Principle and technical analysis of loop drive

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Abstract: researches on loop drive usually focus on describing the flying trajectory after the table tennis ball detaches from bat, but the theoretically explanation of loop drive is rarely reported. In this work, the tribology, mechanics, and space plane geometry deformation theories are adopted to investigate the motion features of loop drive, which are also employed to analyze the corresponding force distribution of bat.

In brief, an integral loop drive motion consists of four movement stages and five friction pairs. The first stage is swinging the bat colliding with ball's edge in a small angle. During this process, a slanting elastic concave-convex space deformation of rubber turns impact energy into relative tangential motion. Meanwhile, it forms a frictional normal load and with an elastic rolling normal surface structure, which frictionally carries and rebounds the ball to detach from bat with strong top-spin. This process is named as tangential hit. The second stage is the ball flying in a banana-ball trajectory. The third stage is collision process between ball and table, which also company with the ball's slant-concave deformation and rolling over the table, and then the ball tosses out of the table in a decreasing angle with an irregular oscillation. The last one is a banana-ball track again. This work intends to figure out the intrinsic characteristics of loop drive, originates a tangential hit theory on loop drive.

Furthermore, this work also intends to establish a loop drive technical system. In order to produce high quality loop drive, the player should swing bat to tangentially hit the ball in an appropriate small friction angle with a back-spinning-push track on the speedy time-space overlap area. Only by this way, the maximum frictional normal load can be obtained and get a loop drive of high quality.

Keywords: loop drive, tangential hit, slanting rolling concave-convex deformation, frictional carry, banana-ball trajectory.

1. INVENTION OF LOOP DRIVE

In order to guide teaching and training of loop drive, it is necessary to investigate the mechanisms of its generation, rotation and precession.

It is more than half a century since the loop drive has been invented by Japanese. Till now, most researches on loop drive focus on the description of the flying trajectory of table tennis ball detached from bat, but no comprehensive theoretical explanation on loop drive is reported [1-11]. It is hard to satisfy the requirements of players and coaches in training and competition. For promoting the development of table tennis, it is necessary to establish the theoretical and technical system of loop drive. In this work, the tribological and mechanical theories (biological movement mechanics, and aerodynamics, etc.), combined with the space plane geometry deformation theory, are adopted to analyze the characteristics of loop drive and establish a tangential hit theory.

2. PRINCIPLE OF LOOP DRIVE

An integral loop drive motion consists of four movement stages and five friction pairs. The first stage is the swing of the bat with its plane for- and downward colliding with the ball's edge in a small angle. During this process, a slanting elastic concave-convex space deformation of rubber turns impact energy into relative tangential motion. Meanwhile, a frictional normal load is produced and accompanying with an elastic rolling normal surface structure, which frictionally carries and rebounds the ball detaches from bat with strong top-spin. This process named as tangential hit. Here, the frictionally carry is proposed by Qiu and Wu in 1979 for

the first time [7]. The second stage is the ball flying in air with a banana-ball trajectory because of air friction and gravity. The third one is the collision process between ball and table, which also with a slant-concave deformation and rolling on table, and then the ball tosses out of the table in a decreasing angle with a little bit oscillation in an irregular pattern. The last one is a banana-ball track again. Therefore, the loop drive is produced by tangential hit, and the motion energy origins from collision deformation, friction, and carry, and is characterized with a banana-ball trajectory. Based on these analyses, the tangential hit theory about loop drive is established. It is significant for us discussing and understanding the generation and motion features of loop drive. Meanwhile, it is also meaningful to satisfy the requirements of players and coaches in training and competition.

2.1 Tangential hit

The formation of tangential hit includes two steps. First, the bat and ball collide together and form frictions, and then the ball spins out and detaches from the bat by the force of rebound. In the first process, the collision between bat and ball is soft elastic collision. In the second process, the collision between ball and table is inflexible. These two processes have the similar mechanism.

The tangential hit also involves geometry space deformation theory. It makes the rubber forms tangential deformation, which is larger than the ones without continuous plane surface such as pimples out rubber. Meanwhile, the frictional carry, rebound area, and strength produced by pimples in rubber are larger than that produced by pimples out rubber, which are also larger than those produced by collision methods.

The geometry space deformation theory could be used to illustrate the rotation and precession features of loop drive. The first tangential hit procession is showed in Fig. 1. Tangential hit process just likes a plane dives in a small angle and touches with runway, the wheels deformation and friction dramatically. While, as the active-wings erect, they will form a normal surface structure, which favors enlarged resistance and reduced speed.

Till now, only the pimples in rubber tangentially hit with ball could produce high-quality loop drive. It should be noted that, all rubbers in this work are referred to the pimples in rubber, except the ones that are specially mentioned. Generally, in the tangential hit processing, the strength of swinging bat is large enough that both rubber and ball will deform. Here, the deformation of rubber is larger than that of ball (which can be ignored) at the moment of collision with racket, for the elasticity of rubber is larger than that of ball and the hardness of rubber is smaller than that of ball. Because of friction, the speed of ball will approach to zero. This process will produce flash temperature, which will change the mechanical properties of rubber and ball. Due to the collision and extrusion between rubber and ball, parts of contacts in the rubber are higher than flat surface, which will enlarge the contact area, promote the strength, and speed the motion. Only with appropriate angle, strength, and speed, can the tangential hit produce elastic rolling normal surface structure and high-quality loop drive. This is the first part of tangential hit.

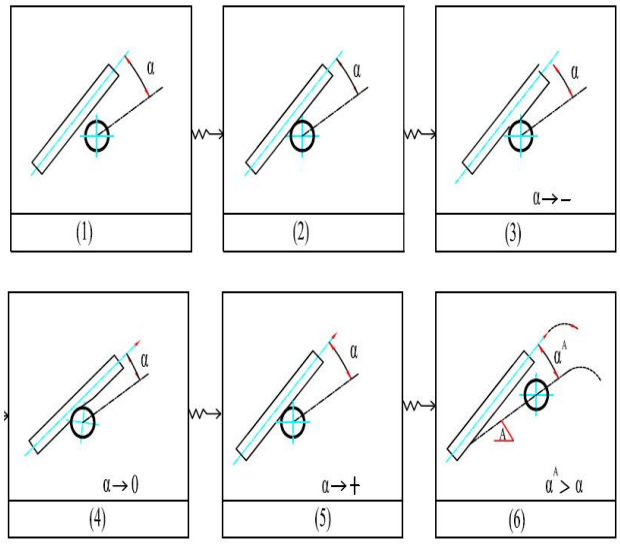

Fig. 1 Schematic of tangential hit process.

In the second part of tangential hit, the elastic rolling normal surface structure, the frictional normal load, and elastic rebound between rubber and ball are produced, which is accompanied with an elastic rolling normal surface structure. The frictionally carries and rebounds make the ball flying off the bat with strong top-spin. The changes of shape, potential energy, and kinetic energy that are produced by tangential hit are called as

the generation conditions of loop drive. Only these conditions if relatively optimized could produce high-quality loop drive.

2.2 Frictional carry and rebound

Friction is the resistance to motion during sliding or rolling, which occurs when one solid body moves tangentially over another with contact. The relative tangential force, which acts oppositely to the direction of motion, is defined as friction force [12]. The loop drive is mainly involved in the sliding friction and rolling friction. Furthermore, some tribology laws also involved, such as friction is proportional to normal load, friction is proportional to the actual contact area, and so on.

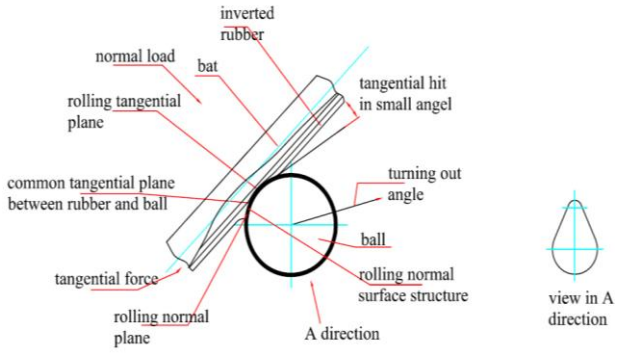

Fig. 2 Schematic illustration of loop drive.

Tangential hit forms the first pair of friction as showed in Fig. 2. The rubber that with large rebound force guides the ball moves following the bat's direction. Meanwhile, the rubber also moves with bat. The loop drive is produced by frictions, which are generated in the tangential hit process, such as adhesion, rolling friction, normal surface structure and friction carry. This is the mechanism of friction carry and rebound in tangential hit.

2.3 Rolling normal surface structure

During the tangential hit process, the friction between rubber and ball will form a common tangent plane. Meanwhile, the adhesion and friction will cause flash temperature, which will increase adhesion and friction. Furthermore, the ball decelerates in the common tangent plane, which will increase slanting rolling concave-convex deformation and increase the rebound force. Because of collision and extrusion, the contact area between rubber and ball is larger than the flat surface of bat. As mentioned above, this is helpful to enlarge the contact area and promote the strength. This is the mechanism of rolling normal surface structure, and only the length larger than depth is useful. This is the method to judge the validity and quality of tangential hit.

2.4 Rotation and precession

The precession of loop drive is generated by tangential hit. Theoretically, the friction and normal surface structure are produced by tangential hit. For the different elastic modulus between ball and bat, the generated dislocation rolling has different velocity. There is a dislocation slip, which generates a relative linear velocity at the contact line of common tangent plane between rubber and ball. Meanwhile, the rolling will form a relative angular velocity between the centre line of rubber and the axis of ball, and the rotation generates the angular velocity at the common normal of the contact area between rubber and ball. The displacement of rolling normal surface structure and frictional carry makes the ball have rolling rotation and rebounding kinetic energy. This is the mechanism of rotation and precession.

In tangential hit process, the friction maintains the ball steadily at the contact point. Meanwhile, there also has relative slippage between bat and ball, which makes them have elastic stress. As this stress is larger than adhesion, the ball will roll off from the adhesion point and move to the next point. And these adhesion and detachment processes will continue from the beginning of contact till the ball detach from bat. This is the generation process of loop drive.

In order to improve the quality of loop drive, it is necessary to enhance the friction between rubber and ball, which needs the rubber with proper adhesion that is easy for detachment. Therefore, it is important to enhance the movement friction. While, the claims that should to improve adhesive friction are not correct, for the adhesive friction is hard to preserve, which will increase the rubber consumption and costs.

As the velocity and the force that are produced by tangential hit are large enough, the rolling normal surface structure is larger than the compression ratio, and the tangential rebound is larger than the normal rebound of bat, the rubber will generate a rebound force

on the rolling normal surface structure. The direction of force is along the tangential direction of bat which is also in the same direction of ball. This is another property of loop drive.

The loop drive will increase the tangential rebound force which will speed the precession velocity of ball. Although the bat and ball move in the same direction, the velocity of ball is larger than bat. This is the rebound precession properties of loop drive.

Except the surface of rubber and ball, some factors, such as the internal gel column, sponges, the air in- and outside ball are also associated with the frictional carry in tangential hit. In this process, the rubber is fully compressed, which forms slanting rolling concave-convex deformation. If the tangential hit is strong enough, the sponges will deform with rubber, which leads the contacted area higher than the rubber's flat surface. As mentioned above, this structure favors enlarge the contact area between ball and bat and promote the rebound strength. From this point of view, it is useful for us to understand the reason that pimples in rubber produces higher kinetic energy than pimples out rubber.

2.5 Precession characteristics and stages of loop drive

As the ball detached from bat with strong top-spin, because of air friction and gravity, the ball flies in a banana-ball trajectory. Subsequently, it collides with table and is accompanied with slant-concave deformation and rolling. Finally, it leaves the table in a decreasing angle with a little bit oscillation in an irregular pattern. These are the precession characteristics of loop drive.

2.5.1 First stage: banana-ball trajectory

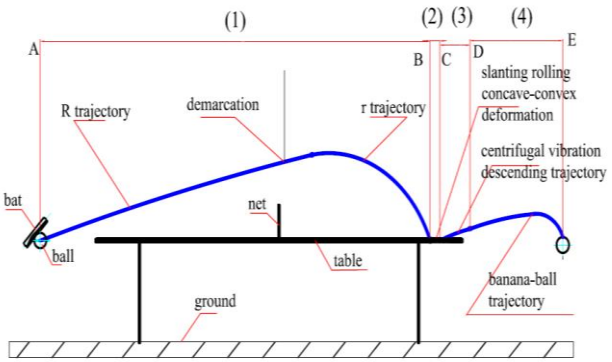

Fig. 3 Schematic illustration of movement stages (from (1) to (4)) and characteristics of loop drive.

The precession and stages of loop drive are shown in Fig. 3. From the bat and ball tangentially hitting with each other till the ball contacting with table is the first stage. In this process, the bat provides positive pressure, the ball flies in a banana-ball trajectory with a R trajectory.

However, because of air friction, the upper pressure on the ball is larger than the bottom part, and the movement direction does not coincide with fore direction, which forms a lateral force and makes the ball moves in a sudden shrink during precession curvature. We called this as back-spinning-push track. These are the process and characteristics of banana-ball trajectory and could be illustrated by Magnus effect. The banana-ball trajectory is helpful to improve the hitting rates. In the precession progress, the ball frictions with air, and the air which is in- and outside ball plays an important role in maintaining the flying stability and improving the hitting rates.

2.5.2 Second stage: rolling rebound trajectory

From the ball contacts with table till it detaches from table is the second stage, which is also the second tangential hit process. In this process, the ball frictions with table and with slanting rolling concave-convex deformation as showed in Fig. 4.

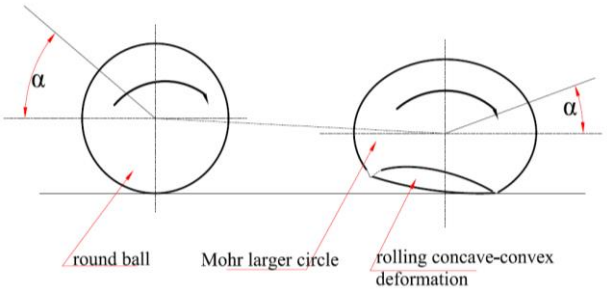

Fig. 4 Schematic illustration of ball friction with table and slanting rolling concave-convex deformation.

In this process, the air, the deformed ball, and the table formed the second pair of composite friction. This tangential hit process does not like the plane loading on the ground. It changes the ball's movement direction and produces flash temperature, which changes the ball's mechanical properties and makes the ball slanting rolling concave-convex deformation. We called this as the rolling rebound trajectory. Here, the deformation of

ball is larger as it collides with table, because the ball's elasticity and hardness is smaller than table. At this point, deformation of table can be ignored.

The rolling rebound trajectory makes the ball form the third pair of composite friction, which is composed by air, the deformed ball and table. In this process, the ball's shaft, shape center and mass center are offset from the center of spherical ball. Meanwhile, the air inside ball also centrifugally changed. These effects make the ball slant-concave deformation and rolling on the table.

2.5.3 Third stage: irregular pattern

From the ball detached from table till the moment it recovers to a spherical shape is the third stage, which is displayed in Fig. 3. As the ball detaches from table, there forms the fourth pair of composite friction, which is composed by air and ball that recovers to sphere. During this process, the existence of centrifugal effect makes the ball tossed out of the table in a decreasing angle with a little bit oscillation in an irregular pattern. The irregular pattern has close relationship to the ball's deformation, which is the reason for loop drive has higher hitting rates than other methods and bats.

2.5.4 Fourth stage: banana-ball track

In the fourth stage, as showed in Fig. 3, the ball detaches from table and recovers to sphere. Meanwhile, the ball's shape center, mass center, and shaft center all passes its center, which form the fifth pair of composite friction. In this stage, the ball is also flying along a banana-ball trajectory. But this stage is not like the second stage, which flying in a banana-ball trajectory and with top-spin. While in this stage, because of centrifugation, the ball departs off table in a decreasing angle.

Here, the loop drive can be defined as swinging the bat and tangentially hitting the ball in a small angle to make the ball flying in a banana-ball trajectory with top-spin.

In order to produce high quality loop drive, strong hip body strength and fast arm strength must be superposed to form a powerful resultant force, by which a stable and strong swing of bat can be formed. And then tangentially hit the ball with back-spinning-push track in the overlapping space. By this way, the maximum frictional normal load and the highest speed of bat can be reached.

3. CONCLUSIONS

In this work, the tribology, mechanics, and space plane geometry deformation theories are employed to investigate the motion characterizations of loop drive and the force distribution of bat. An integral loop drive motion process consists of four movement stages and five friction pairs. This work tries to figure out the intrinsic characteristics of loop drive, and construct a tangential hit theory to illustrate the motion of loop drive.

Meanwhile, this work also intends to establish a loop drive technical system. In order to produce high quality loop drive on the time-space overlap area, players should swing the bat to tangentially hit the ball in an appropriate small frictional angle to get the maximum frictional normal load, with back-spinning-push track and fast frictional carry and rebound with coherence and stability. The detailed analysis in this work can help players and coaches construct a comprehensive understanding on the mechanisms of loop drive, improve the training techniques and quality, and increase the possibility of success.

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