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Estimation of the Improvement of the Shock vibrations at the wrist joint using the Thermoplastic Composite Tennis Racket

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Abstract

It is reported that a tennis racket using thermoplastic composite with a thin flexible unidirectional tape prepeg (UD flex tape) has good damping characteristics and therefore gives soft impact feel to the player during tennis impact. This paper predicts and estimates the performance of thermoplastic composite and compares it with that of ordinary racket in terms of the shock vibrations at the wrist joint when a player hits the ball, which is closely related to the feel or comfort. It is based on the experimental identification of the racket/arm system and the simple nonlinear impact analysis. The predicted results could explain the mechanism of difference in the feel between the thermoplastic composite racket and the ordinary composite racket.

Key Words: Tennis Racket, Thermoplastic Composite, Feel

Introduction

It is reported that a tennis racket using thermoplastic composite with a thin flexible unidirectional tape prepeg (UD flex tape) has good damping characteristics and therefore gives soft impact feel to the player during tennis impact [1]. This paper predicts the performance of thermoplastic composite racket and compares it with that of ordinary racket in terms of the shock vibrations at the wrist joint when a player hits the ball, which is closely related to the feel or comfort. It is based on the experimental identification of the racket/arm system and the simple nonlinear impact analysis [2-12]. The details of specifications and physical properties of the test rackets are shown in literature [2]. The racket called FX-110TP is a thermoplastic (TP) composite racket (341 g including the weight of strings), while the racket called Ex-110 is a conventional composite racket (365 g including the weight of strings). The TP material is made of reinforced fiber and thin resin film. Standard modulus 12 K carbon fiber and a Nylon 6 based resin were selected for its suitable physical properties and cost balance [1].

Prediction of the Waveforms of Shock Vibrations at the Grip and at the Wrist Joint

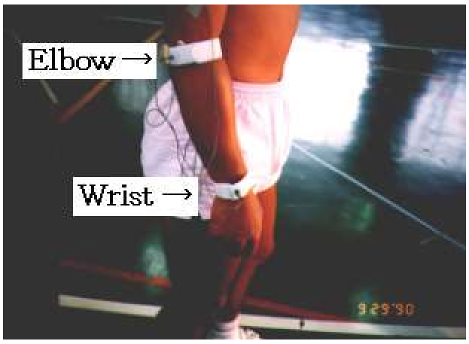

Fig.2 Location of Wrist joint

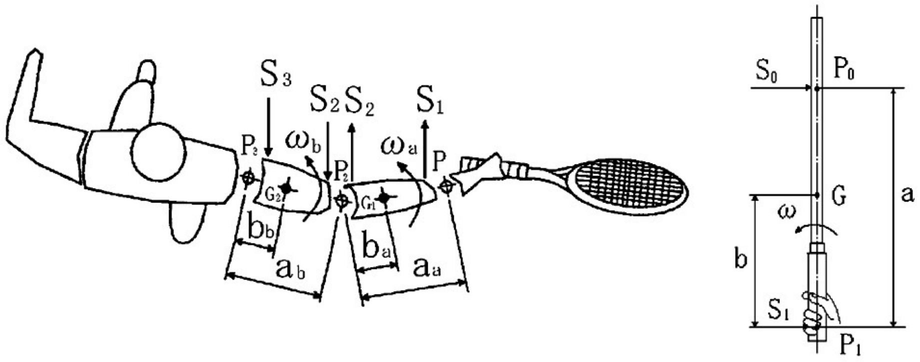

Fig.1 Impact model for the prediction of the shock force transmitted to the arm joints from a racket.

Figure 1 shows an impact model for the prediction of shock forces transmitted to the arm joints from a racket, where a male tournament player hits flat forehand drive. Figure 2 shows the locations of attached accelerometers at the wrist joint and the elbow joint in the experiment.

The impact force S_0 at P_0 causes a shock force S_1 on the player's hand P_1, a shock force S_2 on the elbow P_2, and finally a shock force S_3 on the player's shoulder P_3 during the impact at which the player hits the ball with his racket. The gravity force and muscular action are not taken into account. Accordingly, we consider the racket to be freely hinged to the forearm of the player, the forearm being freely hinged to the arm and the arm freely hinged to the player's body. We can deduce that the inertia effect of the arm and the forearm can be attributed to a mass M_H concentrated in the hand; therefore the analysis of impact between ball and racket can be carried out by assuming that the racket is free in space, as long as the mass M_H is applied at point P_1 of the hand grip. If the impact force S_0 between a ball and the racket is given when the ball hits the racket, the shock force S_1 can be obtained [10-12].

The vibration characteristics of a racket can be identified using the experimental modal analysis and the racket vibrations can be simulated by applying the approximate impact force-time curve to the hitting portion on the string face of the identified vibration model of the racket. When the impact force component of k-th mode frequency f_k in the frequency region applies to the point j on the racket face, the amplitude $X_{ij\,k}$ of k-th mode component at point i can be derived using the residue $r_{ij\,k}$ of k-th mode between arbitrary point i and j. The energy loss due to the racket vibration induced by impact can be derived from the amplitude distribution of the vibration velocity and the mass distribution along a racket frame when an impact location on the string face and the impact velocity are given. The coefficient of restitution e_r (COR) can be derived considering the energy loss E during impact. Furthermore, the force-time curve of impact between a ball and a racket considering the vibrations of a racket frame can be approximated.

$$S_0(t) = S_{0\,max} \sin(\pi t / T_c) \quad (0 \leqq t \leqq T_c) \quad (1)$$

where

$$S_{0\,max} = (\pi/(2T_c))(V_{BO} - V_{Ro})(1 + e_r)\, m_B/(1 + m_B/M_r). \quad (2)$$

The contact time T_c during impact can be determined against the pre-impact velocity (V_{BO} - V_{Ro}) between a ball and a racket assuming the contact time to be half the natural period of a whole system composed of the mass m_B of a ball, the equivalent stiffness K_{GB} of ball/strings, and the reduced mass M_r of the racket.

The shock acceleration $A_{nv}(t)$ at the hand grip considering the equivalent mass M_H of the arm system can be represented as

$$A_{nv}(t) = S_0(t)\,[\,1/(M_R + M_H) - (a/I_G)X] \quad (3)$$

where X denotes the distance between the center of mass of racket-arm system and the

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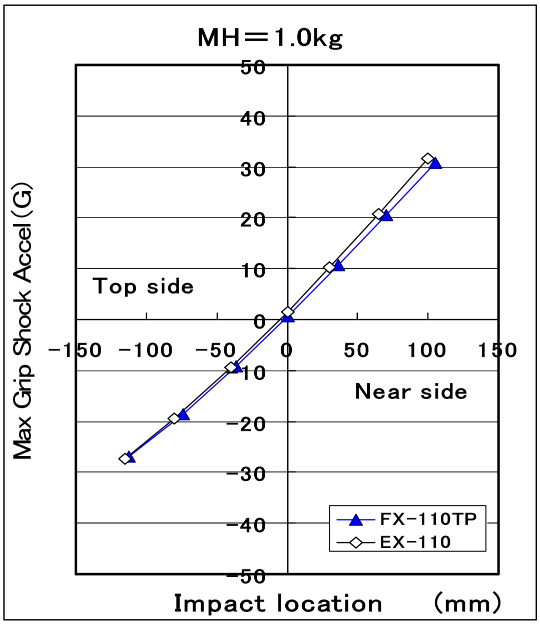
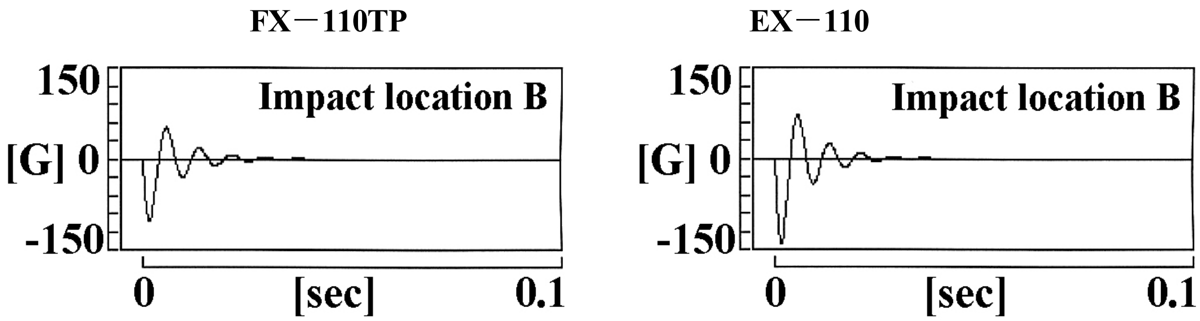


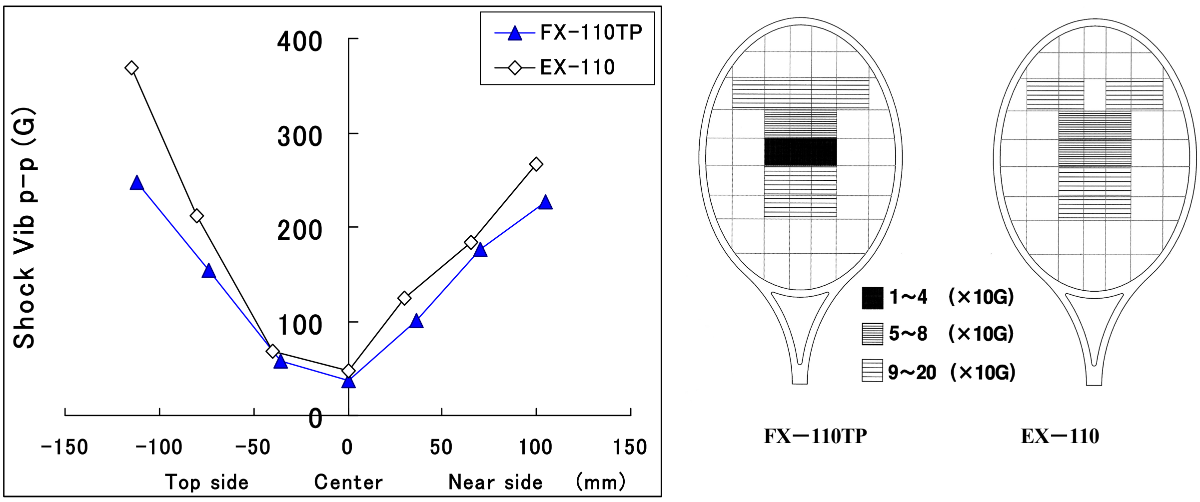
Fig.3 Predicted Maximum shock acceleration at the grip.

location of hand grip, a the distance between the center of mass of racket-arm system and the impact location of the racket, I_G the moment of inertia around the center of mass of racket-arm system, respectively. The maximum shock force S_{1max} transmitted to a wrist joint corresponds to the maximum impact force $S_{0\,max}$. Figure 3 shows the predicted maximum shock acceleration at the grip of hand-held racket. There is no big difference between two rackets. The vibration acceleration component of k-th mode at the location i of handgrip is represented as

$$A_{i\,j,k}(t) = -(2\pi f_k)^2\, r_{ijk}\, S_{0j}(2\pi f_k)\exp(-2\pi f_k \zeta_k t)\sin(2\pi f_k t) \qquad (4)$$



(a) Predicted shock vibrations at the wrist joint (Impact location : Top side B)



(b) Shock vibrations peak value at the wrist vs. impact locations (Impact velocity : 30m/s)

Fig.4 predicted shock vibrations at the wrist joint.

where j denotes the impact location between ball and racket on the string face, ζ_k the damping ratio of k-th mode, $S_{0j}(2\pi f_k)$ the fourier spectrum of Eq.(1).
The summation of Eq.(3) and Eq.(4) represents the shock vibrations at the handgrip.
Figure 4 shows the predicted shock vibrations of a wrist joint. Figure 4(a) is a comparison of two rackets when a ball strikes a racket face on the topside. The impact velocity between a ball and a racket face is 30 m/s. The damping ratio of a hand-held racket in the actual impact is estimated as about 2.5 times that of the one identified by the experimental modal analysis with small vibration amplitude. Furthermore, the damping of the waveform at the wrist joint was 3 times that at the grip portion of the racket handle. Figure 4(b) shows the shock vibrations peak value (Fig 5) at the wrist against the longitudinal impact locations on the racket face (Impact velocity : 30m/s). It also shows the predicted sweet area with respect to the shock vibrations at the wrist joint.
The shock vibrations of thermoplastic composite racket is smaller than those of conventional racket. It is predicted to be comfort when the ball is hit with.

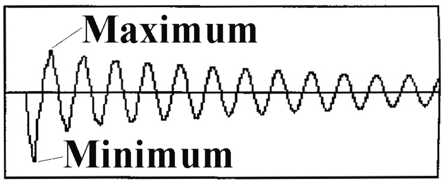


Fig.5 Peak- peak value of the wave form.

Conclusions

This paper has investigated the tennis racket performance in terms of the feel or comfort. It predicted the effect of the thermoplastic composite rackets on the impact shock vibrations of racket handle and the player's wrist joint when a player hits flat forehand drive. The prediction is based on the identification of the racket characteristics, the damping of the racket-arm system, equivalent mass of the player's arm system and the approximate nonlinear impact analysis in tennis.
The predicted results could explain the mechanism of difference in the feel between the thermoplastic composite racket and the conventional composite racket. The result of the comparison shows that the shock vibration of the thermoplastic composite racket is smaller than that of the conventional racket.
It is predicted to be comfort when the ball is hit with.

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