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Mechanical analysis of tennis racket and ball during impact based on finite element method

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ABSTRACT

Mechanical analysis of tennis racket and ball during impact is of utmost importance to advance development of sports activities. Finite element analysis is often applied to further our understanding of the mechanics of sports equipment. Based on the finite element method, in the present paper FE model of tennis racket and meshing can be developed. The effect of incident angle and velocity of ball, tennis racket material and the relationship with incident/rebound velocity of ball are researched in detail to demonstrate the internal relation during the racket/ball impact. It is found that the incident angle and velocity, the racket material and the ratio of incident/rebound velocity are main influencing factors.

KEYWORDS

Mechanical analysis; Tennis racket; Incident angle; FE model; Racket/ball impact.

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INTRODUCTION

Tennis sport, which has a rich history and the first rules were laid down in 1873, is a beautiful and intense, netting separated without body contact sporting events. As the training method of updating, the modern tennis competition has become the game which should be demanded to have the comprehensive abilities with the faster speed, larger angle, more rotation and higher strength. For example, a professional tennis player can serve an extraordinarily fast ball through an arc-shaped movement of his arm. So it requires that the player has not only strong muscle power but also the ability to control his arm dynamics so that it can make sure to defeat the other players. No matter what the players are professional or amateur tennis enthusiasts, they enjoy the joy of tennis sports but trouble with the pain of injures. The statistics has suggested that over 50% of all people playing tennis regularly have suffered pain at the elbow region at least once in their lifetimes[1-3]. Therefore, it is of utmost importance to research mechanical analysis of tennis racket and ball during impact.

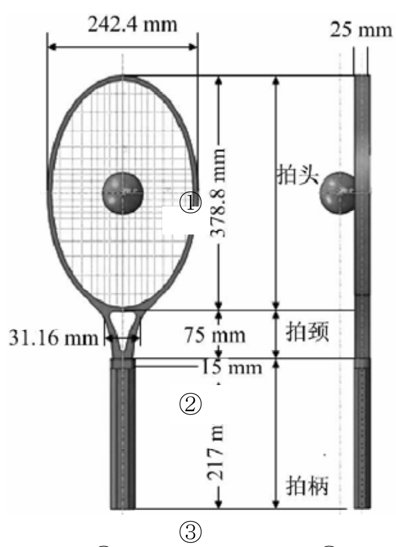
Many experimental and analytical studies[2-3] were used in the past to research various racket parameters and determine their effect on ball return velocity, but these studies only analyzed the duration of ball contact. And most of studies also summarized in their analysis the hand reaction forces during racket/ball impact. Casolo and Ruggieri[2] have developed a different approach by means of an analytical model to take into account the inertia of the arm, forearm, and hand in addition to the racket. Several others investigators[4-6] demonstrated experimentally that ball-rebound velocity after an eccentric impact against a tennis racket remains unchanged for two extreme conditions of grip firmness, i.e., when the grip is firmly clamped and when it is allowed to stand freely on its butt.

Over the past decades, a number of authors have developed tennis ball/bat impact models of varying complexity. James et al. (2012)[7] presents a rigid body model of a tennis bat based on Newtonian mechanics. Smith and Singh[8] present a finite element (FE) model of a cricket ball/bat impact. A linear visco-elastic material model was applied to the ball, with material coefficients selected to provide agreement with a load-time curve for a ball impacting a load cell at 27m/s. A linear elastic material model was applied to the handle of the bat and a linear orthotropic material model was applied to the blade. The FE model for the ball/bat impact was shown to be in good agreement with experimental data, in terms of the rebound speed of the ball. However, despite independent characteristic of the ball for an impact on a fixed rigid surface, the material coefficients applied to the ball required further adjustment to achieve the level of fit presented for the ball/bat model.

The process of impact tennis racket is a material nonlinearity, geometric nonlinearity and contact nonlinear impact process. The objective of this paper was to analyze and validate the internal relation during the racket/ball impact. Based on the finite element method, in the present paper FE model of tennis racket and meshing can be developed. The effect of incident angle and velocity of ball, tennis racket material and the relationship with incident/rebound velocity of ball are researched in detail.

MECHANICAL ANALYSIS MODEL BY FEM

Generally speaking, mathematical size model of tennis racket and ball in detail is shown in the Figure 1. The tennis racket is made up of racket upper, middle part and bottom (see Figure 1). Every part can be made by various kinds of materials, such as wooden, GRP and CFRP and so on. Consequently, it may lead to different mechanical performance, the impact zone and rebound velocity. In this paper, the finite element method is utilized to simulate the mechanical process during racket/ball impacting. Based on ANSYS software, FE model was developed by meshing the different elements of parts (see Figure 2).



① Racket upper; ② Racket middle part; ③ Racket bottom

Figure 1 : Mathematical size model of tennis racket and ball

The study on the tennis racket and nonlinear impact theory model has been researched by a few of scholars. However, most of the presented models are regarded to be just reduced to the system composed of quality, play tennis spring and damper. The line is viewed as a nonlinear spring bed and the ball string as a linear elastic material simulated by the truss element. In the previous analysis, the frame of racket treated as a rigid body has the effect of simplified calculation, to reduce the computational accuracy. What's more, in the calculated results the tennis racket of elastic deformation force and the effect of movement could not be taken into account. In the present paper, assuming the racket as deformation, the elasticity of the racket and the influence of deformation on the ball have been considered, showing to be in good agreement with the actual situation. The physical parameters of material (Young's modulus, density, poisson's ratio) in every part of tennis racket are shown in the TABLE 1.

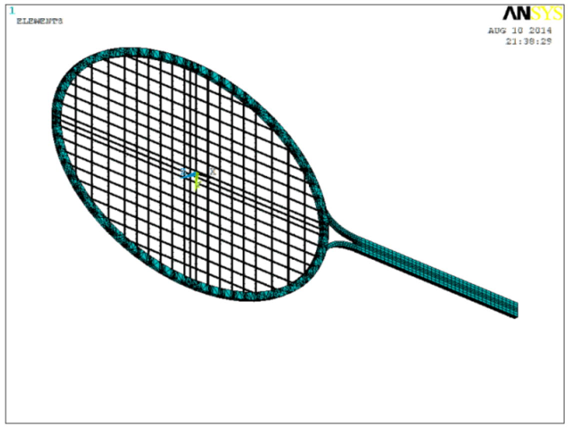


Figure 2 : ANSYS model of tennis racket

TABLE 1 : Physical parameters of material

Racket parts	Young's modulus E (GPa)	Density, ρ ($\times 10^{-6}$kg/mm^3)	Poisson's ratio υ
Frame of racket	25	1.75	0.3
Racket bottom	25	1.75	0.3
Prince	6.895	1.068	0.25

RESULTS AND DISCUSSION

The effect of incident angle and velocity of ball

The incident angle is formed by the impact with tennis balls and tennis rackets (see Figure 3). Maeda et al. has studied on the friction characteristics of holding a tennis racket to produce 30° to 45°, which is verified as the most meaningful angles. So in this paper incident angles of 30° and 45° are chosen to calculate and consider its influence. The ball is usually impacted by the two styles of flattening and rotation, which is used to compare each other. Relationship with incident velocity of the ball and the reaction force of the racket is shown in the Figure 4. From the graph, it is easily found that the relation between incident velocity of the ball and the reaction force of the racket has the liner relationship as the following:

$$F_y = a \cdot v + b \tag{1}$$

For the other thing, the reaction force with incident Angle of ball 45° is bigger than the one with 30°. When it has the same speed, reaction force produced by the different incident angles is greater to hit the ball. Therefore, it suggests that the greater the incidence angle, the stronger the rotation; the faster the ball speed, the more difficult to impact.

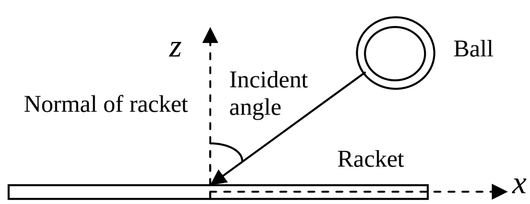
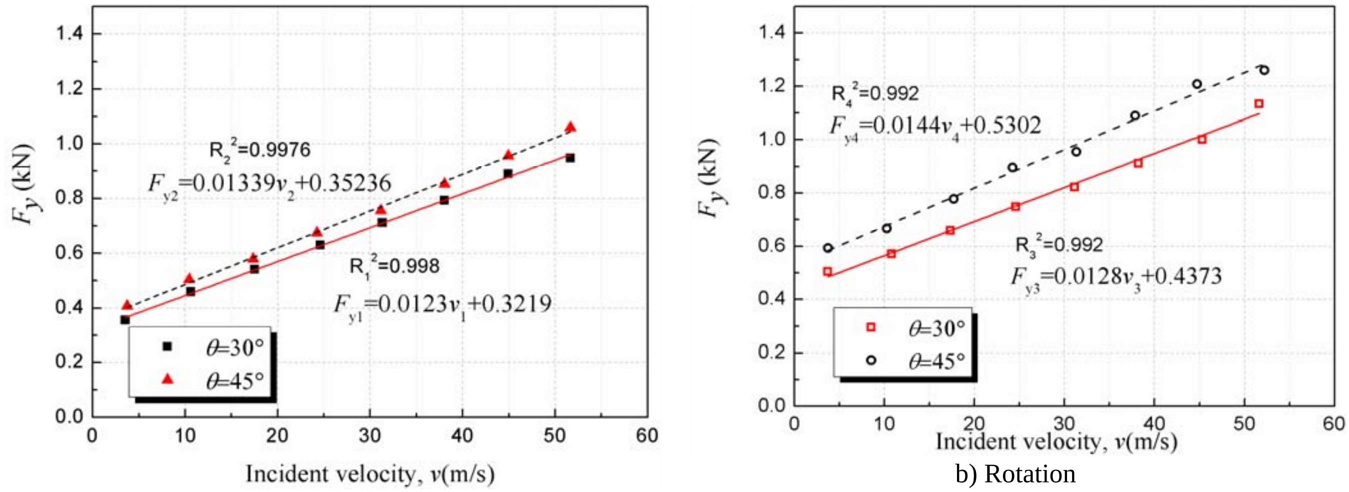


Figure 3 : The diagram of incident angel definition



a) Flattening style

b) Rotation

Figure 4 : Relationship with incident velocity of the ball and the reaction force of the racket

The effect of tennis racket material

Torsion and displacement results of various tennis racket materials are shown in TABLE 2. It is found that the best impact zone of ball with three kinds of tennis rackets (wooden, GRP, CFRP) can be vividly depicted by the pictures. It is usually of great significance to the training of the tennis athletes so that it can improve the competitive power.

TABLE 2 : Torsion and displacement results of various tennis racket materials

Racket material	Weight (*g*)	*E* ($\times10^5$kg/cm^2)	Bending stiffness *EI* ($\times10^6$kg/cm^2)	Torsion stiffness *GIK* ($\times10^6$kg/cm^2)	θ	Δ
Wooden	369	1.0	0.377	-	0.2014	0.5586
GRP	316	1.5	0.262	4.48	0.2394	0.298
CFRP	310	2.28	0.534	8.21	0.1110	0.1896

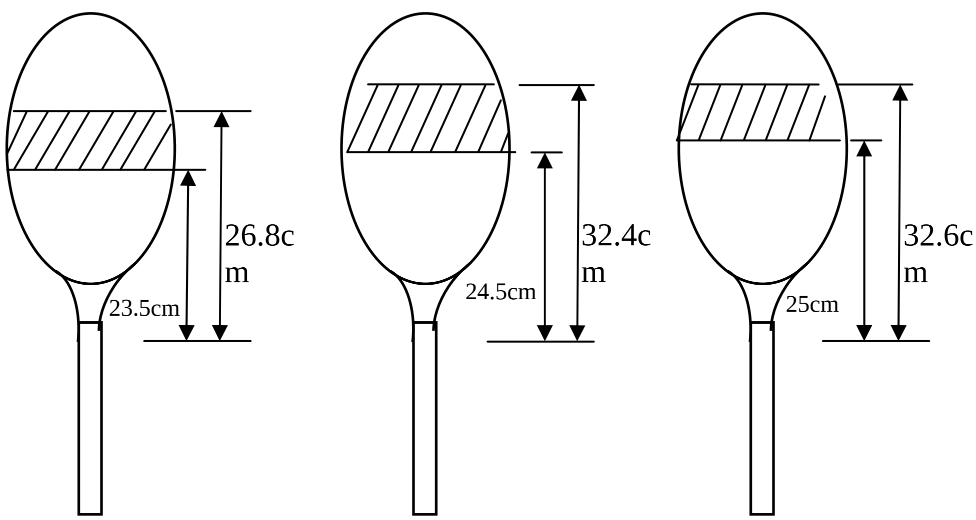


Figure 5 : The best impact zone of ball with three kinds of tennis rackets

The relationship with incident and rebound velocity of ball

Figure 6 shows results for the ball and racket impact. The experimental data shows the ratio of rebound/incident velocity decreased as incident velocity increased. The relationship with incident and rebound velocity of ball can be well found as shown in the Figure 6 and 7. It is shown in good agreement with the results by Smith and Singh in the year of 2008[8].

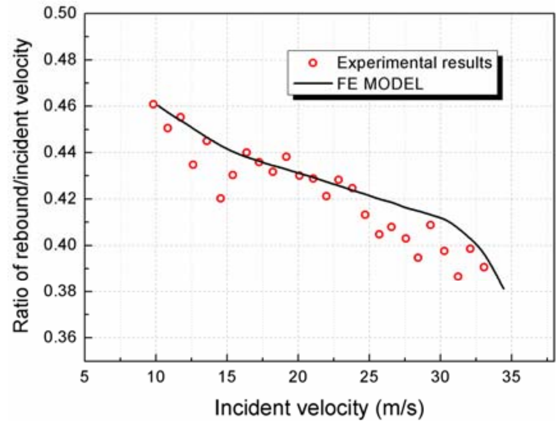


Figure 6 : Relationship with rebound to incident velocity during ball/racket impact

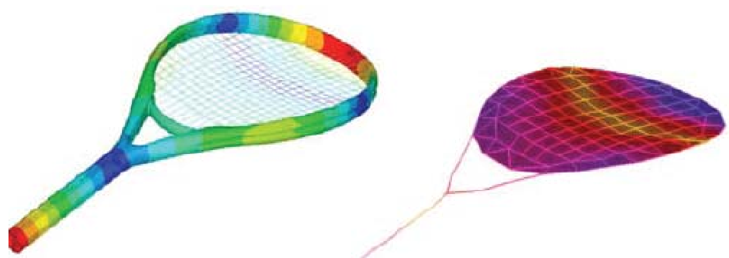


Figure 7 : Racket deformation:(a) FE model; (b) experimental results

CONCLUSIONS

This paper has shown the mechanical analysis of tennis racket and ball during impact based on finite element method. By means of tennis racket model developed by ANSYS, the main conclusions in this paper can be briefly summarized as the following:

(1) The effect of incident angle and velocity of ball was clearly studied and suggested that the relation between incident velocity of the ball and the reaction force of the racket is linear. And it suggests that the greater the incidence angle, the stronger the rotation; the faster the ball speed, the more difficult to impact.

(2) Through the result comparison with three kinds of tennis racket materials, the best impact zone of ball can be found and it benefits to the exercise of tennis players. The relationship with incident and rebound velocity of ball also suggests that the ratio of rebound/incident velocity decreased as incident velocity increased.

REFERENCES

[1] Hiroshi Maeda, Masaaki Okauchi; Friction Properties of the Face of a Hand-Held Tennis Racket[J], Procedia Engineering, **34**, 544-549 **(2012)**.

[2] F.Casolo, G.Ruggieri; Dynamic analysis of the ball-racket Impact in the Game of Tennis[J], Meccanica, **26**, 67-73 **(1991)**.

[3] C.H.Yang, P.C.Lin, Y.J.Chiu; The influence of vibration mode on response of tennis racket[J], Journal of Biomechanics, **40(S2)**, **(2007)**.

[4] Linin Li, Sund Hanyang, H.Chang-soon et al; Effects of string tension and impact location on tennis playing[J], Journal of Mechanical Science and Technology, **23**, 2990-2997 **(2009)**.

[5] T.I.Tijana, J.Bojan, D.Swetta et al; Tennis champion of the future[J], Complex Sports Biodynamics Cognitive Systems Monographs, **2**, 235-297 **(2009)**.

[6] M.Buechler, L.Espino, G.Thompson et al; Vibration modeling and suppression in tennis racket[R], 21st Int. Modal Analysis Conf. (IMACXXI), **(2003)**.

[7] D.James, D.Curtis, T.Allen et al.; The validity of a rigid body model of a cricket ball-bat impact, In: Edited by Drane, P., Sherwood, J. (Ed), The Engineering of Sport 9-Proceedings of 9th ISEA conference, Procedia Engineering, **34**, 682-687 **(2012)**.

[8] L.Smith, H.Singh; An examination of cricket bat performance, In: Estivalet, M., Brisson, P. (Ed), The Engineering of Sport 7-Proceedings of 7th ISEA conference, Springer, Biarritz, 475–482 **(2008)**.