Structural design and analysis of a one-way drive clutch for printers

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Abstract. Based on the application background of the paper reversing function of a duplex printer, a clutch which can realize one-way transmission is designed. The driving gear and driven gear are dynamically connected by a connector with wedge teeth and spiral slope. When the motor rotates forward, the clutch can normally output power to the load, and when the motor reverses, the power is cut off, and the load cannot rotate. The clutch can not only realize the paper reversing function, but also make the load not rotate with the reverse of the motor, so as to protect the toner cartridge and heating roller. The clutch has the advantages of few parts, low cost, convenient installation, compact structure and low noise after assembly. In addition, on the basis of the structural design, the necessary mechanical properties of the clutch are analyzed to provide theoretical support for structural improvement.

1. Introduction
With the increasing popularity of office automation system, photocopier, printer, scanner and other office equipment are more and more favored by people. At the same time, people's requirements for these office equipment are higher and higher, the speed of equipment is faster and faster, and the functions are more and more complex and diverse. Automatic duplex printing has gradually become one of the indispensable performances of laser printers in the market. The design of the duplex printing mechanism is usually based on the conventional printer structure, which requires a more complex transmission mechanism to realize the automatic reversal of paper in the printing process, realizing automatic duplex printing, freeing the user's hands and bringing fast and convenient use experience.

The internal structure of a laser printer is complex. The static and dynamic characteristics of its structure and the dynamic characteristics of paper are the research hotspots in the technical field of printers[1]. The deformation of paper in complex motion state is more likely to cause paper jam in the printer, such as the paper reversal in the paper feeding mechanism. Yang Shengjun, Ma Junxing, Chen Xuefeng and others[2, 3] respectively analyzed the mechanical properties of paper by using the plate shell element calculation model, gave the matrix calculation formula of the triangular plane shell element described by the modified Lagrangian method, and established the static and dynamic incremental balance equations for the analysis of geometric nonlinear problems, and based on this, the dynamic and static analysis of paper under cantilever state was carried out. Shigeo yanabe et al.[4] carried out a series of studies on the paper transfer function of the rubber paper taking roller in the paper feeding mechanism of the printer and the separation mechanism, and obtained the optimal matching mode of the geometric parameters, force and speed of the paper feeding mechanism. Kawamoto et al.[5] proposed an electrostatic copy separation mechanism, and through simulation and
experiment, it is proved that the paging function of the mechanism is stable and continuous. The printer needs to run frequently in the process of use, and the dynamic performance of its internal mechanism is the key to affect the product quality[6, 7]. Shen Xianfa[8] established and solved the mathematical model of the force between the paper and roller in the paper feeding mechanism of the copier, and simulated the movement of the mechanism. Wang Bing et al.[9] carried out a simulation study on the paper taking and paging mechanism of the copier, and analyzed the dynamic behavior of paper in this process, as well as the influence of the positive pressure of the roller and the angle of the feeding guide rail on the performance of the mechanism.

Based on the above research, the major manufacturers carry out the design of duplex printing mechanism on the basis of conventional printer structure. At present, there are two ways for the printer to reverse papers: one is to drive the motor to keep one-way rotation, and the action of an electromagnetic relay drives the reversing gear train to realize the reversing of the paper output mechanism, so as to reverse papers. The structure of this method is simple, but the service life of the relay is low, the reliability of the mechanism is poor, and the noise in the printing process is large. The second way is to drive the motor forward and reverse. When the motor rotates forward, the front of the paper is printed, and the paper is turned over when the motor reverses. This method has the advantages of low noise, reliable but complex structure. In addition, when the motor is reversed, the OPC (Organic Photoconductor) drum in the toner cartridge and fuser heating roller are not allowed to reverse, otherwise it will seriously affect their service life and printing quality, and even cause printer failure. Therefore, it is necessary to design a clutch mechanism which can realize one-way transmission in the transmission mechanism.

According to the second way of reversing paper mentioned above, a one-way drive clutch which can be directly applied to the transmission mechanism of a duplex printer is designed in this paper. When the motor rotates forward, the clutch drives the load such as the OPC drum and heating roller through the gear; when the motor reverses, the clutch disengages the load, and the OPC drum and heating roller will not reverse with it, but will be stationary. In this paper, the detailed structural design is carried out, and the necessary static analysis is carried out to verify the mechanical properties of the clutch. It can be widely used in the design of office equipment.

2. Design of the one-way drive clutch

2.1. Structural design

In office equipment, the mechanisms commonly used to realize one-way transmission include ratchet mechanism, one-way bearing mechanism, etc. As the most widely used desktop office equipment, the laser printer has the characteristics of compact structure and low noise. However, the movement accuracy of ratchet mechanism is low, and there will be impact and noise when the motor reverses; the non-standard design of one-way bearing mechanism is limited by the size of standard parts such as bearings. Therefore, the above two mechanisms are not suitable for application in the duplex printer. Because the transmission mechanism of the printer is mainly composed of gear trains, this paper designs a one-way drive clutch as shown in figure 1 with gears as input and output components.
The clutch is composed of a driving gear, a connector and a driven gear. The three parts are injection moulded with POM (polyoxymethylene) material with self-lubricating function. The driving gear, connector and driven gear are successively fit on the same supporting shaft. The driving gear is connected to the transmission system of the printer, and the power of the motor is input into the clutch and transmitted to the OPC drum and heating roller through the driven gear, so that the OPC drum and the heating roller rotate when the motor rotates forward. When the motor reverses, the clutch will not transfer the power to the OPC drum and the heating roller, realizing the separation of the transmission and avoiding the OPC drum and heating roller reversing with the motor.

2.1.1. The driving gear. As shown in figure 2, the driving gear is a standard involute helical cylindrical gear (the teeth are not shown in the figure) for power input. The center cylindrical hole of the driving gear is used for assembling with the supporting shaft, and the central cylinder is used for assembling the connector. The cylinder at one end of the gear protrudes outward, and a circle of wedge-shaped teeth is designed around the hole. The cylinder at the other end is approximately flush with the end face of the gear, and only stiffeners are arranged around it.

![Figure 2. Structure of the driving gear.](image1)

The wedge-shaped teeth are evenly distributed around the central cylinder, and the specific structure is shown in figure 3. The axial section of the tooth is wedge-shaped, the top of the tooth is the big end, and the bottom of the tooth is the small end. The slope surface from the top to the bottom of the tooth is a spiral surface coaxial with the central cylinder. This design can make the connector draw into the tooth bottom with the least impact, which is conducive to the clutch operation of the parts in rotation and reduce the noise.

![Figure 3. Structure of the wedge-shaped teeth.](image2)

2.1.2. The connector. As shown in figure 4, the connector is cylindrical as a whole, which is used to dynamically connect the driving gear and the driven gear. The center hole is used to fit on the center cylinder of the driving gear, and a small clearance is used between the two to ensure the assembly of coaxiality and relative rotation. The center hole at one side of the connector is provided with wedge-shaped teeth which are exactly the same as those of the driving gear, which are meshed with the wedge-shaped teeth of the driving gear. At the other side of the connector, two claws with a certain height are radially symmetrically arranged. There are two spiral slopes in the circumferential direction
between the two claws, and the two spiral slopes have the same ascending or descending trend along
the same direction of the circumference.

Figure 4. Structure of the connector.

2.1.3. The driven gear. The tooth part of the driven gear is a standard involute helical cylindrical gear,
which is used to mesh with the load and output power; the non-tooth part is in the shape of a cylinder
and connected with the connector, as shown in figure 5. The center hole of the driven gear is used to
fit on the supporting shaft, and the outer circumference of the central cylinder is divided into two
annular grooves through four stiffeners. The claws of the connector are inserted into the two annular
grooves and can be rotated in the annular grooves. After assembly, the large end face of the driven
gear contacts with the convex end face of the driving gear.

Figure 5. Structure of the driven gear.

2.2. Working principle
Assembly: first, put the driving gear on the support shaft and limit its position with the shaft shoulder.
Then, put the connector on the convex cylinder of the driving gear. Finally, put the driven gear on the
supporting shaft, and the large end face of the driven gear contacts with the convex end face of the
driving gear, and the outer end of the driven gear is axially limited by a clamp ring or other parts. In
this way, the axial positions of the driving gear and driven gear are fixed, but the axial position of the
connector is not limited. Therefore, the wedge-shaped teeth of the driving gear are not necessarily in
mesh with the wedge-shaped teeth of the connector, as shown in figure 6(a).
When the motor rotates forward, the power is transmitted to the driving gear through the gear train, so that the driving gear rotates in the direction shown in figure 6(a) (anticlockwise when viewed from the left side). Under the friction between the center hole and the cylinder body of the driving gear, the connector rotates with the driving gear, and its spiral slopes keep contact with the large end face of the driven gear. At this time, the driven gear is still under the action of a large load. Therefore, when the connector rotates, it will be pushed by the large end face of the driven gear on its spiral slopes and move along its axial (close to the driving gear), so that the wedge-shaped teeth of the connector and the wedge-shaped teeth of the driving gear gradually enter into mesh. In this way, the driving gear drives the connector to rotate in the same direction through the wedge-shaped teeth. When the connector rotates until the claw contacts the side wall of the stiffener of the annular groove of the driven gear, it will drive the driven gear and its load to rotate in the same direction, as shown in figure 6(b).

When the motor reverses, the driving gear rotates in the opposite direction as shown in figure 6(a). Under the action of the meshing component force of the wedge-shaped teeth, the connector is forced to stay away from the driving gear in the process of rotation until the wedge-shaped teeth are completely out of mesh. At this time, the driven gear has no power input, and the OPC drum and other loads will remain stationary.

To sum up, when the motor rotates forward, the load is driven by the clutch. When the motor reverses, the clutch cuts off the power and the load cannot rotate. The design in this paper meets the expected requirements.

3. Finite element analysis of the gear structure
The power input and output effect of the one-way drive clutch directly affects the transmission stability and reliability of the whole transmission mechanism and the whole machine. Therefore, it is necessary to analyze the mechanical properties of the clutch structure.

3.1. Finite element model
Firstly, the 3D model is imported into the finite element analysis software ANSYS, and the solid element solid185 is selected for simulation. The material characteristics of parts in the clutch are shown in table 1.

| Material | density (kg/m³) | Poisson's ratio | Elastic modulus (MPa) | Yield limit of material (MPa) |
|----------|----------------|----------------|-----------------------|-----------------------------|
| POM      | 1390           | 0.39           | 2600                  | 67                          |
The "mesh tool" provided by the software is used for free mesh generation. The finite element model of the clutch is shown in figure 7.

Figure 7. Finite element model of the clutch.

According to the actual working conditions, the model is constrained and loaded. The internal surface of the center hole of the driving gear is constrained to limit the displacement in X and Y direction respectively, and the convex end face of the central cylinder of the driving gear is constrained to limit the displacement in Z direction.

In order to facilitate the analysis, the loading process is simplified as follows:

1) Only a single tooth was loaded.

2) Because the loading on the meshing line of a helical gear in ANSYS is too complex, the load can be applied to the top of the tooth for the convenience of loading[10].

3) The normal load acting on the tooth surface along the meshing line is decomposed into two mutually perpendicular components at the node, i.e. circular force and radial force:

\[ F_t = \frac{2\pi T}{d} \]  \hspace{1cm} (1)

\[ F_r = F_t \cdot \tan \alpha \]  \hspace{1cm} (2)

In this equation, \( F_t \) is the circumferential force, \( T \) is the torque and \( d \) is the diameter.

Under the actual working condition, the torque \( T \) carried by the gear is 0.43 N·m. According to equation (1) and equation (2), the circumferential force \( F_t \) of the driven gear is 4.2 N, the radial force \( F_r \) is 1.5 N, and the load is applied on the tooth top line. There are 14 nodes on the tooth top line, each node is loaded with a circumferential force of 0.3 N and a radial force of 0.1 N. Similarly, the circumferential force \( F_t \) of the driving gear is 1.9 N and the radial force \( F_r \) is 0.7 N, a circumferential force of 0.1 N and a radial force of 0.08 N are loaded on each node on the tooth top line. The loads are shown in figure 8.

Figure 8. loads on the clutch.
3.2. Analysis results
The static stress nephogram and displacement nephogram of the clutch structure are obtained by calculation, as shown in figure 9 and figure 10.

![Figure 9. Static stress nephogram of the clutch.](image)

![Figure 10. Static displacement nephogram of the clutch.](image)

In this paper, a certain safety factor of 1.34 is selected for the strength check, so the allowable stress of the material is 50 MPa. From the stress nephogram, the maximum working stress of the structure occurs at the edge of the tooth top. By extracting the stress analysis results, it can be seen that the equivalent stress at this position is about 2.48 MPa, which is far less than the allowable stress of the material. Therefore, the static strength meets the use requirements. From the displacement nephogram, the maximum deformation of the structure is located at the tooth top of the driven gear, and the deformation is 0.019 mm, which can meet the design requirements.

4. Conclusions
Based on the application background of a duplex printer, a clutch which can realize one-way transmission is designed in this paper.

(1) The gears are used as the input and output end of the clutch, and the dynamic connection between the two gears is realized by a connector. When the motor rotates forward, the clutch can
output power to the load normally. When the motor reverses, it cuts off the power and the load cannot rotate.

(2) It can be directly applied to a duplex printing mechanism to realize the paper reversal and ensure that the load will not reverse with the motor.

(3) It is composed of three parts, less parts and low cost.

(4) The assembly of the clutch does not need any auxiliary tools or additional connectors, so it is easy to install.

(5) The coaxial nested fit is adopted between the parts. After assembly, the whole structure is compact and the running noise is low.

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