Testing method for veer of table tennis ball

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Abstract: Under the premise of fully respecting Technical Leaflet T3 developed by the International Table Tennis Federation (ITTF), this paper proposes an effective method for testing the veer degree of the table tennis ball based on airflow suspension and machine vision. By sequentially capturing the images of the ball in the stable state of spinning and suspension, a set of fitting circle centres from different circular sections can be obtained by circle fitting through the least square method. The minimum circumscribed circle (MCC) diameter of these centres is served as a basic parameter to evaluate the veer degree of the ball. Experimental results show that this diameter can effectively reflect the veer degree of the ball. The method proposed in this paper can provide a technical basis for the veer online testing of the table tennis ball.

Key words: table tennis ball; veer; minimum circumscribed circle (MCC)

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0 Introduction

Table tennis is very popular worldwide. The quality of the table tennis ball used in the game is directly related to the appreciation and fairness of the game. However, the current testing method for veer of table tennis ball is still in the period of manual operation, which is subjective, inefficient and incomplete. Besides, this method is of inapplicability to the status of the vigorous development of the ball without seam. Although the International Table Tennis Federation (ITTF) gives a supplementary explanation of the testing method for veer of the ball without seam in Technical Leaflet T3: The Ball (Version for 40 mm Balls)[1], this method is still based on the characteristics of the ball with seam. Therefore, the rationality of this method for the ball without seam recommended in Technical Leaflet T3 remains to be studied.

1 Current testing method for veer

Technical Leaflet T3 developed by ITTF requires that the testing method for veer should use the veer device, as shown in Fig. 1.

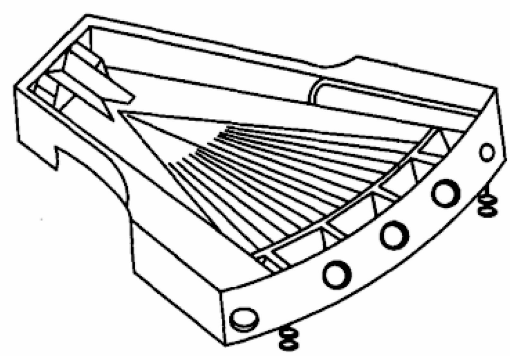

Fig. 1 Veer device

Veer is measured by rolling the ball down a slight incline onto a horizontal surface. The incline is 100 mm long at 14 degrees to the horizontal; on a table that is 100 cm long, a rolling time of about 3 s is sufficient. For the ball with seam, it needs to roll twice on the seam, and once about an arbitrary axis. For the ball without seam, it needs to roll one time on red, blue and green lines which are drawn artificially and perpendicular to each other. In three roll-

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ing tests, the maximum distance that the ball deviates from a straight line, the "centre line", is measured to reflect the veer degree of the ball as it rolls across the surface.

In fact, only when the veer direction (The line connecting the ball's centre of mass and centre of form) is perpendicular to the rolling cross section, the maximum distance mentioned above can reflect the veer degree of the ball. On the contrary, when the veer direction is coplanar with the rolling cross section, the ball will not roll off the "centre line" even if there is veer in it.

Three traces shown in Fig. 2 are obtained according to the method recommended in Technical Leaflet T3 with a ball whose veer direction has been determined in advance. The ball's veer direction is separately perpendicular or parallel to the red, blue and green line cross sections. The testing results of traces 1 and 2 are basically the same and approximately equal to zero. In this case, the veer direction is coplanar with the rolling cross sections. The testing result of trace 3 is the maximum value of all results. In this case, the veer direction is perpendicular to the rolling cross section. In three rolling tests, the testing result of trace 3 can be adopted to reflect the ball's veer degree.

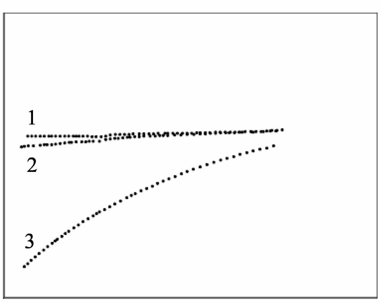

Fig. 2 Ideal traces

The traces shown in Figs. 2 and 3 are based on the same testing conditions except for the rolling cross sections. In this case, the veer direction is not perpendicular to or coplanar with the rolling cross sections. If the maximum distance, the testing result of trace 3, is adopted to reflect the ball's veer degree, it will result in a small testing result and bring the testing error.

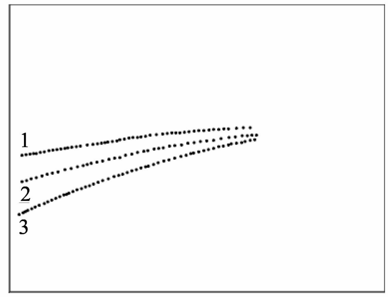

Fig. 3 Actual traces

For the ball with seam, the rolling cross section is the ball seam section; for the ball without seam, the rolling cross sections are three mutually perpendicular line sections which are drawn randomly. Both of these ways cannot guarantee that the veer direction happens to be perpendicular to one of the rolling cross section. Therefore, the veer testing method recommended in Technical Leaflet T3 is random.

Aiming at the randomness in the current testing method for veer, this paper proposes a method for testing the veer degree of table tennis ball based on airflow suspension and machine vision under the premise of fully respecting Technical Leaflet T3 developed by ITTF. The schematic diagram of the testing platform used in this method is shown in Fig. 4, mainly including a camera, a background plate and an air floating platform which consists of a concave sphericity and two air holes.

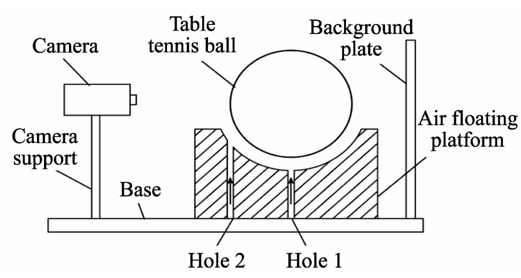

Fig. 4 Schematic diagram of testing platform

The airflow from hole 1 can form an air cushion between the table tennis ball and the concave sphericity and thus the ball can be suspended in the air; the airflow from hole 2 can make the suspended ball spin. By choosing a concave sphericity size and airflow velocity reasonably, the table tennis ball could stay in a stable state of spinning and suspension. Based on the premise of the same mass and angular velocity of the ball, the bigger the veer degree is, the bigger its vibration amplitude will be. Based on this phenomenon, the minimum circumscribed circle (MCC) diameter formed by a set of fitting circle centres, which are calculated from the circular sections captured by the camera, can reflect the veer degree of the ball. The testing method for veer of the ball proposed in this paper overcomes the randomness of the current method.

2 Testing principle

As the table tennis ball is in the fluid environment, it is very complicated to study fluid viscosity, fluid motion, fluid flow resistance and Magnus effect. Accordingly the testing model is simplified in a certain degree in order to explain the testing principle easily in this paper.

2.1 Ideal table tennis ball

2.1.1 Static analysis

As shown in Fig. 4, take an ideal table tennis ball as the research object, and place it in the ideal concave sphericity. Here, the ideal table tennis ball has a high spherical profile tolerance and its centre of form coincides with its centre of mass. By choosing a concave sphericity size and airflow velocity of hole 1 reasonably, an air cushion that is symmetrical distribution can be formed between the ball and the concave sphericity. The lifting force generated by the air cushion can balance the gravity of the ball and make the ball suspend statically in the air. If the concave sphericity is too large, the gap between the ball and the concave sphericity will increase, and the air cushion will not be strong enough to make the ball suspend. If the concave sphericity is too small, an interference that blocks the ball's follow-up movement will occur. Therefore, it is essential to design a reasonable concave sphericity size. Here, the direction of hole 1 is vertical upward.

2.1.2 Dynamic analysis

As shown in Fig. 4, the airflow from hole 2 provides the circumrotate momentum for the ball and breaks the balance mentioned in Section 2.1.1. However, in the state of suspension, the balance can be automatically reestablished by adjusting the thickness of the air cushion. The spinning ball is accelerated du to the airflow from hole 2, and the bigger the angular velocity is, the bigger the friction between the table tennis ball and the air will be[2]. When the resistance moment generated by the friction is equal to the moment generated by the airflow from hole 2, the table tennis ball will stop acceleration and stay in a uniformly spinning state. At this time, the ball's centre of form is stationary relative to the air floating platform. Here, Hole 2 is set at 20 mm to the hole 1 and the nominal diameter of the table tennis ball is 40 mm.

2.2 Veer table tennis ball

For the ball with veer, it vibrates while spinning because of the veer. As shown in Fig. 5, let O be the ball's centre of mass, C be the centre of form. The ball rotates around the X-axis during the balance process. Let rotation plane pass C and be perpendicular to the X-axis, shown as plane YCZ. Let e be the distance between O and C, which is defined as the ball's veer value, r be the distance between O and the X-axis. The ball is affected by gravity G acting on O, which causes centre of mass O to rotate around the Z-axis. The effect of this force is to push O closer to YCZ until O goes into it. As a result, after balancing, r is equal to e.

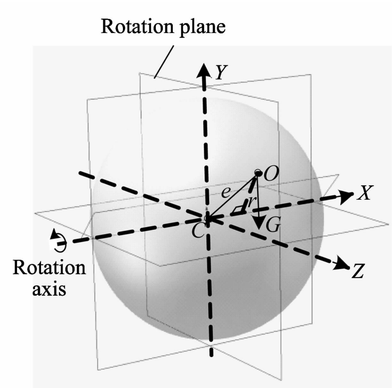

Fig. 5 Schematic diagram of testing principle

A theoretical measurement plane is defined as a plane which is passing through the hole 2's central axis and is parallel to the gravity G. The spin of the ball is caused by the airflow from hole 2. After balancing, rotation plane should pass through the hole 2's central axis as well, namely the rotation plane coincides with the theoretical measurement plane.

The suspended ball does the centrifugal motion in the tangential direction of the velocity, which changes the thickness of the air cushion, the airflow velocity around the ball and the pressure distribution around the ball. These changes cause changes in lifting force and pressure gradient force[3], and hinder the centrifugal motion. The ball will achieve a dynamic balance under the actions of gravity whose magnitude is unchanging, lifting force and pressure gradient force whose magnitude are changing. The inertia centrifugal force F_{cf} can be used to describe the centrifugal motion, the formula is

$$F_{cf} = m\omega^2 r, \tag{1}$$

where m is the ball's mass; ω is the ball's angular velocity; r is the distance between O and X-axis, as shown in Fig. 5. After balancing, r is equal to e, and thus Eq. (1) can be rewritten as

$$F_{cf} = m\omega^2 e. \tag{2}$$

If m and ω are constant, F_{cf} is directly proportional to e. The bigger the veer value is, the greater the inertia centrifugal force will be. At the same time, the change in vibration amplitude can cause changes in lifting force and pressure gradient force to form a new dynamic balance automatically. As a result, the vibration amplitude of table tennis ball is directly related to its veer degree in this condition. In fact, the horizontal component of F_{cf} varies with the spin of the ball. Taking the limitation of the concave sphericity into account, the horizontal projection of the ball's trajectory is complex, thus the ball's motion law is complex too. However, we mainly focus on the ball's vibration amplitude, rather than the motion law. With a camera whose optical axis is perpendicular to the theoretical measurement plane, the ball's outline can be recorded and then a set of fitting circle centres from different circular sections can be obtained. The MCC diameter of these centres can reflect the maximum vibration amplitude of the ball. As long as we use this diameter, the ball's veer degree can be easily reflected. The testing method for veer of table tennis ball described here can achieve veer classification, and solve the problem of mass centre testing which cannot be contacted.

In this paper, the pinhole camera model is used as the camera imaging model. As shown in Fig. 6, O_c is the perspective centre, l is the tangent circle which is determined by the light ray of the maximum camera field and the ball surface. The actual measurement plane, the tangential circle plane, does not coincide with the theoretical measurement plane, but is parallel to it. It reflects the actual source profile of the testing data. The data of the theoretical measurement plane can be obtained by camera calibration.

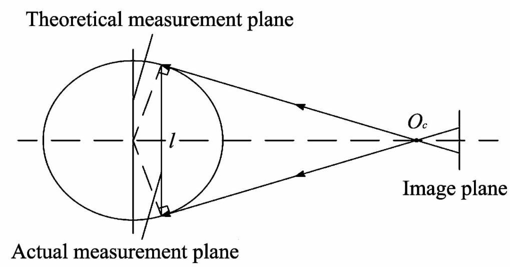

Fig. 6 Pinhole camera model

3 Testing process

3.1 Testing platform

In order to reduce the difficulty of image processing and enhance the contrast of the ball's outline, the testing platform is painted with black paint and the background plate is installed in the view of the camera. The testing platform is shown in Fig. 7.

Fig. 7 Image of testing platform

Experimental results show that when the airflow velocity of hole 1 is 32 L/h, hole 2 is 72 L/h and the diameter of the concave sphericity is 42 mm, the table tennis ball, whose veer is in a certain degree, can suspend and spin stably.

3.2 Image processing

As we known, the image captured by the camera cannot be used directly due to noise interference. Median filtering is the nonlinear filter mainly used to remove the noise from an image, and it is more effective than convolution when the goal is to simultaneously reduce noise and preserve edges[4]. Therefore, a 3×3 neighborhood around the corresponding pixel in the input image is used in this paper.

Contour extraction[5] is the key elements to inspection and it is one way in which regions of the image that is likely to correspond to objects of interest can be identified. Here, IMAQ Extract Curves VI of Labview is used to extract the contour of the binary image obtained by threshold segmentation. Thus, the ball's outline can be obtained easily and be used for fitting a circle in the follow-up processes.

3.3 Veer calculation

As shown in Section 2.2, the MCC diameter of a set of fitting circle centres from different circular sections can reflect the ball's veer degree and these centres can be obtained easily by circle fitting through the least square method.

MCC has a high computational complexity[6-7]. To simplify the calculation, LIU et al.[8] proposed an approximate calculation method which is adopted in this paper. Firstly, construct a convex hull by using the centres mentioned above. Secondly, the centre of the least square circle can be obtained by fitting the vertexes of the convex hull. After that, the doubling of the maximum distance between the centre and the vertexes of the convex hull is regarded as the approximate diameter of MCC. Finally, the approximate diameter is served as a basic parameter to evaluate the veer degree of the ball.

3.4 Flow chart of testing process

Fig. 8 shows the flow chart of the testing process, which gives the specific process from the ball's image to the ball's veer degree.

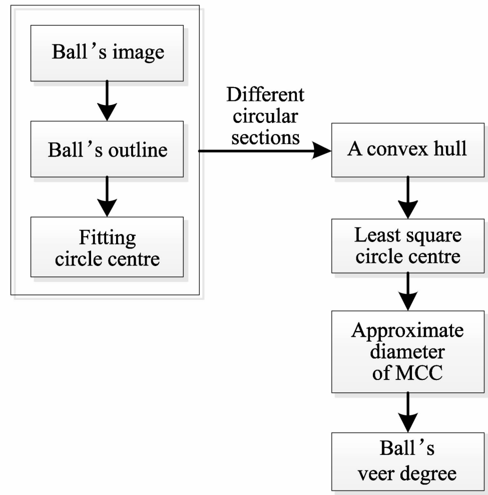

Fig. 8 Flow chart of testing process

3.5 Camera calibration

All data used in Section 3.3 are expressed in pixels, but what we need is a physical size, therefore it is necessary to establish a conversion relationship between them. Pixel equivalent is the ratio of the physical size and its pixel size and can be represented as

$$k = D/d, \tag{3}$$

where k is the pixel equivalent; D is the physical size; d is the pixel size of the physical size. The accuracy of the pixel equivalent is directly related to system precision[9]. Law of standard component is adopted to calibrate the camera before testing.

The key to two-dimensional measurement was to ensure that the camera optical axis is perpendicular to the measurement plane. The size obtained by the camera is a size with projection measurement error. Here, the projection plane is perpendicular to the camera optical axis. The parallel projection size of the standard sphere in any direction is equal to the diameter, which will not bring the projection measurement error. Thus the standard sphere is an ideal standard component. When the standard sphere and table tennis ball have the same diameter, the calibration process and the testing process will have the same conversion relationship between the theoretical measurement plane and the actual measurement plane. Based on this, the data of the theoretical measurement plane can be obtained without specific calculation. Finally, a 40 mm standard sphere was chosen as the standard component.

Camera lens is a non-ideal optical system with distortion. The larger the field is, the bigger the distortion will be. And the lens magnification is various to different object distances. The calibration process and the testing process are completed on the same testing platform, which makes them have the same field and object plane, ensuring the same distortion and magnification. In addition, it is necessary to ensure that the camera exposure, the method of contour extraction and the visual environment are consistent during these two processes. If any changes occur, the camera needs to be recalibrated.

4 Experiments

4.1 Camera calibration test

Over 66 mm×52 mm field of view, a digital camera whose resolution is 1 280 (H)×1 024 (V) picture elements was chosen to record the outline of the ball.

A calibrated precision ball was chosen as the standard sphere, whose mean diameter is 39.998 3 mm, maximum form error is 0.05 μm, maximum uncertainties of roundness measurement is ±0.05 μm and maximum uncertainties of diameter measurement is ±0.5 μm. Pixel size of the ball's diameter was measured several times by using the testing platform, and the mean pixel size of these measurements is 778.473 1 pixels. By using Eq. (3), it can be calculated and pixel equivalent k is 0.051 4.

4.2 Veer reference value test

Beacuse the use of the veer device is random, only when the veer direction is perpendicular to the rolling cross section, the distance that the ball deviates from the "centre line" can reflect the veer degree of the ball. Therefore, in order to determine the veer reference value, the veer direction needs to be known in advance. It is worthwhile to note that determining the veer direction in advance is not part of the testing method for veer recommended in Technical Leaflet T3.

In this experiment, the liquid suspension method was adopted to determine the veer direction and the alcohol that has small coefficient of surface tension was chosen as the suspension liquid. The principle of this method is as follow: under the action of gravity, the line connecting the ball's centre of mass and centre of form will turn to the vertical direction so that the ball's gravitational potential energy will reach the minimum. By using a camera (fixed visual angle), the top point of the ball can be obtained and the veer direction can be determined.

And then, adjust the ball's veer direction perpendicular to the rolling cross section, roll off the ball stably from veer device for several times, and take the mean of the distances that the ball deviates from the "centre line" as the veer reference value. Three table tennis balls that are numbered 1, 2 and 3 were taken as our testing objects. Table 1 displays the veer testing data of these three balls after determining the veer direction.

Table 1 Veer reference value results

Time	Ball 1	Ball 2	Ball 3
1	115	185	220
2	105	200	240
3	110	190	215
4	110	185	250
5	120	175	250
6	115	170	250
7	100	170	235
8	120	180	200
9	100	175	210
10	100	190	250
Veer reference value	110	181	232

4.3 Technical Leaflet T3 test

Testing method for veer recommended in Technical Leaflet T3 was taken to test the balls mentioned in Section 4.2. Roll off the ball stably from veer device on red, blue and green lines. In three rolling tests, the maximum distance that the ball deviates from the "centre line" as it rolls across the surface is measured to reflect the ball's veer degree. Repeat the test for several times, each time with a different group of rolling cross sections. The distribution map of these veer testing data is shown in Fig. 9. The reference values in Fig. 9 are determined in Section 4.2.

As shown in Fig. 9, testing data of these balls have a significant overlap. The variable quantity of data is greater than 65%, which means the testing method for veer recommended in Technical Leaflet T3 cannot achieve veer classification. Here, variable quantity is defined as the ratio of the data range and the data mean.

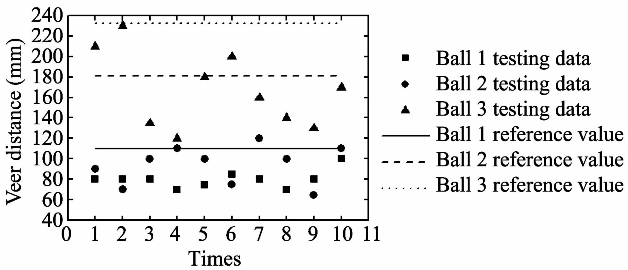

Fig. 9 Distribution map with method of Technical Leaflet T3

4.4 Airflow suspension test

Use the testing platform shown in Fig. 4 to test the balls mentioned in Section 4.2. One of the images from the testing process is shown in Fig. 10. The lower part of the ball is blocked by the air floating platform, thus only the upper part is used for contour extraction, as shown in Fig. 11.

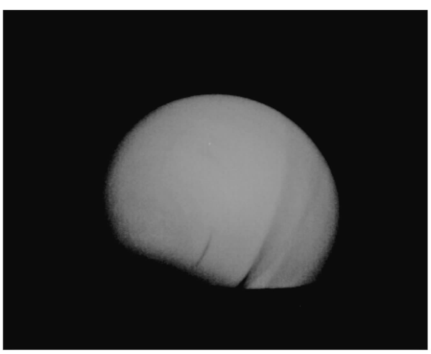

Fig. 10 Image of testing process

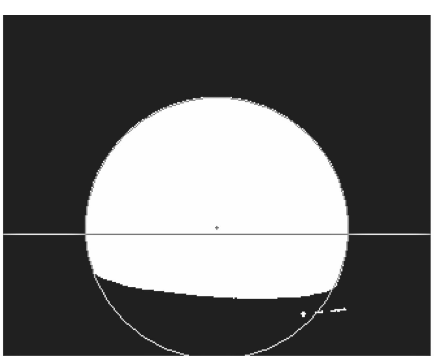

Fig. 11 Image of contour extraction

After the ball is balanced, we captured 1 000 frames of images sequentially and calculated a MCC diameter. Each table tennis ball is tested for 10 times. The distribution map of these MCC diameters is shown in Fig. 12.

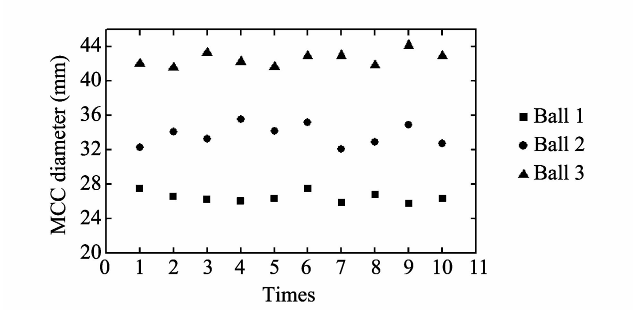

Fig. 12 Distribution map with method of airflow suspension

As shown in Fig. 12, the MCC diameters have the same trend as the veer reference values shown in Section 4.2, which verifies the validity and rationality of this method. The variable quantity of these data is less than 15%, which means the testing method for veer proposed in this paper can achieve veer classification.

By contrasting Fig. 9 and Fig. 12, the veer testing method proposed in this paper has improved greatly in the change range of the testing data and it can achieve veer classification which cannot be done by the method recommended in Technical Leaflet T3.

5 Conclusion

Under the premise of fully respecting Technical Leaflet T3 developed by ITTF, the method proposed in this paper overcomes limitations of the current testing method for veer, which is valid, rational and can provide a technical basis for the online testing. The testing results of this method are mainly affected by the ball's veer degree, but to some extent, it is also affected by the ball's surface quality, airflow stability and some other secondary factors. Thus, the optimization goal of the this testing method for veer proposed here is to improve the stability of the testing data and solve the disturbances from the secondary factors.

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乒乓球偏心检测方法

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摘　要： 在充分尊重现行国际乒乓球联合会制定的新 T3 标准的前提下，提出了一种基于气流中悬浮和机器视觉的乒乓球偏心的检测方法。该方法通过多次有序摄取处于悬浮旋转状态的乒乓球图像，以不同截面圆最小二乘拟合圆圆心点集的最小包容圆直径作为评价乒乓球偏心程度的基本参数。实验结果表明，拟合圆圆心点集的最小包容圆直径能有效反应乒乓球的偏心程度。该方法为乒乓球偏心的在线检测提供了技术基础。

关键词： 乒乓球；偏心；最小包容圆

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