880. Interface dynamics of table tennis

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(Received 11 September 2012; accepted 4 December 2012)

Abstract. The purpose of this study was to discussed the Interface Dynamics of Table Tennis. The experiment was conducted based on the imaging principle of hot air flowing. We adopted the imaging principle of hot air flowing through rotating ball to simulate the flow phenomenon generated by air flowing through table tennis after striking by different rackets. The conclusion and suggestion after analyzing and discussing are described below: (1) The rotation of table tennis ball and flow field will change based on the roughness of rackets, which making its own contribution to the existence of changes in the rotation of table tennis ball. (2) It can learn that angle should forward 30 degrees with flat strike, 25 degrees with short particles and 20 degrees with long particles at the rotational speed of 7500 rpm. All flow fields of different rackets are similar.

Keywords: table tennis, interface dynamics, flow.

Introduction

The table tennis game originated as a sport in Britain during the early nineteenth century, and the techniques of table tennis were promoted, especially the improvement of the rubber racket. The skills and strategies of table tennis were greatly changed as well. In 1903, the British Kut (Goodea) invented the shot rubber particles, bringing the rotation generation of table tennis. In 1951, both of the speed and strength of table tennis increased by the invention of sponge racket [1]. The techniques and rotation of table tennis have been extensively changed since the long-pimpled rubber was invented in 1959. Therefore, the racket plays an important role on the table tennis techniques. Nowadays, the academic research focus mostly on the performance, coefficient of restitution or applications of rubber instead of the characteristics of rubber [2-4].

Rotation is an integral part of modern table tennis tactics from the beginning to the end of the game. Particularly, as racket performance is continuously innovated and improved, high-speed spin is a crucial factor to the player's success or failure in the competition. Hence, sports mechanics of rotating table tennis ball shall be further analyzed and understood. Due to importance of rotating table tennis ball in table tennis, scholars at home and abroad investigated the influential factors to the rotation of table tennis ball by means of mechanics principle analysis, numerical method, kinetic mathematical modeling and computer simulation, respectively and proposed the remarkable viewpoint to analyze the equation of motion of table tennis and the relationship among force, speed and location while batting and described the rotating ball is much superior in table tennis game and proposed the way for speed to against with [5-8]. Yu-Fen Chen et al. [9-10] adopted the IR thermal imager as instrument and this experiment was based on the imaging principle of hot air flowing through rotating ball to successfully conduct the system of experimental analysis of rotating table tennis balls. This study also discussed the flow field distribution of rotating and stationary table tennis ball under forced convection impact.

IR thermal imager is one of the modern physics detection techniques by using the photographic principle of infrared radiation to study the distribution and variations of temperature, also known as the temperature difference photography. The application on IR thermal imager with the characteristics of non-contact and non-destruction is much wider since the rapid scanners have been made great progress in recent years. The measurement range of thermal imager can be a wall even the entire surface of the ocean for detection, survey and mapping in military, examination in industrial materials, medical diagnostics, civil engineering and so on. Currently, some researchers detected the body temperature of specific parts of athletes with IR thermal imager in order to obtain the adaptation situation of sports injuries or sports training of athletes [11], showing the IR thermal imagers were applied extensively.

In order to easily understand the characteristics of rubber, based on the IR thermal imager with the characteristics of non-contact and non-destruction, this experiment adopted the imaging principle of hot air flowing through rotating ball to simulate the flow phenomenon generated by air flowing through table tennis after striking by different rackets. What is the flow field effect generated after striking by different rackets while detecting the rotating table tennis ball by the thermal imager? This study provided the different flow field effects generated by different rackets for researchers or athletes' reference.

Methods

Experimental equipment

Experimental equipment (shown in Fig. 1) for this study consists of four systems, including (1) air supply system; (2) experimental testing system; (3) heat supply system; (4) thermal image capture system. The gas for the experiment is compressed air, which is produced by 10 HP mute type air compressor and stored in gas receiver. When the gas is pressurized to rated pressure, it flows through oil & gas filter and refrigeration dryer for moisture filtering, then air flow is controlled by SIN-DP electronic flow controller; finally, air enters into the testing system after being heated by a set of high-power heater. Experimental testing system is provided with an open space, which is mainly formed by table tennis ball, drive motor and baffle plate. The table tennis ball with diameter up to 40 mm is rotated by differential motor, with its speed controlled by frequency converter. The thermal image capture system used in the research is NEC TH9100PM/PWV IR full-face thermal imager, which is operated by a principle to track the emissivity on the object surface for capturing the temperature. But, a black baffle plate must be arranged between the table tennis ball and drive motor for tracking easily the emissivity of the thermal flow field via the IR thermal imager. Finally, the captured images are sent to the computer for image analysis.

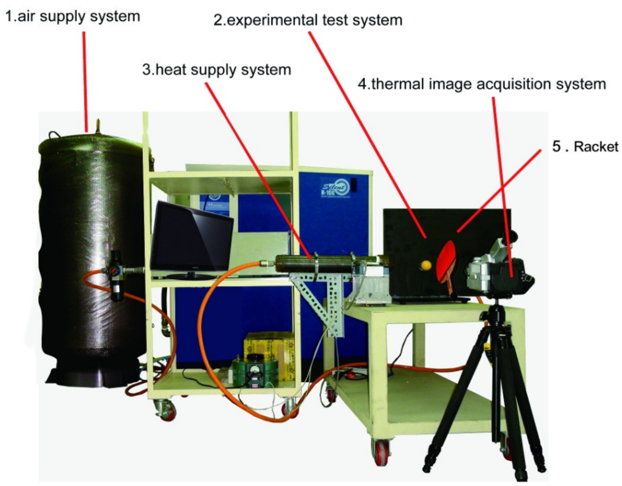


Fig. 1. Experimental equipment

The main parameters in this experiment are the rotation (Ω), the heat (W), Reynolds number (Re) and the rackets angle (θ), respectively. The heat flux for this experiment is set as 30 V and Reynolds number (Re) set as 6800; the rotational speed (Ω) set as 0 rpm, 1500 rpm, 3000 rpm, 4500 rpm, 6000 rpm and 7500 rpm, respectively. Meanwhile, the rackets angle set as 0 degrees, 10 degrees, 20 degrees, and 30 degrees.

The flat, short particles and long particles rackets are separately placed two centimeters from the table tennis ball in order to discuss its field distribution at different rackets after striking, respectively.

The experimental method

The experiment was conducted based on the imaging principle of hot air flowing through table tennis, so as to simulate the flow phenomenon generated by air flowing through table tennis after striking by different rackets. The research focuses on the application to table tennis movement sports on the basis of the experimental result for effectively enhancing the techniques of movement level, the experimental procedures are described below.

First, place the table tennis ball at appropriate position in the testing system and racket is placed two centimeters from the table tennis. Then, startup temperature capture device, experimental computer, air compressor, power supply for heating, motor frequency converter, flow meter and drier, etc. When the pressure of compressed air is increased to a certain value, adjust the flow meter to a setting value, then allow the compressed cold air to flow through the heating tube and spray the generated hot air stream onto the table tennis ball of test section, and adjust the power supply to a heating voltage of 30 V for continuous heating. Then, adjust the motor frequency converter to the frequency required for the speed. The images captured by the thermal image capture system are converted by a computer into a level chart for analysis of thermal flow field. After finishing one group of image capturing, the experimental parameters will be changed for next groups.

The theoretical analysis

In this research, the theory of sports mechanics of rotating table tennis will mainly focus on the governing equation and boundary condition, the related introduction is briefly described below.

The governing equations

To simplify the mechanics analysis of the rotating table tennis ball, the flow field around the rotating table tennis ball has been made some assumptions as follows:

(1) The type of flow around the table tennis ball is fluid, steady, laminar and incompressible.

(2) The property of flow around the table tennis ball is firm.

(3) The flow field around the table tennis ball is axisymmetric, (i.e. $\partial/\partial\theta = 0$).

The non-dimensional parameters of flow field around the table tennis ball are set as follows:

$$R = \frac{r}{\delta},\ Z = \frac{z}{\delta},\ U_r = \frac{u_r}{r_i\Omega},\ U_\theta = \frac{u_\theta}{r_i\Omega},\ U_z = \frac{u_z}{r_i\Omega},\ \mathrm{Re} = \frac{r_i\Omega\delta}{\nu},\ \mathrm{Pr} = \frac{\nu}{\alpha},\ \Theta = \frac{T - T_o}{T_i - T_o} \quad (1)$$

In addition, the stream function (Ψ) and rotating vorticity (ω) around the table tennis ball have been further calculated as follows:

$$U_r = -\frac{1}{R}\frac{\partial \Psi}{\partial Z},\ U_z = \frac{1}{R}\frac{\partial \Psi}{\partial R},\ \omega = -\frac{\partial U_z}{\partial R} + \frac{\partial U_r}{\partial Z} \tag{2}$$

The motion equation around the table tennis ball can be converted as follows:

$$-\omega = \frac{\partial^2 \Psi}{\partial R^2} + \frac{\partial^2 \Psi}{\partial Z^2} \tag{3}$$

$$\frac{\partial(U_r\omega)}{\partial R} + \frac{\partial(U_z\omega)}{\partial Z} - \frac{2U_\theta}{R}\frac{\partial U_\theta}{\partial Z} = \frac{1}{\mathrm{Re}}\{\frac{\partial}{\partial R}[\frac{1}{R}\frac{\partial}{\partial R}(R\omega)] + \frac{\partial^2 \omega}{\partial Z^2}\} \tag{4}$$

$$U_r\frac{\partial U_\theta}{\partial R} + U_z\frac{\partial U_\theta}{\partial Z} + \frac{U_r U_\theta}{R} = \frac{1}{\mathrm{Re}}[\frac{1}{R}\frac{\partial}{\partial R}(R\frac{\partial U_\theta}{\partial R}) + \frac{\partial^2 U_\theta}{\partial Z^2} - \frac{U_\theta}{R^2}] \tag{5}$$

$$U_r(\frac{\partial \Theta}{\partial R} + U_z\frac{\partial \Theta}{\partial Z}) = \frac{1}{\mathrm{Re\,Pr}}[\frac{1}{R}\frac{\partial}{\partial R}(R\frac{\partial \Theta}{\partial R}) + \frac{\partial^2 \Theta}{\partial Z^2}] \tag{6}$$

Boundary conditions

In the axial direction of $Z = 0$ and $Z = L/r_i$ of the table tennis ball, its boundary condition is as follows:

$$U_\theta = \Psi = \frac{\partial \Theta}{\partial Z}0,\ \omega = \frac{-1}{R}\frac{\partial^2 \Psi}{\partial Z^2}, \tag{7}$$

while $R = r_i/\delta$,

$$U_\theta = \Theta = 1,\ \Psi = 0,\ \omega = \frac{-\partial}{\partial R}\left(\frac{1}{R}\frac{\partial \Psi}{\partial R}\right), \tag{8}$$

while $R = r_o/\delta$,

$$U_\theta = \Psi = \Theta = 0,\ \omega = \frac{-\partial}{\partial R}\left(\frac{1}{R}\frac{\partial \Psi}{\partial R}\right) \tag{9}$$

The air resistance of table tennis ball movement

This research aims to calculate the air resistance of the rotating ball based on law of Dynamical Similarity. The air resistance can be calculated by the following equation:

$$R_a = C_X\frac{\rho}{2}SV^2 \tag{10}$$

In this equation C_X represents air resistance coefficient with non-units; ρ represents air density (per unit volume of air quality, gravitational unit is $\mathrm{kgs}^2/\mathrm{m}^4$, and $\rho = 0.125 = 1/8\ \mathrm{kgs}^2/\mathrm{m}^4$ under the standard atmospheric pressure of 1 atm and 15 degrees); *S* represents the area of windward side of the table tennis ball (m^2); *V* represents the movement velocity (m/s) of table tennis ball. Based on the air resistance of table tennis ball with geometry shape in equation (10), air density will be proportional to the area of windward side of the table tennis ball and the square of movement velocity of table tennis ball.

The uncertainty analysis of experimental parameter

The inaccuracy is a common problem for engineering experiment because any properties, variables, and data obtained from any engineering measurement are not possible to achieve the absolute accuracy. Therefore, the uncertainty should be first found out before establishing the experimental data and design. It's for sure that range for concerning the uncertainty is quite extensive, especially including measured parameter and calculated parameter. Measured parameter contains the data calculated by any experimental instrument; for example, pressure, electric current, voltage, pipe with geometry shape and flow rate during experimental tests. On the contrary, calculated parameter contains the data parameter should be calculated instead of obtaining directly from experiment; for example, Reynolds number, Nusselt number, Rotation number, centrifugal buoyancy and other parameters can be included.

The error value of measured parameter in the experiment will be caused by the instrument system and reading error, respectively or parameter error will be generated by mathematical interactive calculation. All errors for calculating parameter are combined with measurement parameter error; therefore, the uncertainty analysis of this experiment established the data-reduction equation with uncertainty based on the analysis methods proposed by Colman et al.:

$$F = F(X_1, X_2, X_3, ..., X_n), \tag{11}$$

where F: parameters calculation, X_n: parameters measurement.

The following equation represents the uncertainty of parameters measurement:

$$\delta F = \left[\sum_{i=1}^{n} \left(\frac{\partial F}{\partial X_i} \delta X_i \right)^2 \right]^{1/2} \tag{12}$$

The uncertainty of $\delta X_i = \pm X_i$.

With the above formula of uncertainty analysis, measured parameter and calculated parameter in this experiment are analyzed for uncertain parameter values respectively.

Results and discussion

The flow field changes after striking by different rackets.

The flat, short particles and long particles rackets are separately placed two centimeters from the table tennis ball in this research to simulate in different rackets and angles respectively, and the angle simulation was shown in Fig. 2.

The flow field observation of the experimental results was shown in Fig. 3. In any angle, the wake area will be more smoothly after striking flatly, short particles of wake area will be irregular jagged, and long particles of wake area will be more irregular due to the rough surface. In fact, take backspin ball as an example, the rotation won't change when the player uses a flatracket; however, the rotation will be reduced while using the short particles rackets and rotation will be changed into topspin ball while using the long particles rackets. The result shows the rotation of table tennis ball and flow field will change based on the roughness of rackets, which making its own contribution to the existence of changes in the rotation of table tennis ball.

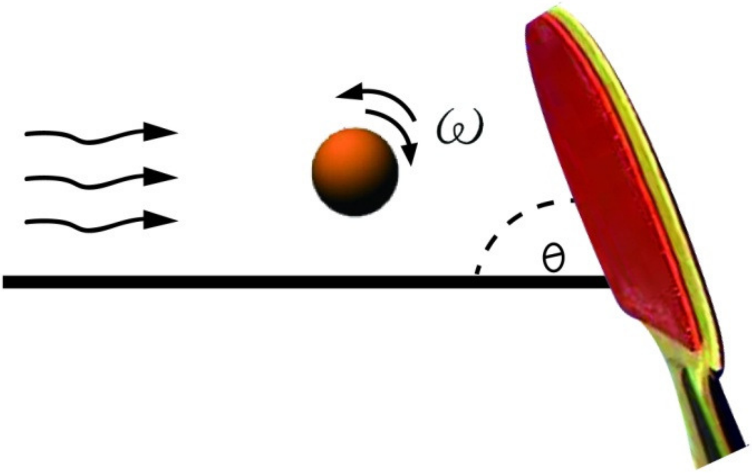


Fig. 2. The racket angle simulation

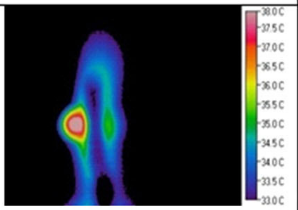
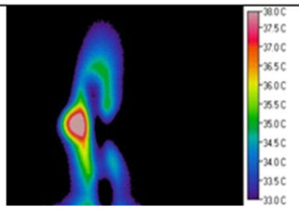
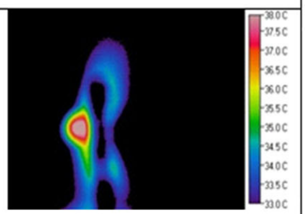
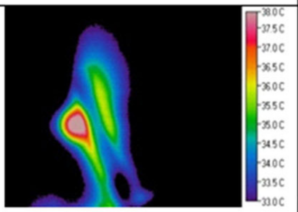
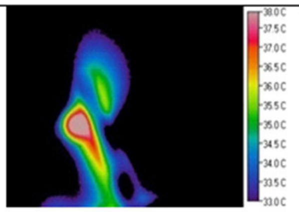
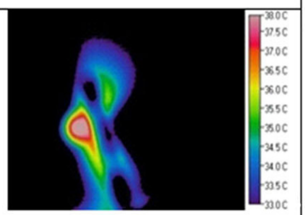
Angle	Flat	Short particles	Long particles
0			
15			

Fig. 3. The flow field of different racket surfaces

The angle transition of different rackets with same rotation

Players should angle forward to strike the table tennis ball back when they receive the topspin balls. The angle will greatly incline with stronger rotation because the bounce force of flat is stronger among short particles and long particles; therefore, the inclined angle of flat should be bigger while dealing with the topspin balls. Fig. 4 shows the flow field observation in different rackets and angles with the same rotation (7500 rpm). It can learn that angle should forward 30 degrees with flat strike, 25 degrees with short particles and 20 degrees with long particles at the rotational speed of 7500 rpm. All flow fields of different rackets are similar.

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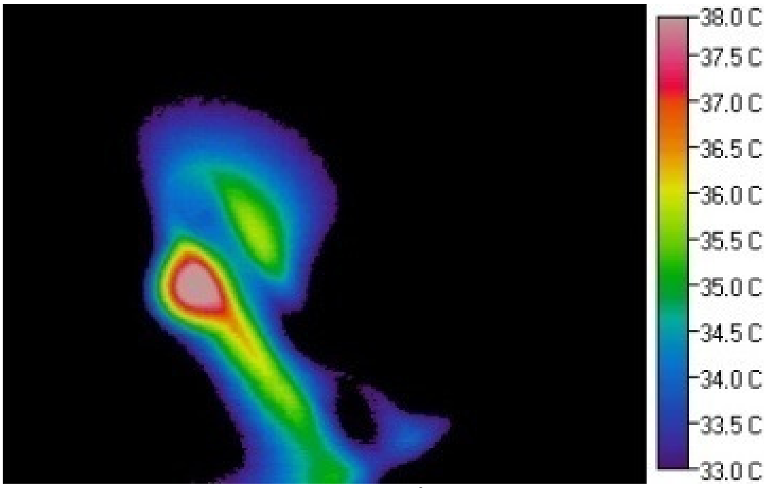
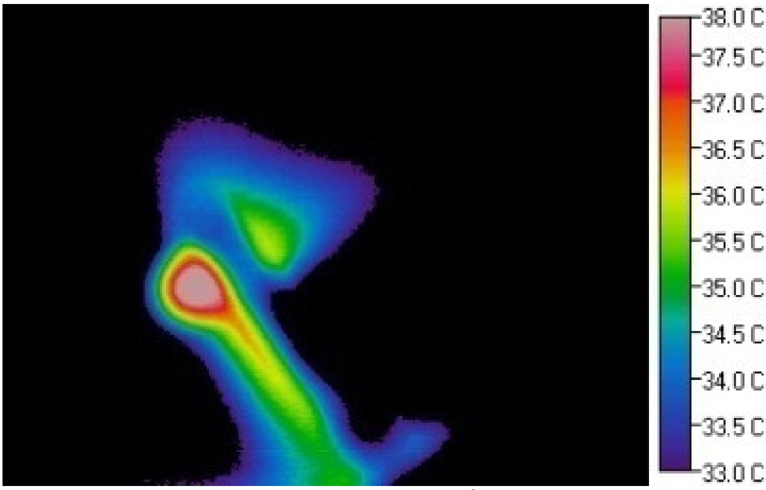
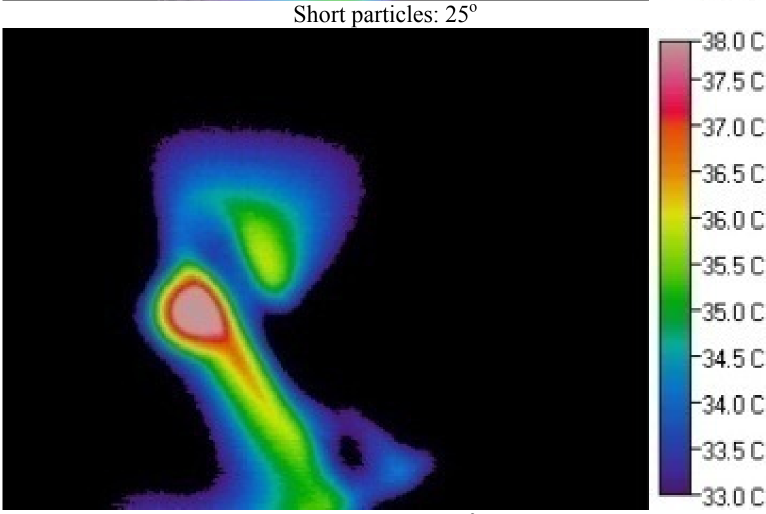


Flat: 30°



Short particles: 25°



Long particles: 20°

Fig. 4. The strike angle of different rackets at the rotational speed of 7500 rpm

Conclusions

The experiment was conducted based on the imaging principle of hot air flowing through table tennis, so as to simulate the flow phenomenon generated by air flowing through table tennis after striking by different rackets. The conclusion and suggestion after analyzing and discussing are described below:
(1) The rotation of table tennis ball and flow field will change based on the roughness of rackets, which making its own contribution to the existence of changes in the rotation of table tennis ball.
(2) It can learn that angle should forward 30 degrees with flat strike, 25 degrees with short particles and 20 degrees with long particles at the rotational speed of 7500 rpm. All flow fields of different rackets are similar.
(3) For players and coaches, the high-speed camera is recommended to take photos for ball rotation with different rackets after striking, and combined available simulation software and flow field of simulation to identify ball changes with different rackets after striking.

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