Simulation and analysis of the dynamics of 2K-V reducer based on RecurDyn

ABSTRACT: The 2K-V reducer is characterized by large transmission ratio, large load carrying capacity, high transmission accuracy and smooth transmission, and it is of great significance to study its dynamic characteristics. Taking a certain type of 2K-V reducer as the research object, a parametric three-dimensional model was established in SolidWorks, and the dynamics model of 2K-V reducer was established by RecurDyn. After simulation and analysis, the key zero part transmission speed curve and transmission error are obtained. The research method has certain guiding significance for the precision design of 2K-V reducer.
Keywords: 2K-V, dynamics simulation, transmission error.

INTRODUCTION

2K-V reducer is a core component mainly used in industrial robot joints, which mainly has the advantages of compact structure, large transmission ratio, high transmission precision, long service life, low noise and so on. In recent years it is also widely used in aerospace, automation equipment, CNC machine tools and other fields. For the design of RV reducer, it is of great significance to study its complex dynamic characteristics. Jia Jishuai et al. sorted out the research status of RV reducer at home and abroad, analyzed the research results of RV reducer transmission error, backlash, torsional stiffness, wear life and processing technology, and explored the problems that there is still room for progress in the domestic reducer compared with foreign countries. Xiang Zhaoshen et al. took RV-80E reducer as the research object, used UG software to carry out motion simulation, and came up with shaft bearing force and crank shaft angle, cycloidal gear force change curve, which provided the basis for parts optimization. Wu Xinhui et al. based on the dynamics analysis software ADAMS to establish a virtual prototype established by the robot for simulation and analysis, to obtain the transmission error curve of the robot with the RV reducer, for the robot with the RV reducer virtual prototype simulation to lay the foundation for the study. Xu Lixin et al. carried out the dynamic transmission error analysis and test of RV reducer under load conditions, and explored how the transmission error changes under the increase of load torque, etc.[8] In this paper, a simplified three-dimensional transmission error curve is used. In this paper, a simplified three-dimensional model is used to establish a dynamic model of the 2K-V110E reducer, and the dynamic response curves of key components are obtained. The research method has certain guiding significance for the precision design of RV reducer.

1. 2K-V REDUCER TRANSMISSION PRINCIPLE

The 2K-V reducer is a closed differential gear train, which consists of an input gear, a planet gear and a planet carrier. The enclosed part is a cycloid-needlewheel planetary drive mechanism consisting of a crankshaft, cycloidal gear, pin wheel and needle gear housing[10]. When the spur gear is shifted, the input shaft is turned opposite to the spur gear. When the differential gear changes speed, the crankshaft rotates, the eccentric cam drives the oscillating wheel to swing, the crankshaft eccentric shaft is symmetrically arranged, and the two oscillating wheels swing synchronously in opposite directions. The two oscillating wheels oscillate in the same process, with a phase difference of 180°. The oscillating wheels oscillate and press the pinion pin to produce relative rotation with the output flange[3].The 2K-V reducer transmission sketch is shown in Figure 1.

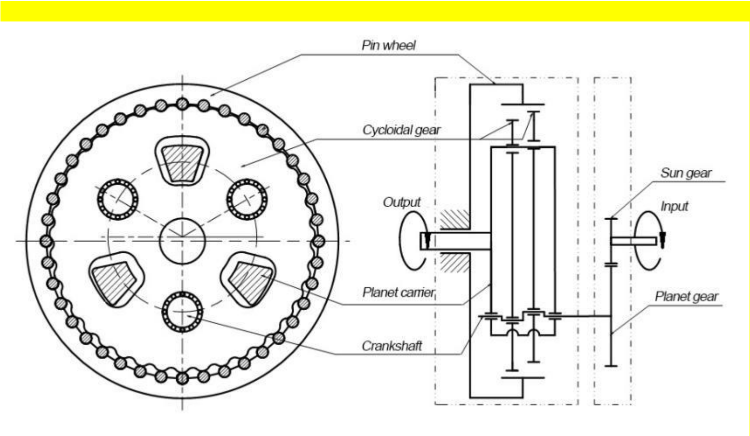

Fig. 1. 2K-V reducer transmission principle sketch

2. 3D MODELING OF 2K-V110E REDUCER

According to the 2K-V110E engineering drawings were modeled by SoildWorks software,The 3D model is shown in Figure 2.

Fig. 2. Cutaway view of 2K-V reducer

After the establishment of 2K-V110E three-dimensional model needs to be assembled on its parts, this paper takes the cycloid needlewheel as the reference for assembly. After assembly, it is necessary to carry out the interference test, mainly to check the fit between the parts of the assembly and whether the modeling of the parts is correct, after the inspection of the reducer does not have interference problems.

3. 2K-V110E REDUCER DYNAMICS SIMULATION MODELING

3.1 Material parameter setting and constraint type setting

To import the 2K-V110E 3D model into RecurDyn, you need to save the 3D model as (*.x_t) format via SoildWorks.[1] Then set the model name, unit system and gravity direction, where the unit system in this paper is MMKS (millimeter, kilogram, newton, second).After importing the geometry model, the parts are edited independently and the material properties are added to the model. The material parameters are known from the 2K-V reducer design manual and the reducer specification. The settings are made according to Table 1.

Table 1. Material Properties of 2K-V110E Reducer Components

Name	materials	Young's modulus（N/mm^2）	Poisson's ratio（μ）
Input shaft	20CrMo	2.11E+05	0.292
Planet gear	20CrMo	2.11E+05	0.292
Input flange	QT450-10	1.73E+05	0.3
Needle gear housing	QT450-10	1.73E+05	0.3
Output flange	QT450-10	1.73E+05	0.3
Crank shaft	20CrMnMo	2.07E+05	0.254
Swivel arm bearing	GCr15	2.19E+05	0.3
Cycloidal gear	20CrMo	2.11E+05	0.292
Needle tooth pin	GCr15	2.19E+05	0.3

By setting the constraint types for the 2K-V110E reducer, the simulation achieves the effect of actual operation in a realistic environment. The setting of constraint types is essentially the setting of the motion relationship between the parts of the reducer, and once the constraint relationship between the parts is determined, the degrees of freedom of the mechanism are also determined. Theoretically, the more accurate the constraints between parts are set, the more accurate the motion relationship will be, but this will cause a lot of wasted arithmetic power[7].In order to avoid the emergence of the above problems, first of all, the 2K-V110E type reducer mechanism motion transfer fully understand, only set up the motion vice that conforms to its output logic, to maximize the realization of simulation of real operation. The component constraints are shown in Table 2 below.

Table 2. 2K-V110E reducer parts constraint type

Binding subject 1	Binding subject 2	Type of constraint
input shaft	ground	rotating disk
spur gear	input shaft	gear pair

Input flange	Output flange	stationary sub
Needle gear housing	ground	stationary sub
Output flange	Needle gear housing	plane sub
Crank shaft	spur gear	stationary sub
Swivel arm bearing	Crank shaft	rotating disk
Cycloidal gear	Swivel arm bearing	rotating disk
Needle tooth pin	ground	stationary sub

3.2 Dynamic model drive and load settings

By checking the datasheet of the 2K-V110E reducer, it is known that its transmission ratio is 111, the input shaft speed is 9990° /s under the rated working condition, and the rated load is 1,078 Nm. Based on the above basic operating parameters under the rated working condition, the additions and parameterizations of the drive and the load are set in RecurDyn[4].

First, as shown in Figure. 3, add "Rotary Drive" to the preset input axis rotary sub, select the Use Edit Function STEP(time,0,0,0.2,9990d) defined in "Function Drive", and then click "Apply" to apply it. In this way, the input axis accelerates smoothly to the rated speed within 0.2s under rated operating conditions, and the input speed of the input axis runs smoothly at 9990° /s (1665r/min) after 0.2s.

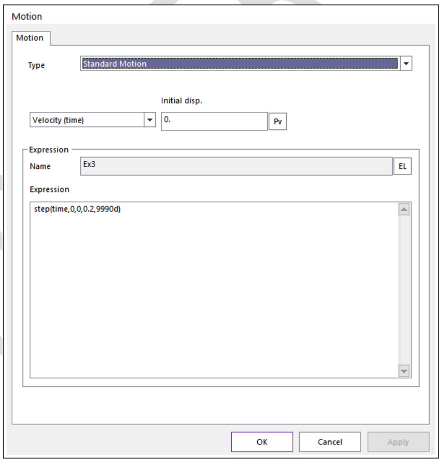

Fig. 3. Adding a driver

Finally, as shown in Figure. 4, a fixed moment is applied to the output flange rotating sub as a load to realize the output simulation at rated operating conditions, and the editing function is STEP(time,0.2,0,0.5,1.078e+6), which starts applying the load smoothly from the beginning of the virtual machine after 0.2s, and finishes applying the load at 0.5s at the same time as the completion of the input acceleration, and subsequent loads will be maintained at 1078Nm without further change.

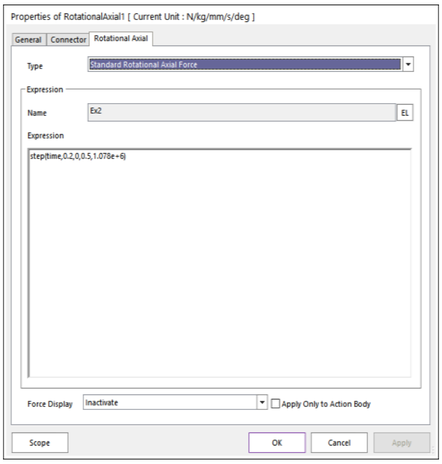

Fig. 4. Adding a load

4. SIMULATION ANALYSIS RESULTS

4.1 Verification of the simulation results of 2K-V110E reducer

In order to verify the correctness and reasonableness of the constraints and model motion added in the previous section, it is necessary to simulate the established model and analyze its motion form. According to the settings in the previous subsection, the input rotational speed of the input shaft is 174.34 rad/s, and the simulation time is set to 4.5s, because it takes 4s for the output of 2K-V110E gearhead to be one week, so it is simulated by the dynamics software and the simulation is terminated with the time set to 4.5s. The input shaft rotational speed is 174.34 rad/s, as shown in Figure 5. The rotational speed of the input shaft is 174.34 rad/s, as shown in Fig. 5. The rotational speed of the output flange fluctuates around 1.57 rad/s, as shown in Figure. 6. Therefore, it can be concluded that the dynamic simulation modeling is correct.

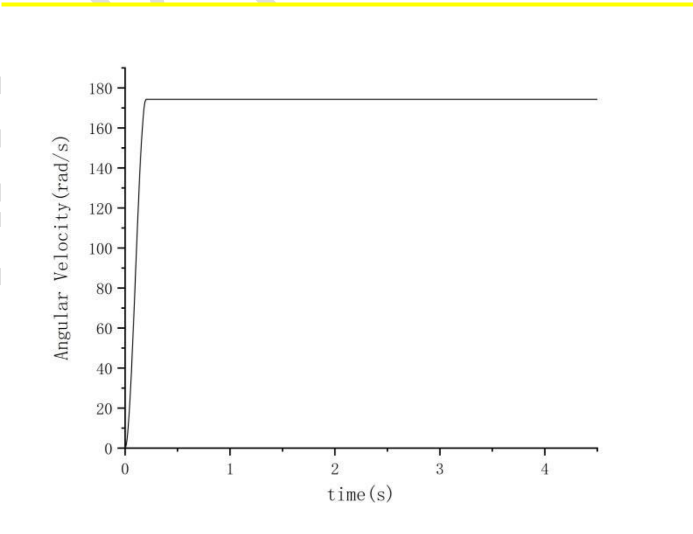

Fig. 5. Input Axis Angular Velocity

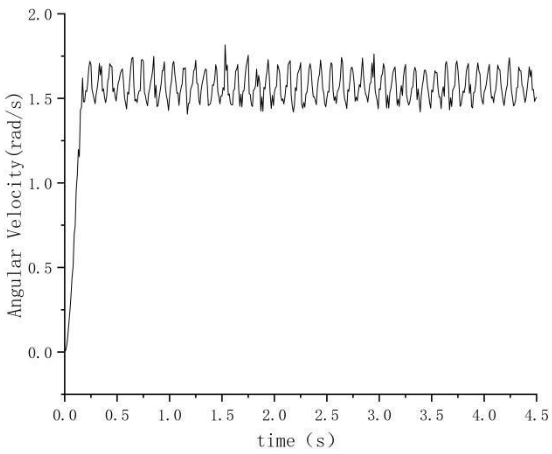

Fig. 6. Output Axis Angular Velocity

4.2 Dynamic response analysis of related components

Given the input shaft speed of 174.34 rad/s, rated load of 1078 N/m, and total reduction ratio of 111 under rated condition, the theoretical output speed is 1.57 rad/s. Because the crankshaft is fixedly connected with the planetary wheel, which rotates in the opposite direction of the input shaft, the direction of angular velocity of the crankshaft is also opposite to that of the input shaft[9]. Figure 7 shows the crankshaft angular velocity change, in the theoretical angular velocity -61.26rad/s fluctuations up and down near the maximum angular velocity of -65.045rad/s, the minimum angular velocity of -56.62rad/s. Figure 8 shows the cycloidal gear angular velocity change in 0.2 seconds after the cycloidal gear rotation tends to stabilize, 0.2s angular velocity is too large because of the reducer driven by the load driven by the reducer in the start-up resistance is large. The figure shows that the amplitude of the angular velocity of the cycloidal gear fluctuates around the theoretical value of 1.57rad/s, the maximum angular velocity of 4.44rad/s, the minimum angular velocity of 0.601rad/s. This situation occurs due to the engagement is to use geo surface contact, the impact between the rigid body generated. Figure 9 shows the output flange angular velocity, amplitude fluctuates up and down near the theoretical value of 1.57rad/s, the maximum angular velocity is 2.674rad/s, the minimum angular velocity is 0.398rad/s. The reason for this is that the wheel teeth are meshed with the impact of the contact and other factors, which is in line with expectations[5].

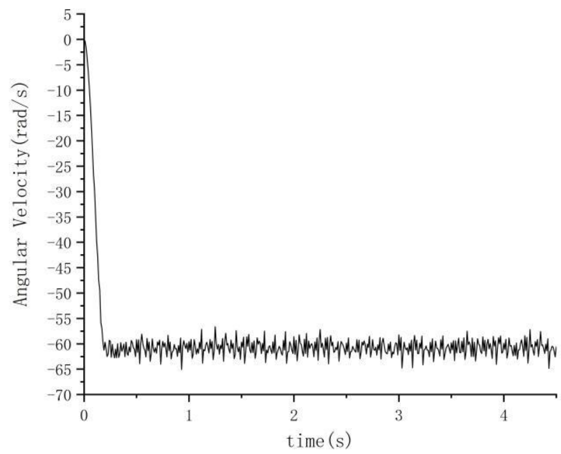

Fig. 7. Crankshaft angular velocity

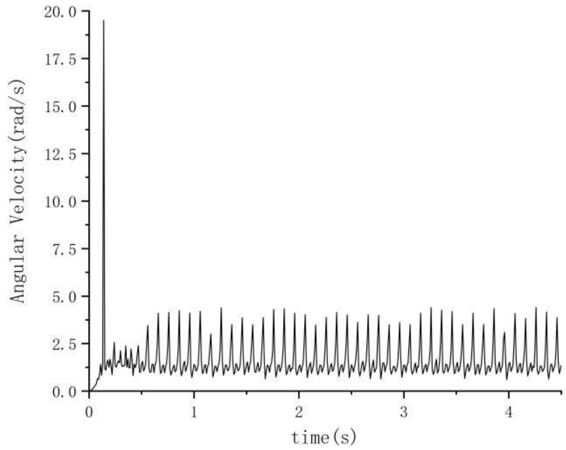

Fig. 8. angular velocity of the cycloid

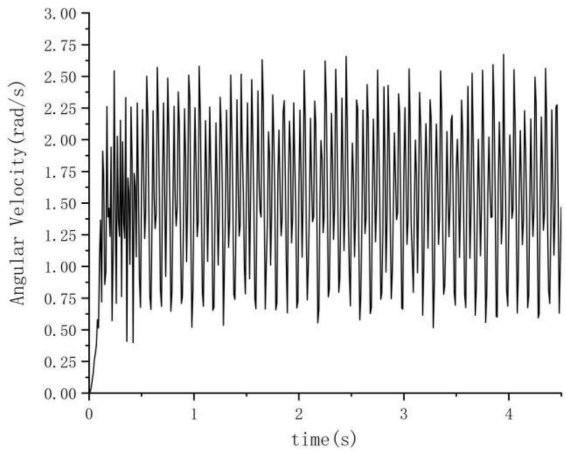

Fig. 9. Output flange angular velocity

4.3 Transmission Error Analysis

Transmission error as one of the important indicators of the size of the 2K-V reducer transmission accuracy, which represents the meaning of the input shaft unidirectional rotation of any moment of the output shaft at the same moment the difference between the actual value of the angle and the theoretical value[2]. In this paper, the transmission error is calculated by the following formula in the case of motion where the Needle gear housing is fixed, the input shaft is input and the planetary carrier is output[11]:

$$\theta_{er} = \frac{\theta_{in}}{i} - \theta_{out}$$

Where, θ_{er} is the transmission error, $\frac{\theta_{in}}{i}$ is the theoretical turning angle of the output end, and θ_{out} is the actual turning angle of the output end.

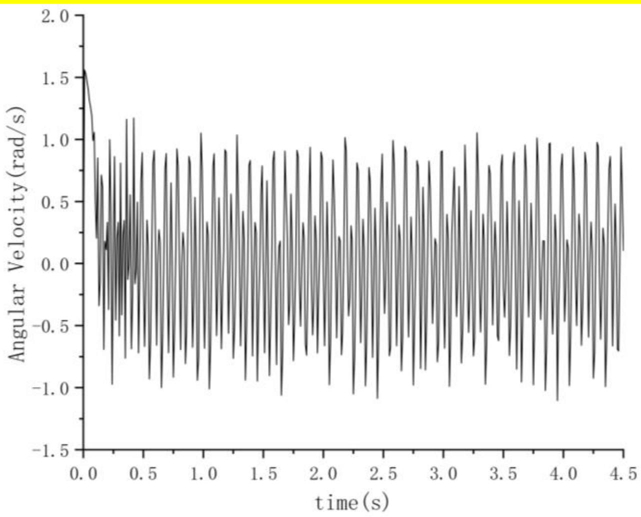

Fig. 10. Transmission error at rated load

The discrete point of angular velocity change obtained by post-processing can be converted to angular displacement through relevant processing, and then the transmission error change from 0. 2~4.5s in the stabilization stage is obtained, as shown in Figure. 10[6]. That is, the relative error under the rated condition is about 69.13%. In this paper, we consider the parts are rigid body without considering the flexible body, so it is within the range of error under rated condition. The relative error is calculated as follows[12]:

$$\theta = (i - i') / i$$

Where i is the theoretical calculated transmission ratio and i' is the simulation calculated transmission ratio, $i = \theta_{in}/\theta_{out}$.

CONCLUSION

(1) A 3D model of 2K-V110E was established using SolidWorks, and the correctness of the 3D establishment was verified by assembly interference test. The dynamic simulation model of the 2K-V reducer was imported into RecurDyn software, and the dynamic simulation model of the 2K-V reducer was established by adding material properties and constraints, which provided the conditions for the further study of predicting the life of key components based on rigid-flexible coupling.

(2) The angular velocity of the input shaft is 174.34rad/s and the angular velocity of the output shaft is 1.57rad/s, which is basically consistent with the theoretical angular velocity of the input shaft of 174.35rad/s and the theoretical angular velocity of the output shaft of 1.57rad/s, which verifies the correctness of the dynamic simulation model. The dynamic response curve of the angular velocity of key components under rated speed and rated load conditions was obtained. By analyzing the dynamic response curve of 2K-V110E reducer, it can be seen that the transmission error is about 69.13%, which is in line with the error range under real working conditions. It provides a reference for further research on the effect of adding the elastic deformation of key parts such as the cycloid wheel on the transmission error.

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