DYNAMIC BALANCE OPTIMIZATION OF THE CUTTING HEAD FOR FLEXIBLE MATERIALS BASED ON SOLIDWORKS

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In order to solve the problems that severe vibration and noise, caused by the eccentric wheel cutting head of cutting machine for flexible materials, affect the normal operation of the cutting machine, the paper analyzes the working principle, establishes the model of eccentric mechanism for this cutting head, simulates the motion of the eccentric wheel by the SolidWorks Motion software, and investigates the forces and reaction forces in the Y and Z directions of the eccentric wheel axis to find the best counterweight. Besides, the paper verifies that the kinematics simulation of the eccentric wheel mechanism with parametric design is the optimal solution method for obtaining the eccentric counterweight because the eccentric wheel mechanism not only realizes rapid completion of the mechanism design, but also gets dynamically balance. The testing results show that the simulation by transforming the practical operation into SolidWorks Motion model can not only obtain more accurate value of counterweight than manual operation, but also save the time.

Keywords: Dynamic balance optimization; Eccentric mechanism; Cutting machine; SolidWorks motion

1. Introduction

As a common motion mechanism in crank linkage mechanism, the eccentric wheel link mechanism is equivalent to the slider-crank mechanism which is characterized with the feature that the rotary motion of the crank is converted into a linear reciprocating motion of the slider. Due to its simple structure, fast speed and easy manufacturability, the mechanism is widely used in much machinery equipment, especially in flexible material cutting equipment.

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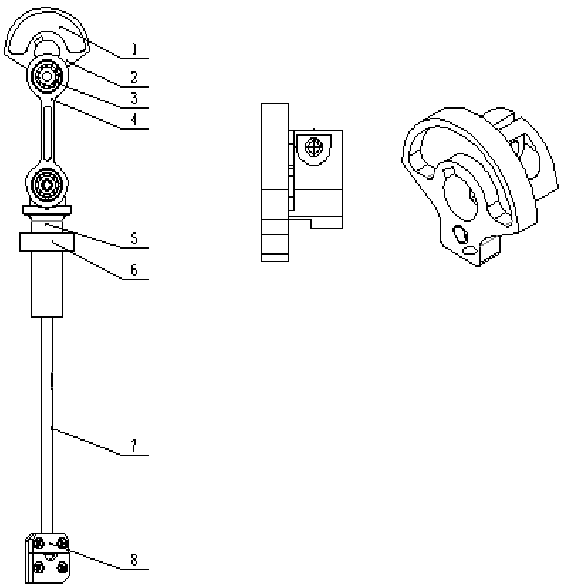
Furthermore, the slider-crank mechanism is also widely applied in heavy machinery equipment [1] due to its bearing ability for large loads and low occurrence of wearing between two elements in lower pair contact.

In the process of high-speed cutting, the spindle unbalance resulted from its high speed will cause large inertial centrifugal force. Therefore, it is very important to solve the unbalance problem in spindle-tool system. Thus, dynamic balancing is considered as a necessary condition for high-speed machining in traditional application and the Kennametal balancing system [2] is a good choice for this work. The Kennametal system is composed of balancing tool handle, acceleration sensor, controller and regulator, and has the following property: the electromagnetically driven counterweight disc is arranged in the tool handle. By automatically adjusting the relative position of the disc of the tool handle, the system can balance the spindle and the tool system as a whole without using a special spindle. It is self-evident that this system takes advantages of not only eliminating the complexity of artificial weights, but also monitoring dynamic balance of the tool at any time. However, this system also has some drawbacks. For example, sometimes, the internal and external conditions of the machine tool are too complex to correctly determine the dynamic balance when the tool is running. Besides, if the dynamic balance system is used in the workshop with many machine tools, the cost will be unbearable. In this paper, a typical eccentric wheel mechanism in the cutter head for flexible material cutting machine is analyzed to realize the dynamic balancing optimization design using SolidWorks 2016 (x64 edition), find the optimum counterweight of the eccentric wheel mechanism, and solve the noise caused by the eccentric wheel movement.

2. Kinematic analysis of eccentric wheel mechanism

The eccentric wheel mechanism in the cutter head of cutting machine for flexible materials is shown in Fig. 1. The driving motor shaft in the cutter head of this cutting machine is connected with the driving eccentric wheel 2 through the key, and fastened through the screw on the clamping device, integrated with the driving eccentric wheel 2. As such, the screw on the clamping device tightly connects the driving eccentric wheel 2 and driving connecting rod 4, and driving connecting rod 4 and guiding shaft 5. Furthermore, connecting rod 7 and guiding shaft 5 are connected by threads and also fastened by screws; Cutter holder 8 and connecting rod 7 are fastened by four screws. Obviously, the clamping device behind the eccentric wheel may not only tighten the driving eccentric wheel 2 with the extension shaft of the motor, but also increase the mass of the eccentric wheel, and make the center of mass of the whole mechanism close to the center of rotation, so that the centrifugal force and centrifugal moment of the whole mechanism are reduced and hence the vibration is decreased [3].

The working principle of the cutting head is stated as follows: the motor drives the driving eccentric wheel 2 to rotate, the driving eccentric wheel 2 drives the driving connecting rod 4 to swing, and the driving connecting rod 4 drives the guiding shaft 5, the connecting rod 7 and the cutter holder 8 to move up and down. The directional guide sleeve 6 remains fixed and plays a directional and guiding role. When the cutter head is working, the power is transmitted to the tool holder and the tool by the connecting rod and by means of the rotary motion of the eccentric wheel. The flexible material is cut by the up-down reciprocating motion of the cutter clamp and the cutter [4]. The cutter head of flexible material cutting machine is mainly composed of counterweight groove, driving eccentric wheel, driving connecting rod, connecting rod and cutter clamp. The counterweight area for the eccentric wheel is specified as the counterweight groove, in which the eccentric wheel is counterweighted. Rotating motion of driving eccentric wheel is transformed into up-down reciprocating motion of connecting rod and cutter clamp by driving connecting rod [5].



1. counterweight groove; 2.driving eccentric wheel; 3.bearing; 4 .riving connecting rod; 5.guiding shaft; 6.directional guide sleeve; 7.connecting rod; 8. cutter holder

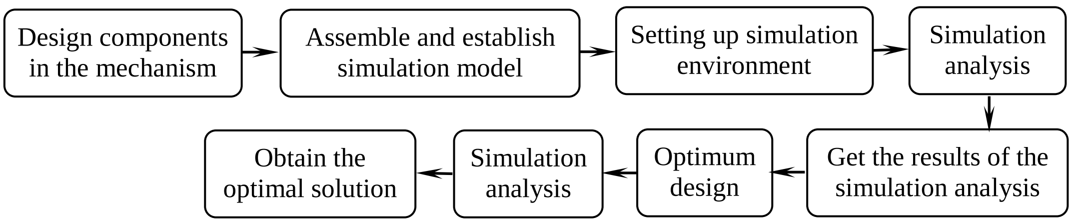


Fig.1. Eccentric wheel mechanism in cutter head of cutting machine for flexible material and the process of dynamic equilibrium analysis and optimization

3. The process of dynamic equilibrium analysis and optimization

SolidWorks software is three-dimensional CAD/CAE/CAM software with main function of design. It also has a feature-based and parameterized solid modeling system with secondary development environment and open data structure. After adding various plug-ins, it may realize three-dimensional modeling, assembly verification, motion simulation, finite element analysis, processing simulation, numerical control processing and formulation of processing technology and truly realize digital design and manufacturing of products, and besides, the software has the characteristics of simple use and easy operation due to its humanized operation interface [6].

After simplifying the eccentric wheel mechanism into a crank-slider structure, the parts of the eccentric wheel mechanism need to be designed and assembled before the motion mechanism is simulated and analyzed by SolidWorks motion in SolidWorks. The process and method of motion simulation and dynamic balance analysis of eccentric wheel mechanism based on SolidWorks are presented in Fig. 1.

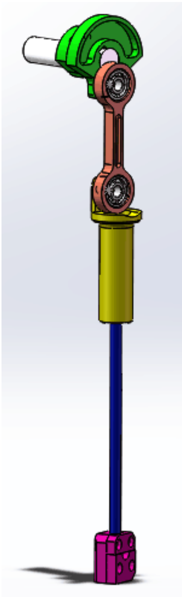


Fig.2. Three-dimensional model of eccentric wheel mechanism

4. Dynamic simulation of the eccentric wheel mechanism

The structure of parts creation and virtual assembly of eccentric wheel mechanism based on SolidWorks is shown in Fig. 2. After adding materials and quality attributes to each part of the assembly, the quality characteristic diagram before optimization of the assembly is obtained as shown in Table 1. In order to obtain the expected movement effect in the process of movement for the parts, the reaction force, speed, position and other parameters of eccentric wheel mechanism in the course of movement are observed and recorded by SolidWorks Motion. At the same time, the analysis results are generated in the form of graphics, so that the designer can better understand the design results of the mechanism.

Table 1

Quality characteristic diagrams before optimization

Override mass	Override center of mass		
	X	Y	Z
0.305 kilograms	117.543 mm	-18.931 mm	123.553 mm

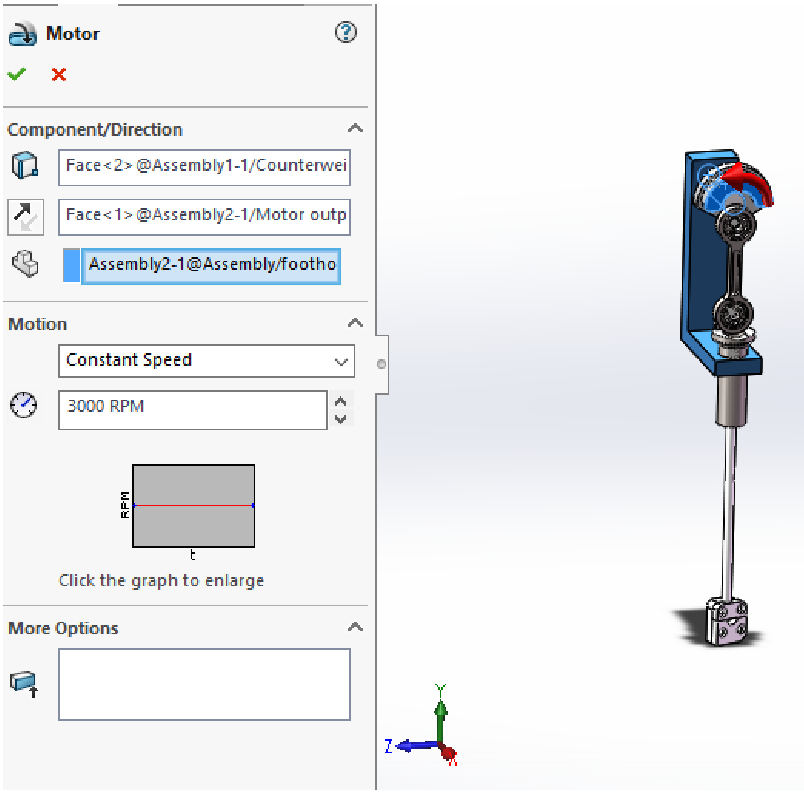


Fig.3. Input parameter diagram of motor

In SolidWorks software, when adding the motor, the basic parameters of the motor may be set as follows according to the parameters of the motor on the flexible material cutting machine: speed: 3000r/min; frequency: 200Hz; output power: 0.4kW. The setting results are shown in Fig.3.

5. Dynamic simulation analysis of eccentric wheel mechanism

The dynamic unbalance force of structural rotation comes from the centrifugal force of the structure itself, which is expressed as the reaction force of the supporting part of the bearing on the structural assembly [7]. Thus, using

SolidWorks motion dynamic analysis to optimize the dynamic balance of the eccentric wheel mechanism, the reaction force diagram at the support of the eccentric wheel is generated and optimized continuously until the peak value of the reaction force fluctuation diagram reaches the allowable range required.

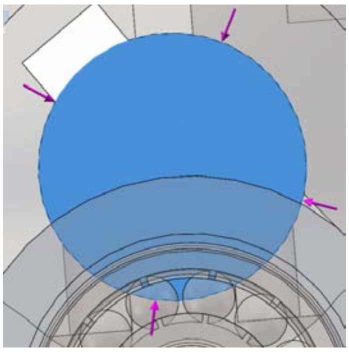
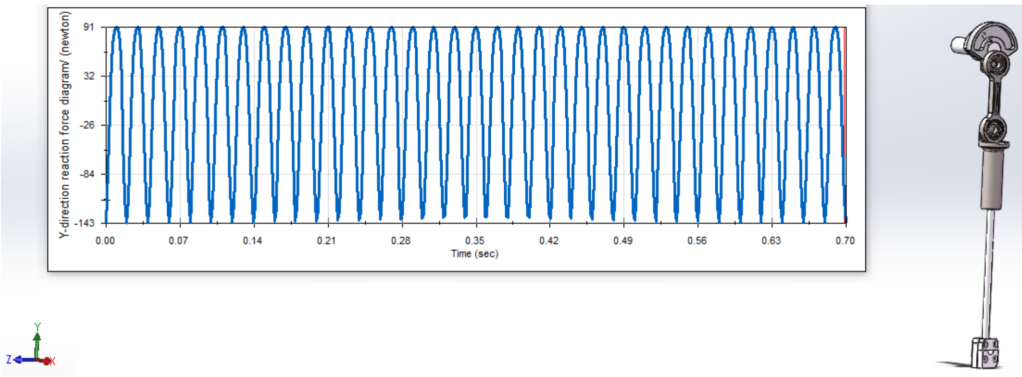
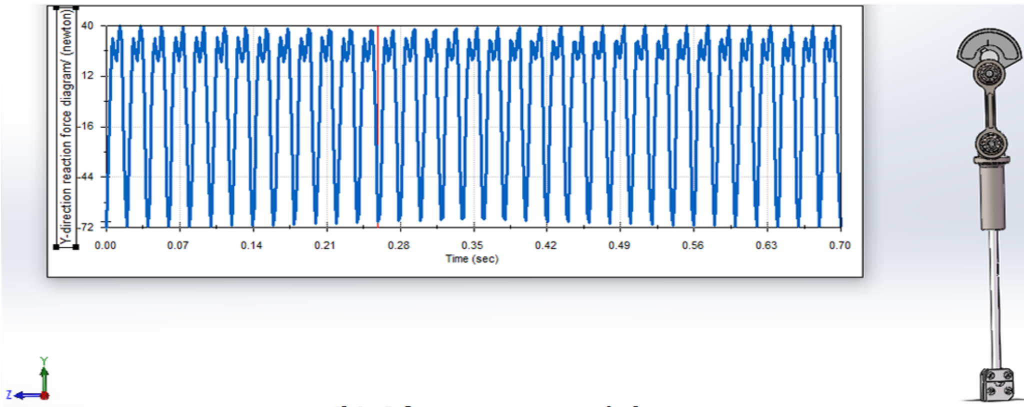


Fig.4. Illustration of the reaction force of the eccentric wheel on the motor shaft



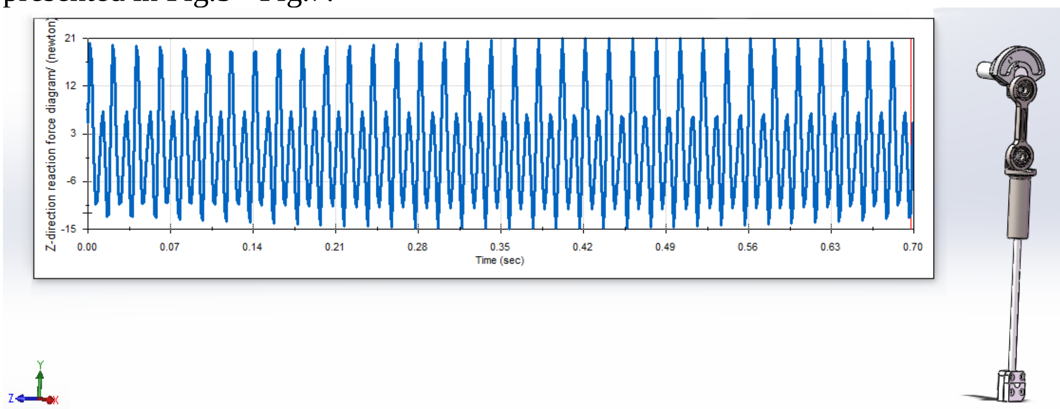
(a) Before counterweight



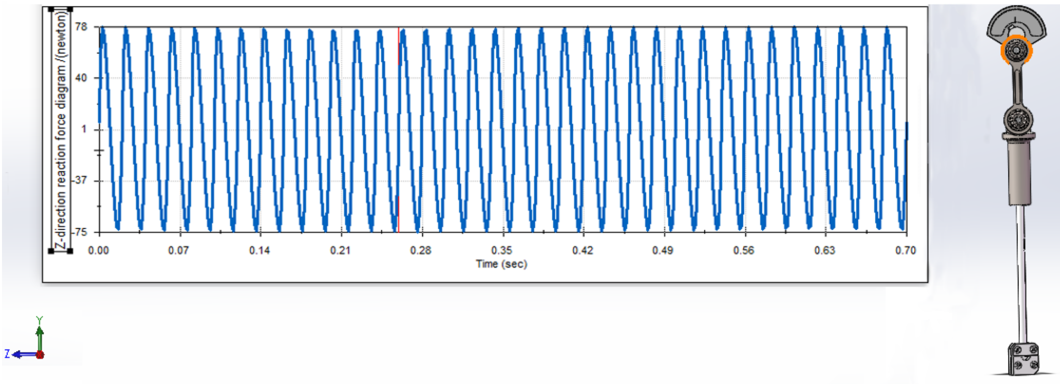
(b) After counterweight

Fig.5. Y-Direction reaction force analysis diagram

When analyzing the motion of the model with SolidWorks Motion, the concentricity of the revolving center axis and the driving eccentric wheel is restrained. The direction of the reaction force generated by the eccentric wheel on the motor shaft is shown in Fig.4. The motor shaft drives the eccentric mechanism to rotate. The process is periodic, thus the reaction force from Y direction, Z direction and the resultant is also periodic. The force along the axis of the motor may be neglected since it has little effect on the vibration. So, the reaction force Y and Z along the normal direction of the motor shaft and the resultant force of the two reaction forces are taken as the output items of the chart. The outputs are presented in Fig.5 - Fig.7.



(a) Before counterweight



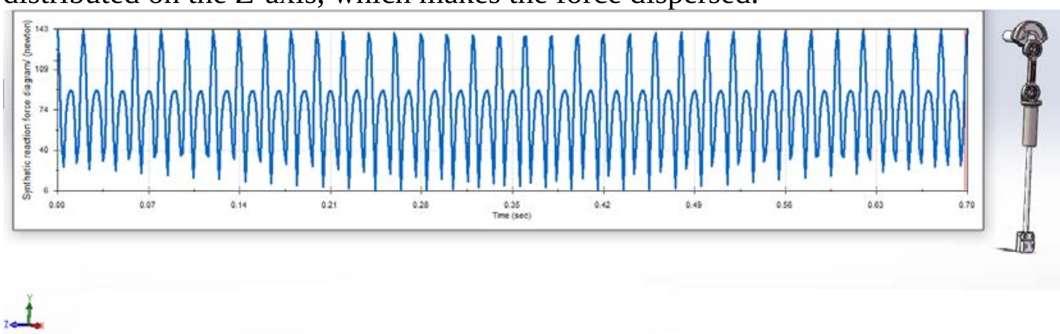
(b) After counterweight

Fig.6. Z-Direction reaction force analysis diagram

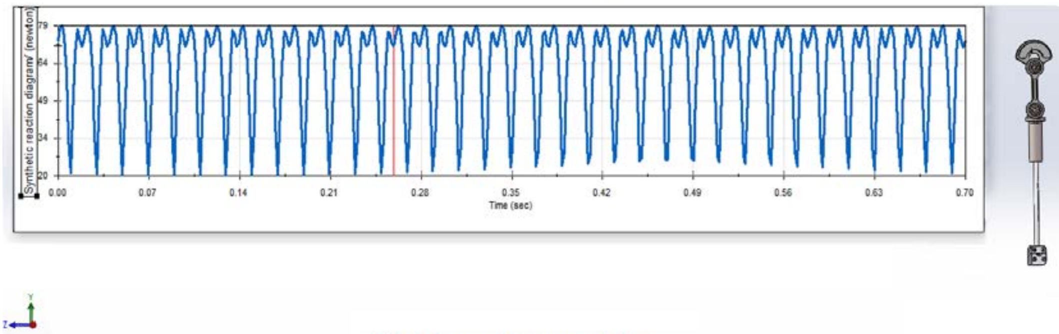
First, Fig.5(a) and Fig.5(b) are the output diagrams of Y-direction reaction force in virtual operation of eccentric wheel mechanism before and after counterweight respectively. Comparing Fig.5(a) with Fig.5(b), we find that the Y-direction reaction force fluctuates periodically due to the periodic rotation of the eccentric wheel, but the fluctuation peak value and range (-143N-+91N) before the counterweight are larger than those (-72N-+40N) after the counterweight.

Obviously, the peak value and range of fluctuation are the important factors affecting the vibration of the eccentric wheel mechanism [8]. The positive and negative value of reaction force is the judgment of the direction of the reaction force in the established reference coordinate system, the peak value of Y-direction reaction force before optimizing the counterweight of eccentric wheel reaches -143N, which is much higher than that of Y-direction reaction force -72N after counterweight. This shows that the Y-direction radial force and shock on the center axle of eccentric wheel are very large before optimization.

Second, Fig.6(a) and Fig.6(b) are the Z-direction reaction force output diagrams before and after counterweight respectively. Comparing Fig.6 (a) with Fig.6(b), it could be found that the Z-direction reaction force also fluctuates regularly. However, the peak value and fluctuation range of Z-direction reaction force before counterweight are from -15N to +21N, which are smaller than those ranging from -75N to +78N after counterweight in Fig.8. The major reason may lies in the fact that the centroid position of the whole mechanism changes after counterweight, and a part of the Y-direction reaction force before counterweight is distributed on the Z-axis, which makes the force dispersed.



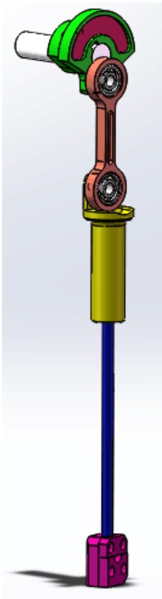
(a) Before counterweight

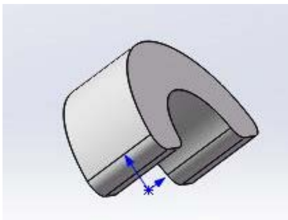


(b) After counterweight

Fig.7. Synthetic reaction force analysis diagram

Third, Fig.7(a) and Fig.7(b) are the synthetic reaction force output diagrams of Y and Z directions before and after counterweight respectively. Likewise, it could be found that the synthetic reaction force fluctuates periodically as presented in Fig.7(a) and Fig.7(b). The peak value (+79N) of synthetic reaction force after counterweight are lower than the peak value (+143N) before counterweight. In addition, the jumping scope of synthetic reaction force ranges from +20N to +79N after counterweight and is 43% smaller than that varying from +6N to +143N before counterweight. Therefore, the radial force and shock on the axle and the noise caused by vibration in the working state of the mechanism are reduced to a large extent.





(a) Eccentric wheel mechanism (b) Counterweight

Fig.8. Eccentric wheel mechanism with optimal counterweight

Table 2

Mass characteristic diagram of the mechanism after optimizing the counterweight

Override mass	Override center of mass		
	X	Y	Z
0.369 kilograms	120.197 mm	-8.560 mm	123.579 mm

Finally, SolidWorks is used to analyze the design example; the result is shown in Fig.8. In the design example, the shape of the counterweight block is determined by taking the distance from the center of the counterweight block shape to the axis of the eccentric wheel and the thickness of the counterweight block as variables and considering the reaction force reaching the allowable range as the objective, the optimal solution of the shape is the balance position and weight of counterweight block required for dynamic balancing [9]. Then, the quality characteristics of the optimized counterweight are shown in Table 2. Compared with the quality characteristics before counterweight, the overall mass of the mechanism increases from 0.305 kg to 0.369 kg, of which the mass of counterweight block is 0.064 kg.

(a) Eccentric wheel mechanism **(b) Cutter head**

Fig.9. New mechanism of eccentric wheel and the complete cutting head

The new mechanism of eccentric wheel and the complete cutting head are illustrated in Fig.9 respectively after the optimization. Results of eccentric wheel mechanism are improved using SolidWorks software.

6. Noise test

In order to measure reduction of noise after the optimization, an AR844 acoustic meter with measuring range 30dB-130dB from Smart Sensor Corporation (Hong Kong) is employed. Noise of the original and optimized structure is detected at a distance of 5cm from the front, back and left sides of the cutting head respectively, when the cutting head is used for high-speed vibration cutting of leather on an intelligent NC cutting machine with a speed of 2000r/min. Because of the structure of the equipment, the noise at 5cm on the right side cannot be detected. The environmental noise is sampled at a distance of 5m from these three corresponding directions when the eccentric mechanism is not working. A sponge cover is taken outside the acoustic sensor to enhance the sampling procedure when the environmental noise is detected. The data are acquired and operated by the supporting software of the instrument and output through displayer.

The testing results are indicated in Table 3. The results shows that, the average noise of the optimized eccentric mechanism at 5cm in three directions is 76.4 dB, which is 11.3 dB lower than the average noise of the original structure of 87.7 dB, and is 6.9 dB greater than the ambient average noise of 69.5 dB at 5 m.

Table 3

Noise test results (Average/dB)

Testing target	Position	Average value	Maximum value
Original structure	Front	88.3	92.0
	Back	90.7	92.3
	Left	84.2	91.9
Optimized structure	Front	74.3	91.4
	Back	75.5	79.0
	Left	73.3	78.5
Environment	Front	70.2	76.7
	Back	69.3	73.4
	Left	69.1	70.9

7. Conclusion

In order to solve the problems that severe vibration and noise, generated by the eccentric wheel cutting head of cutting machine for flexible materials during the working process, affect the normal operation of the cutting machine, SolidWorks Motion is used to optimize the dynamic balance of the cutter head of flexible material cutting machine, and realize the dynamic simulation of the cutter head in virtual environment. The approach, of which combines SolidWorks Motion dynamic balance optimization technology with the principle of dynamic balance of planar revolving parts to optimize the design of cutting head, not only makes the analysis process easier, but also obtains the optimal quality of counterweight block, and further provides a more appropriate and convenient method for dynamic balance research of the cutting tool system. In this paper, the optimum counterweight is found below 80N of the reaction force (enterprise requirements) and by taking the distance from the center of counterweight block shape to the axis of eccentric wheel and the thickness of counterweight block as variables. Compared with the traditional method of obtaining the quality of the weighing block by the field test in factories, the optimization method not only saves manpower, material and time, but also saves the test time in the production practice, and obtains the more accurate weight value than the manual operation method. Finally, the feasibility of the optimization method is verified through noise detection experiments. Moreover, in further studies, the vibration and structure of cutting head will be continually optimized by improving the structural design of driving link and guide shaft or adding the sound insulating material into the outer case.

Acknowledgments

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