DYNAMIC SIMULATION OF TENNIS RACKET AND STRING

Gu Yao-dong, Li Jian-she

Faculty of Physical Education, Ningbo University, Ningbo, Zhejiang, China

This study is based on the finite element method, a computer simulation method, to analyse the dynamic property of tennis racket and string. A three-dimensional model was created in Solidwork according to the geometry of a mid-size graphite tennis racket. Recording the speed and position data of ball and string collision. Using Ansys to calculate the modal frequency and shape, the results illustrate that the fixed racket's model frequency was smaller than free condition, and the string's vibration character was meaningful to both devise and fix the damper.

KEY WORDS: tennis racket, tennis string, finite element method, model shape, frequency

INTRODUCTION: The tennis racket has been significantly changed, despite the play's rules are substantially the same, because new materials and technologies have been widely used in the equipment manufacturing during the last two decades. This freedom creates some troubles to the designers who now must precisely define the project objectives and identify the key mechanical parameters to be tuned for achieving such objectives. Due to these difficulties some rackets are yet designed only by a qualitative approach mostly based on the intuition and on the experience of the sport technicians; this procedure may be fast and profitable but it is unlikely that really innovative equipment will originate by this way. The finite element method (FEM), which analyses the elastic behavior of rackets under static conditions, providing chances for remarkably differentiation of rackets performances (Glitsch, 1998). Also, considering both the racket and ball (Hatze, 2002), it acquires the information on the time-dependent three-dimensional positions and orientations of racket and ball. The model of the racket with different damp was calculated by finite element method and testified the reliability using instrument (Buechler, 1999). But a great deal of racket model research in free handle condition and the string hadn't been taken as important as the racket.

This paper explores and analyzes the vibration characteristics of both tennis racquet and string. Mathematical simulation can help in the evaluation of the effects of possible changes for tennis equipment requirement which can be adopted by the company in order to make tennis play more spectacular. Because the string vibration mode is so hard to acquire by instrument (Brody, 2002), using FEM may be the best way to analyse the string physics characteristic which is so important to produce a better tennis appliance for elite tennis players. Harmful vibrations are also the major reason to cause a tennis elbow.

METHOD: According to the real tennis racket shape, the model of the racket was created in the Solidwork 2005. Through the Ansys10.0, the frame was modeled using beam elements consisting of 226 elements (fig.1). The material properties were determined from bending and resonance experiments with a modern tennis racket (Young's modulus =30.5GPa, Density=2150kg/m3). The first 3 mode shapes were determined for clamped racket handle condition. The major string (table.1) was divided as 21 elements (fig.2), respectively, with different prestress. Special instrument, applied to detect the ball contact on the string area of a tennis racket, in order to acquire the major collision force and time.

Tab.1 Major string geometry and material data

Length	diameter	area	Young's modulus	Density
346.7 mm	1.6mm	2.01mm^2	2.5GPa	1140kg/ m^3

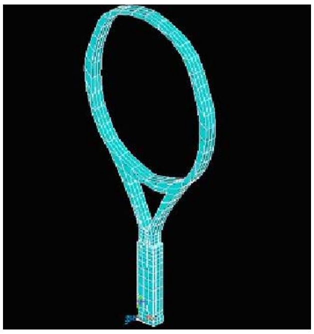


Fig.1 The calculating model of tennis racket

Fig.2 The calculating model of string

In analysis of performance of the equipment in sport, acceleration histories, mode shapes and ball exit velocity have all been shown to be affected by the boundary conditions imposed at the proximal (grip) end of the implement (Wicks et al.,1999). Previous FEA of racket performance have used free conditions (Buechler et al.,1996;Shiang,Tzyy-Yuang, 2001). Although the mass and damping effects of the player's hands were not modeled, we displaced the grip area where people always touch. This assumption was appropriate given the very short impact time ─ if the vibrational waves arrive back at the point of impact after the ball has departed, ball motion cannot be affected by how the handle is secured.

The string was prestressed first, then added the ball force as well as delete the nodes constraints. The force and time value between the ball and string contact were record in the computer(120KM/H,5000HZ). Due to the transient nature of the event, deformations and nonlinear response during sting–ball impact, Mode superposing was accepted to analyse the string harmonic. 250 load steps were using in stepped manner and results were reviewed using POST26 the time-history processor:

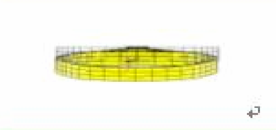
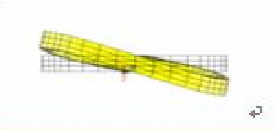
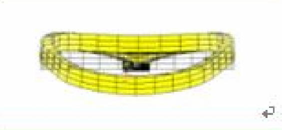
$$\{\phi_s\}_i = -[K_{ss}]^{-1}[K_{sm}]\{\hat{\phi}\}_i \qquad (1)$$

where:
$\{\varphi_s\}_i$ = slave DOFs vector of mode i (slave degrees of freedom are those DOFs that had been condensed out), $[K_{ss}]$, $[K_{sm}]$ = submatrix parts, $\{\hat{\phi}\}_i$= master DOF vector of mode i.

RESULTS: The results of racket model in fixed grip condition were given in table 2. The simulation with the fixed grip pointed out a dominant frequency of about 80 Hz, which was less than an unconstrained racket modal (previous researches indicate the first frequency was more than 100Hz in free condition),and the mode shape was bending. The second modal frequency was 220Hz and the mode shape was torsion. Finally, 470Hz was the value of the third modal frequency, and the mode shape was saddle.

All scientists included 'experimental design' as a common cause of rejection of papers. Although 'clarity' was not a specific item, all respondents indicated that lack of clarity was a common factor by underlining the word 'clearly' in at least one of the item descriptions or by written comment. The results are graphically summarized in Figure 1. Please note that the figures contain all relevant information you want to give. Label and provide the correct dimensions of the axes.

Tab.2 The modal frequency and shape

The first mode shape	The second mode shape	The third mode shape
		
		

Fixing the frame, string shape animation in dominant frequency is shown in tab.3. In the 60 pounds prestress, table 4 indicates the model frequency of the major string and displacement of time post between 2 to 7 nodes. For expressing the comparative value of these nodes, fig.3 describes the nodes displacement in first frequency. From the table below, the node 5 and 6 were the best positions to equip the damper in this situation. T hat was very useful to professional tennis player, because they have the fixed drive point.

Tab.3 In first frequency the string shape animation

Tab.4 The nodes displacement of model frequency in 60pounds prestres

Frequency(hz)	**Node2(m)**	**Node3(m)**	**Node4(m)**	**Node5(m)**	**Node6(m)**	**Node7(m)**
246.02	-0.16E-15	-0.23E-15	-0.11E-15	-0.63E-15	-0.39E-15	-0.26E-16
739.43	-0.11E-12	-0.28E-13	0.65E-13	0.32E-13	-0.28E-12	0.34E-13
1237.0	0.12E-12	0.20 E-12	0.26E-12	0.28E-12	0.35E-12	0.44E-12
1741.4	0.68E-12	-0.76E-12	-0.59E-12	0.72E-12	-0.27E-11	-0.63E-12
2255.6	-0.34E-10	0.56E-10	0.14E-10	-0.14E-09	0.12E-09	0.17E-11
2782.4	-0.19E-09	0.41E-09	0.17E-09	-0.80E-09	0.89E-09	0.14E-09

The string always prestressed between 50 pounds to 70 pounds. Fig.4 illustrates the 5th node displacement in the first frequency of different prestress.

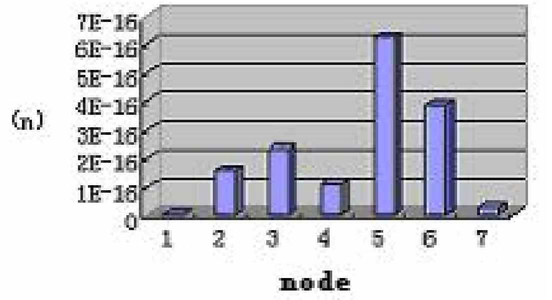


Fig.3 The nodes displacement in first frequency

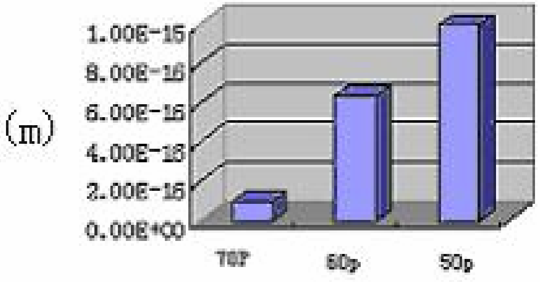


Fig.4 The 5th node displacement

DISCUSSION: The suitability of computer animation techniques for visualizing biomechanical research results has been demonstrated. Increased computer performance and improved graphic facilities have offered this economical and efficient method for communicating and presenting information.

As the handle was fixed, the model frequencies were smaller than the free condition. however, the model shapes were the same as that condition. A numerical analysis was performed to determine the effect of string tension on the frequencies and shape of each mode. The more tension was added, the less displacement appeared in the ball collision. When ball contacts to the string, the different contact point effects different nodal displacement. It's vital to optimize the damper position. Using the FE model for higher string tension, the frequencies they occur at decrease by almost 70%, but the shapes themselves stay the same. The vibration of the tennis racket also was the important reason lead to tennis elbow. It's vital to decrease the vibration in designing phase. The models developed are parametric, that is: geometric and material properties of the frame, strings and ball can be easily changed in order to analyze their influence on equipment performance. This will allow us to conduct sensitivity studies and to apply optimization techniques to tennis play. Most of the tennis research concentrate in the racket, however, the string's property maybe more distinctive to the match result and personal trauma. This remains the subject of our ongoing research.

REFERENCES:

Glitsch, U. and Detlefs C. (1998): Computer simulation in biomechanical testing of tennis rackets. Proc. XVIth Intern. Congress Biomechanics, Tokyo, 143.

H. Hatze, Simulation of dynamic impact characteristics of manusimulator-held tennis rackets. Abstr. vol. II,Second World Congress of Biomechanics, Amsterdam, 2002:134.

Buechler, Motion control: from keyframe to task-level animation. In: State-of-the-art in computer animation. Tokyo: Springer, 1999:3-17.

Brody, H., How would a physicist design a tennis racket[J], Journal of Physics today,2002(12): 26-31.

Brannigan, M. and Adali S. Mathematical modelling and simulation of a tennis racket[J]. Med. Sci. Sports Exerc.1999(13) :44-53.

Widing, M.A.B. and Moeinzadeh, M.H. Finite element modeling of a tennis racket with variable stringpatterns and tensions[J]. Int. J. Sport Biomech. 1999(6): 78-91.

Haug, E. J. Computer Aided Kinematics and Dynamics of Mechanical Systems. 2002, Volume 1: Basic Methods.

Acknowledgement
The authors are grateful to Prof. Xuejun Ren for his collaboration in the organization of the experimental tests. This work was supported by Ningbo University talent project.