 Establishment of a top-level structure

3.2 Establishment of metering pump subsystem

During the subsystem design phase, its control structure, including benchmark features and sketches, is also created, and it should be used as a display unit when designing different subsystems. The subsystem is designed separately as a working part in the new interface. The interface should contain only the control structure linked from WAVE and the control structure needed by the newly established subsystem. In this way, each subsystem can be separated at design time, and the interface is only related to the subsystem, which makes the design interface simple. And through the "copy geometry to components" command under UG/WAVE to establish the remaining top-level control structure Department.

The design of thread rod nut drive mechanism is taken as an example to illustrate the creation process.

The hydraulic end transmission mechanism of metering pump is composed of thread rod nut and has been selected as 2010-2.5 large lead DCT series ball screw. In order to meet the requirement of metering pump, its lead should be kept P_h=10mmunchanged. With different working conditions, the metering pump has different dimensions and specifications. In this case, the working length and diameter of the wire rod are changed only under the condition of keeping the lead of the wire rod unchanged.

step1:Create a subsystem called "cs-screw" in the top-level control structure and link the created modeling benchmarks and main sketches to the subsystem.

step2:Create the model by establishing design benchmarks and sketches in the "cs-screw" subsystem and creating the starting part, the secondary subsystem "cs-screw-start", and linking all features to the starting widget via WAVE, as shown in fig. 3.

step3:After the creation of the screw nut structure, the model is mapped layer by layer to the top layer control structure, and is controlled by the parameters of the top layer control structure. The model tree is updated in fig.4.

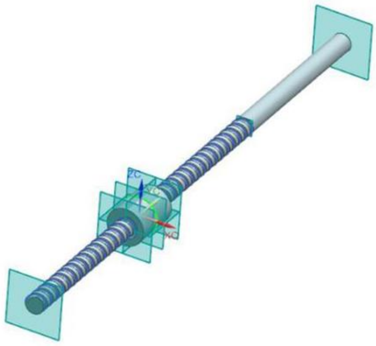

Fig.3 Screw nut mechanism subsystem

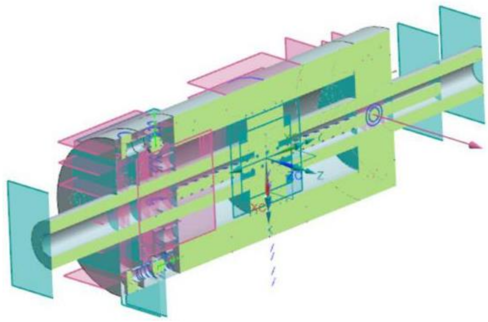

Fig.4 Updated top-level control structure model

3.3 Create a link widget

The top-down parametric design of the whole assembly model of metering pump is completed. In order to realize the modular design, we need to create link parts to extract the required elements and features. In this paper, the link parts can be regarded as the last subsystem, that is, the product structure system containing only the required features. What is actually used for the final assembly is the linked part system.

The link widget is obtained by "creating a link widget" in UG/WAVE mode, and the link widget comes directly from the required set of widget references we set up in the starting widget, so a link widget is a widget in which the detail geometry exists. So any changes that occur in the starter will be passed to the link widget. Set the reference set for the starting part in the subsystem created under the top control structure and add it to the link widget. Because the link component created is the final assembly and belongs to the product level, the "pa" prefix is used as the product code to create a chain for each starting part Connecting parts.

4. Conclusion

The top-down parameterized modeling method based on UG/WAVE synthesizes the idea of system engineering and makes the whole project establishment especially in the face of large complex model the process and train of thought can be moreclear. The complex and large whole system is modularized and layered, so that the whole model is driven by the expression parameters in the control structure and can be managed and feedback separately in the subsystem under the management of the top-level control structure. It supports concurrent engineering well.

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