Research on motion characteristics and application of multi degree of freedom mechanism based on R-W method

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Abstract: This paper has proposed a basic modeling in studying the driving system of the shoe-cover machine, built the multi rigid-body dynamical model and motion equations of this system, and proved the effectiveness and feasibility of R-W method to the special machine. Through ADAMS software, the dynamic simulation of this established driving system has been analyzed, and the outcomes are basically consistent with that of its mathematical model. Through numerically analyzing and simulation analysis, this paper can provide reliably analytic references for the design of structure of a new type special non-woven fabric shoe cover machine and the optimized design of key driving components and parts.

Introduction

Multi rigid body system dynamics was derived from the 60-70's in twentieth Century. It combines the classical rigid body mechanics and computer technology, and analyzes the kinematics and dynamics of complex systems such as aircraft and robots. Robertson and Witten Fort present a general analysis method of multi rigid body system (R-W method) [1]by using the principle of virtual work. This method creatively uses the concept of graph theory and mathematical tool to describe the structure of the multi rigid body system, and take the relative displacement between the adjacent rigid body as the generalized coordinates, derive general form dynamics equations for arbitrary multi rigid body system[1]. This paper uses R-W method to calculate the mechanism movement of an automatic non-woven shoe cover machine drive system, establishes mathematical model, uses SolidWorks to establish three-dimensional model of automatic shoe cover machine drive system, combines ADAMS to carry out the dynamic simulation analysis synthetically, to obtain the optimal data.

Establishment of multi rigid body model of shoe cover machine

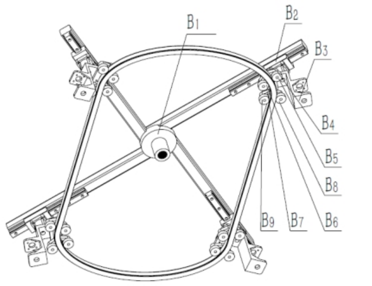
Description of professional shoe cover machine system

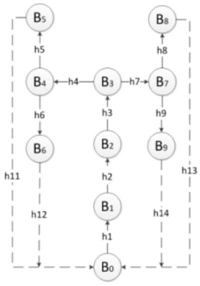
Structure of automatic non-woven shoe cover machine is mainly composed of feeding device, folding device, driving device, discharging device, rack and overlock machine etc, as shown in figure 1. On the raw materials, the use of non-woven fabric has solved the problem of plastic shoe covers and white pollution; technologically, the use of automatic suture has improved the productivity and reduced the labor intensity. Center driving device is the focus of research on drive system of automatic shoe cover machine and an important part of the shoe cover machine. In the working process, the motor drives the rotation center around the elliptical orbit of circular motion, which complete process of non-woven materials to shoes product. The structure of drive system is shown in Fig 1.

Model establishment and motion equation

Automatic non-woven shoe cover machine drive system can be viewed as 9 models of rigid body interaction. According to Fig 1, the connection and relative motion of the structure of drive system determines topological structure of drive system. According to the concept of graph theory based on R-W method, B_0 indicates shoe machine frame; B_1 indicates rotating cross B_2 indicates the linear slider; B_3 indicates supporting frame; B_4, B_7 indicate wheel bracket;B_5,B_6,B_8,B_9 indicates Roller. A directed line segment that connects the adjacent rigid is represented as a hinge, denoted as $h_j(j=1,2\ldots,9)$. Among them h_2 is prismatic pair, the other hinge is revolute pair, hinge direction is defined as far away from the inner body. By using disciplined numbering method to set the direction, get the directed graph of shoe cover machine drive system (oriented system), as shown in Fig 2.

In order to make use of the kinematics equation of the tree system, non-tree system of shoe cover machine drive system is simplified as a tree system: remove the hinge of non-tree oriented system , such as h_{11}、h_{12}、h_{13} and h_{14}, get tree system diagram, is shown in Fig 3.





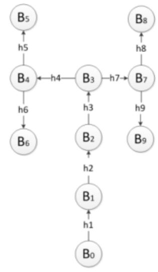


Fig. 1 the structure of drive system Fig. 2 oriented system Fig. 3 tree system diagram

According to the R-W method, the coordinate system of each rigid body is established. Assuming that coordinate system of the frame is (O_0,e_0), that the inner hinge of each body is h_j (j=1,2…,9) and h_2 is a Prismatic hinge, that $h_j(j = 4,5,6,7,8,9)$ are coincident with the center of mass and are rotation hinge of single degree of freedom. Then there are 9 degrees of freedom in the derived tree.

The correlation matrix S and path matrix T of the derived tree system are shown below.

$$S=\begin{bmatrix} -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & -1 & 1 & 0 & 0 & 1 & 0 & 0 \\ & & & -1 & 1 & 1 & 0 & 0 & 0 \\ & & & & -1 & 0 & 0 & 0 & 0 \\ & & & & & -1 & 0 & 0 & 0 \\ & & & & & & -1 & 1 & 1 \\ & & & & & & & -1 & 0 \\ & & & & & & & & -1 \end{bmatrix} \qquad T=\begin{bmatrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ & & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ & & & -1 & -1 & -1 & 0 & 0 & 0 \\ & & & & -1 & 0 & 0 & 0 & 0 \\ & & & & & -1 & 0 & 0 & 0 \\ & & & & & & -1 & -1 & -1 \\ & & & & & & & -1 & 0 \\ & & & & & & & & -1 \end{bmatrix}$$

Assuming the coordinates （O_i,e^i） (i=0,1) of the frame B_0 and rotating cross B_1 coincide, and $e_3^{(i)}$(i=1,2,…,9) is as vertical axis and equal. B_2's center mass O_2 is on the axis $e_2^{(2)}$, z_2 is as the slip distance of h_2 hinge, the distance of the inner hinge h_i pointing to the center of mass O_{ic} is ρ_i, the distance of the inner hinge h_i pointing to the external hinge h_{i+} is L_{ij}(j=1,2,3 is the direction of the axis of the coordinate system). Then the path vector is shown below.

$$d_{11} = r_1 e_3^{(1)} \tag{1}$$

$$d_{1i} = L_{11} e_3^{(1)} - (z_2 + L_{12}) e_2^{(2)} (i = 2,3,...9) \tag{2}$$

$$d_{2i} = -L_2 e_3^{(2)} (i = 3,4,...,9) \tag{3}$$

$$d_{33} = -r_{32} e_2^{(3)} - e_3^{(3)} \tag{4}$$

$$d_{3i} = 0.5 L_{41} e_1^{(3)} - L_{42} e_2^{(3)} - L_{43} e_3^{(3)} (i = 4,5,6) \tag{5}$$

$$d_{3i} = -0.5 L_{41} e_1^{(3)} - L_{42} e_2^{(3)} - L_{43} e_3^{(3)} (i = 7,8,9) \tag{6}$$

$$d_{45} = d_{78} = -0.5 L_{52} e_2^{(4)} - L_{53} e_3^{(4)} \tag{7}$$

$$d_{46} = d_{79} = 0.5 L_{52} e_2^{(4)} - L_{53} e_3^{(4)} \tag{8}$$

$$d_{ii} = 0 (i = 2,4,5,...9) \tag{9}$$

Path vector d_{ij} is vector of external hinge that starting from the inner hinge rigid body B_i, pointing to the centroid to the lateral rigid B_j.

$$D^T = \begin{bmatrix} d_{11} & & & & & & & & \\ d_{12} & 0 & & & & & & & \\ d_{13} & d_{23} & d_{33} & & & & & & \\ d_{14} & d_{24} & d_{34} & 0 & & & & & \\ d_{15} & d_{25} & d_{35} & d_{45} & 0 & & & & \\ d_{16} & d_{26} & d_{36} & d_{46} & 0 & 0 & & & \\ d_{17} & d_{27} & d_{37} & 0 & 0 & 0 & 0 & & \\ d_{18} & d_{28} & d_{38} & 0 & 0 & 0 & d_{78} & 0 & \\ d_{19} & d_{29} & d_{39} & 0 & 0 & 0 & d_{79} & 0 & 0 \end{bmatrix}$$

Matrix form expressions of centroid position vector of the rigid body on tree system[2] are as follows,

$$[r]=r_0[l]_n+[D]^T[l]_n \tag{10}$$

here:

$[r]$——vector array Consisting of B_i mass center position r_i

r_0——vector of Rigid B_1 centroid relative to B_0 centroid

$[l]_n$——$nx1$ column array that elements is 1

$[D]$——$nx1$ column array consisting path vector d_{ij}

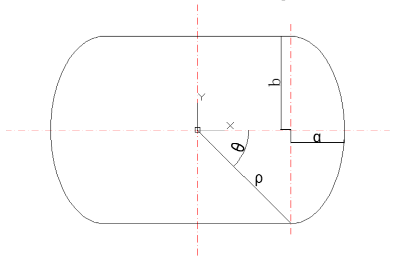
constraint equations

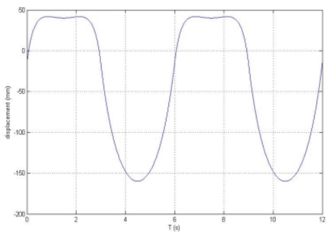
Shoe cover machine driving system is dominated by rotating cross rigid body in rotational motion[3]. In the process of motion, the roller has made a circular movement along the orbit. ρ is polar coordinate parameter equation that the orbit center is as the origin, α is as an elliptical long axis, and b is as a short axis of the ellipse. Simple chart of orbit is shown in Fig 4.

$$r=\frac{b\left(a\left(b^2\cos^2 q+a^2\sin^2 q-h^2b^2\sin^2 q\right)^{1/2}+bh\cos q\right)}{a^2\sin^2 q+b^2\cos^2 q}\left(-\frac{p}{4}\le q<\frac{p}{4}\right) \tag{11}$$

$$r=b\Big/\sin q\left(\frac{p}{4}\le q<\frac{3p}{4}\quad or\quad \frac{5p}{4}\le q<\frac{7p}{4}\right) \tag{12}$$

$$r=-\frac{b\left(a\left(b^2\cos^2 q+a^2\sin^2 q-h^2b^2\sin^2 q\right)^{1/2}-bh\cos q\right)}{a^2\sin^2 q+b^2\cos^2 q}\left(-\frac{3p}{4}\le q<\frac{5p}{4}\right) \tag{13}$$





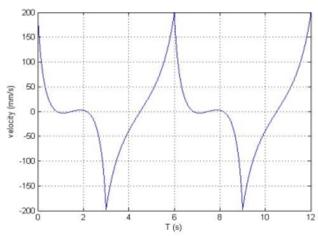


Fig. 4 Simple chart of orbit

Fig. 5 the displacement and velocity curves in MATLAB.

Simulation analysis of the model

Simulation analysis based on MATLAB

According to the above content, the program is written in MATLAB to research the mathematical model of the rigid body obtained above[4,5]. The parameters of the model, such as the center of mass to the hinge point, the size of the rigid body, are estimated and measured by SolidWorks. The response curve of the slider is obtained by the center of the rotating cross at 30 degree /s, as shown in Fig 5 above.

Simulation analysis based on ADAMS

Virtual prototype of shoe cover machine driving system is as shown in Fig 6. In Adams, it is necessary to edit each component to define its material, quality, inertia and other related attributes, so that the virtual prototype and the actual physical prototype have the same or similar physical characteristics, in order to better simulate the actual system. And then set the movement relationship of each part, complete the connection between the moving parts and the driver, simulate for special shoe cover machine in kinematics and dynamics.

Among them, the operation and solving of the various parameters matrix is based on the mechanical model of the assembly, and then set up a mathematical model of the system. Finally, a special dynamic numerical analysis algorithm is used with the iterative solution to analyze the data[6].

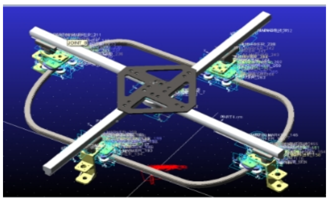


Fig. 6 virtual prototype of driven system Fig

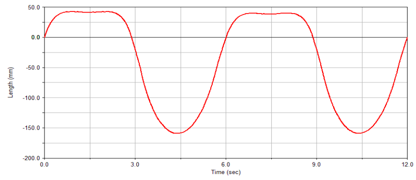


Fig. 7 the response curve of Slider displacement

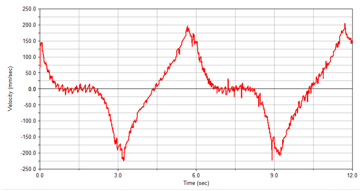


Fig. 8 the response curve of Slider speed Fig

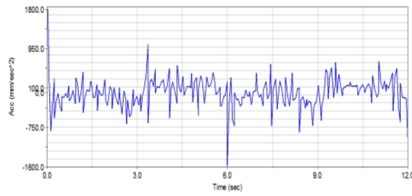


Fig. 9 the response curve of Slider Acceleration

From Fig 5, Fig 7 and Fig 8, it can be seen that the simulation results that based on MATLAB and ADMAS is basically consistent, which confirms the validity of the model. The displacement of the slider is about -175~50 mm, it starts to motion from track line and semi-ellipse tangent point and meets this motion law: semi-ellipse—line — semi-ellipse —line. From Fig 8 it can be seen that the speed curve of the slider is basically consistent with that of Fig 5, but there is a slight fluctuation. This is due to that the two roller center distance is 0.5mm wider than the orbit, and further lead to non-uniform stress state.

From Fig 10, it can be seen that the acceleration of the starting moment is relatively large, in a certain range of fluctuations. Excessive acceleration leads to the impact of the roller and the orbit. If it works on long time, it will make the gap between the roller and the orbit become bigger, which will lead the system's work efficiency being low, and even shorten the life of the whole system.

Conclusion

In this paper, R-W theory of multi rigid body dynamics is applied. It regards the relative coordinate hinge as independent variables, abstracts and simplifies drive system, establishes mathematical model that is consistent with actual mechanical systems, adopts numerical analysis on the spatial kinematics, researches movement regular of shoe cover machine drive system. Through simulation analysis combining with multi body dynamics digital virtual prototype development tool ADAMS and dynamic analysis of shoe cover machine, the response curves of the displacement、velocity and acceleration of each component can be obtained. It is effective to study the dynamic characteristics of the system.

At the same time, by comparing the paper verifies the validity of the simulation program and the correctness of the mathematical model of the shoe cover machine, namely the feasibility of the R-W method to study complex mechanical. The theoretical study in this paper provides a reliable basis for the analysis of shoe design optimization and virtual simulation, so as to shorten the product exploring life cycle, reduce development costs, improve product quality and competitiveness of the purpose.

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