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Sweet Area Prediction of Tennis Racket Estimated by Power: Comparison between Two Super Large Sized Rackets with Different Frame Mass Distribution

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ABSTRACT: This paper investigates the prediction of the tennis racket performance in terms of the sweet area where the post-impact ball velocity is higher when a player strikes a ball. The prediction is based on the impact analysis by using the experimental identification of the racket and ball with a simple swing model. The result of the comparison between the two super-large sized rackets with different mass and mass distribution shows that the sweet area of a super-light racket is wider than that of a conventionally mass distributed racket. However, it also shows that the post-impact ball velocity of the former is lower than that of the latter when a player hit the ball at the near side and off the longitudinal axis of the racket head.

Key Words: Tennis Racket, Sweet Area, Power

INTRODUCTION

The implementation of material composites has led to increased flexibility in the design and production of sporting goods. The increased freedom has enabled manufacturers to tailor goods to match the different physical characteristics and techniques of users. However, ball and racket impact in tennis is an instantaneous non-linear phenomenon creating frame vibrations and large deformations in the ball/string system in the racket. The problem is further complicated by the involvement of humans in the actual strokes. Therefore, there are many unknown factors involved in the mechanisms explaining how the racket frame influences the racket capabilities. This paper investigates the tennis racket performance in terms of the sweet area where the post-impact ball velocity is higher when a player strikes a ball. It predicts the difference in the sweet area in terms of the velocity of the hit ball or power between the two super-large sized rackets with different mass and mass distribution.

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The prediction is based on the impact analysis by using the experimental identification of a racket and a ball with a simple swing model (Kawazoe et al 1989, 1992, 1993, 1994, 1997).

RACKET PHYSICAL PROPERTIES AND PREDICTION OF THE RESTITUTION COEFFICIENT BETEEEN A BALL AND A RACKET

The main specifications and physical properties of the test rackets made of carbon graphite with a head size of 120 square inches are shown in Table 1. The racket

Table 1 Specifications and physical properties of rackets.

Racket	EOS120A	EOS120H
	Super light	Conventional
Total length	690 mm	685 mm
Face area	760 cm^2	760 cm^2
Mass (+ strings)	292 g	349 g
Tension (1 Ib=4.45 N)	79 Ib	79 Ib
Center of Gravity	363mm	323 mm
IGY	14.0 gm^2	16.0 gm^2
IGR	39.0 gm^2	38.0 gm^2
1st freq.	137 Hz	142 Hz
IGX	1.78 gm^2	2.21 gm^2

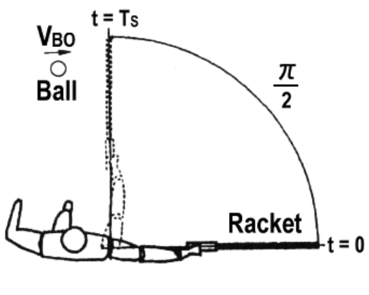

Fig.1 Simple forehand ground stroke swing model.

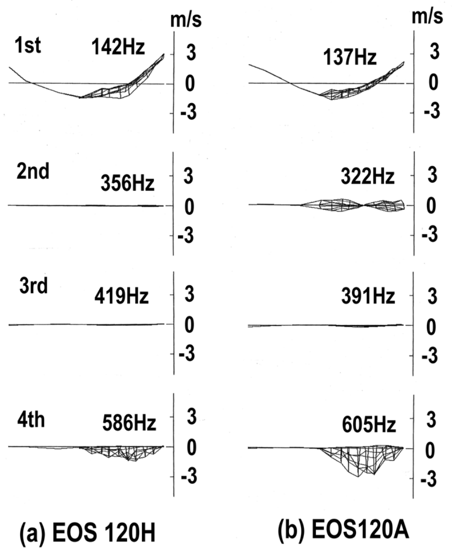

Fig.2 Initial velocity amplitude distributions of the four vibration modes of different type of rackets.

called EOS120A is a super-light racket (292 g including the weight of strings), while the racket called EOS120H is a conventional weight and weight balanced racket (349 g). In Table 1, the sign I_{GY} denotes the moment of inertia about the center of mass, the sign I_{GR} the moment of inertia about the grip portion 70 mm from the grip end, the sign I_{GX} the moment of inertia about the longitudinal axis of racket head.

The racket vibration characteristics were identified using the experimental modal analysis for a racket placed horizontally on a soft sponge (corresponding to mid-air hanging, freely supported racket) and a racket with the handle held firmly by a hand. Since the experimental modal analysis (Kawazoe, 1989,1997) showed that the fundamental vibration mode of a hand-held racket is similar to the mode of a freely supported racket, it is assumed here in this study that the racket is freely supported.

Figure 1 shows a simple forehand ground stroke model used in this study. A player hits a ball coming at the velocity of V_{Bo} where the racket head velocity V_{Ro} is given by L_X (

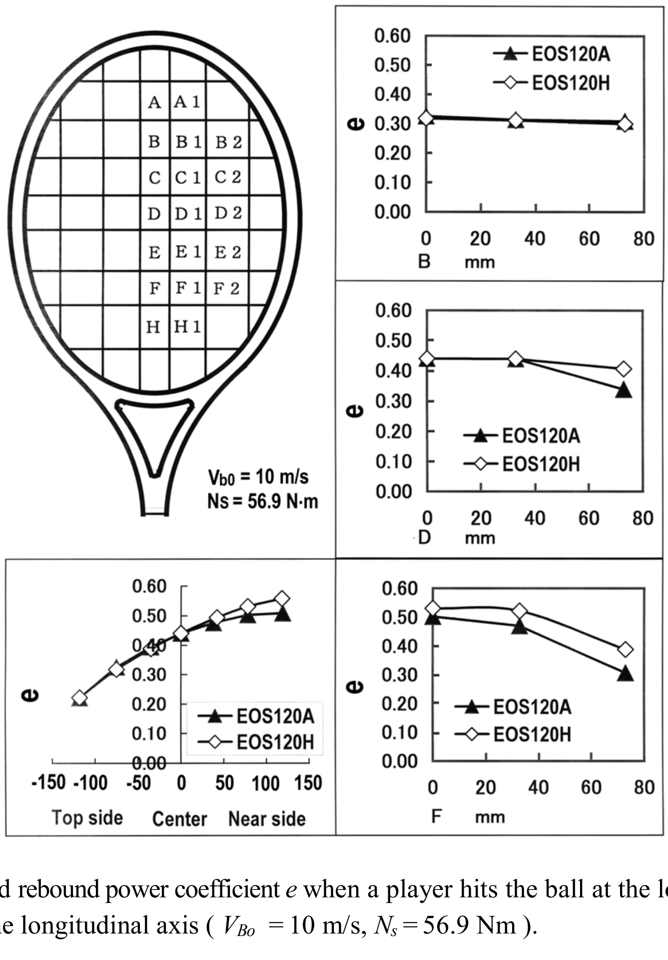

Fig.3 predicted rebound power coefficient e when a player hits the ball at the longitudinal axis and off the longitudinal axis (V_{Bo} = 10 m/s, N_s = 56.9 Nm).

$\pi N_s / I_s)^{1/2}$, the sign L_X denotes the distance between the player's shoulder joint and the impact location on the racket face, N_s the constant torque around the shoulder joint, and I_s the moment of inertia of arm/racket system around the shoulder joint.

The impulse could be approximately derived using a model assuming that a ball with a concentrated mass and a nonlinear stiffness collides with the nonlinear spring of strings supported by a rigid frame, where the measured restitution coefficient e_{BG} inherent to the materials of ball/strings is employed as one of the sauce of energy loss. The contact time T_c could be derived, if it is assumed that the contact time T_c, which is not affected much by the frame stiffness according to the experiment, is determined by the natural period of a whole system composed of the mass m_B of a ball, equivalent compound stiffness K_{GB} of a ball and strings, and the reduced mass M_r of a racket.

On the basis of the approximation of the force-time curve of impact as a half-sine pulse and the application of its Fourier transform to the experimentally identified racket vibration model, the initial amplitude of racket vibration due to impact can be derived. The energy loss due to the racket frame vibration can be derived from the amplitude distribution of the velocity and the mass distribution along a racket frame. Figure 2 shows the initial velocity amplitude distributions of the four vibration modes of the two different types of rackets.

The coefficient of restitution (COR) e_r between a ball and a racket can be estimated by considering the energy loss $\triangle E_1$ due to frame vibration as well as the energy loss $\triangle E_2$ due to large instantaneous deformation of the ball and strings. The coefficient of restitution e_r corresponds to the total energy loss $\triangle E$ ($=\triangle E_1 + \triangle E_2$) could be obtained as

$$e_r = [1 - 2\triangle E(m_B + M_r) / (m_B M_r V_{BO}^2)]^{1/2} \qquad (1)$$

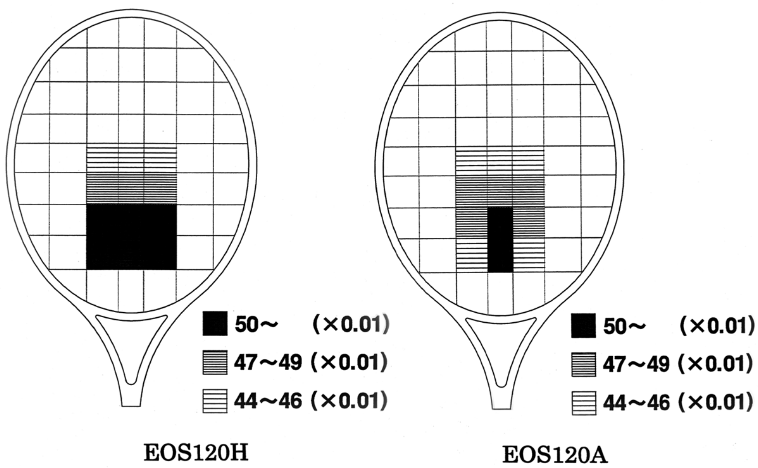

Fig.4 Sweet area with respect to the rebound power coefficient e (V_{Bo} = 10 m/s, N_s = 56.9 Nm).

The predicted restitution coefficient e_r of a super-light weight racket has been lower than that of a conventional weight and weight-balanced racket, particularly at the near side off-center of the racket, where a player hits the ball (V_{Bo} = 10 m/s, N_s = 56.9 Nm).

PREDICTED POST-IMPACT BALL VELOCITY AND THE SWEET AREA IN TERMS OF POWER WITH TWO TYPES OF SUPER-LARGE SIZED RACKETS

Here we introduce the rebound power coefficient e defined by the ratio of rebound velocity V_B against the incident velocity V_{BO} of a ball when a ball strikes the freely supported racket at rest (V_{Ro} = 0) , written as Eq.(3) . The rebound power coefficient e can particularly estimate the rebound power of a racket for a volley.

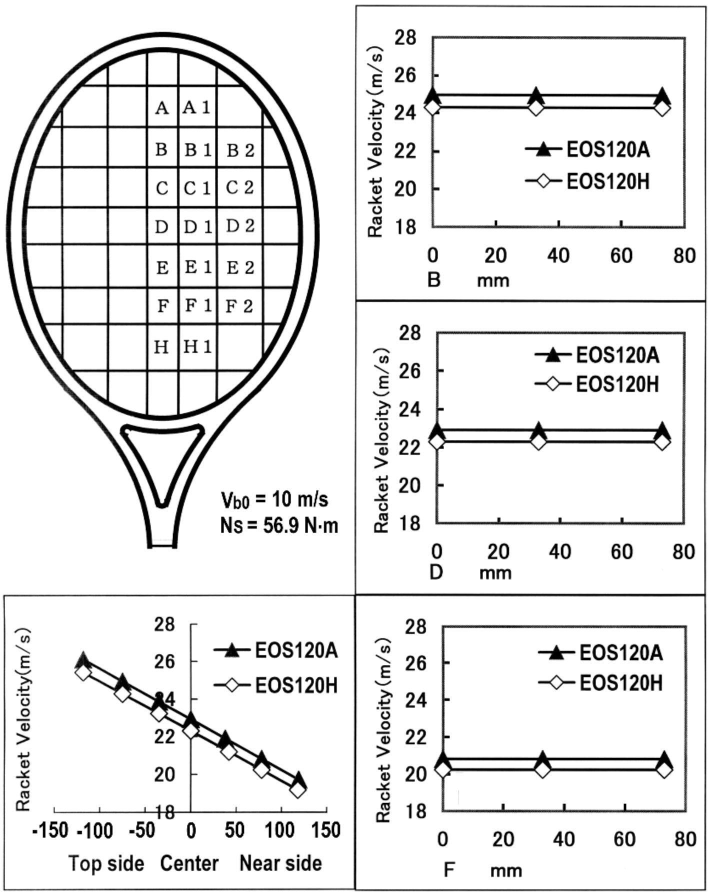

Fig.5 Predicted pre-impact racket head velocity V_{Ro} (N_s = 56.9 Nm).

$$e = -V_B \ / V_{BO} = (e_r - m_B/M_r)/(1+m_B/M_r) \qquad (3)$$

When a player hits the ball with pre-impact racket head velocity of V_{Ro}, the coefficient e can be expressed as

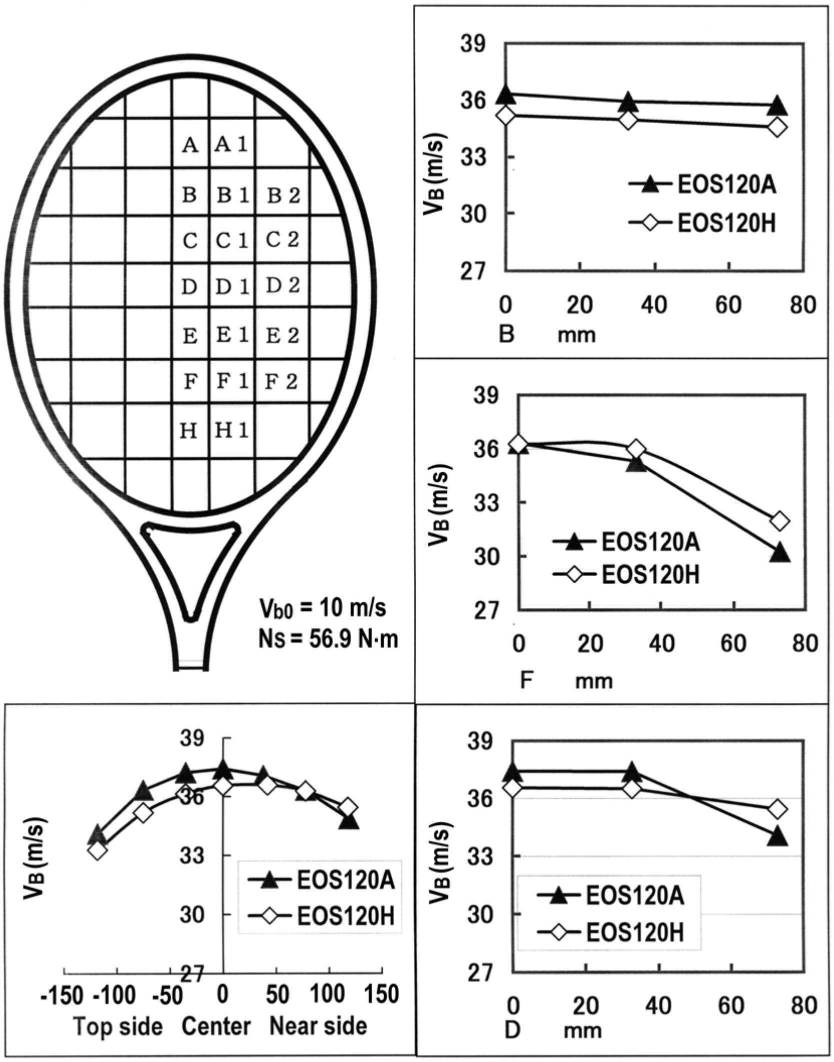

Fig.6 Predicted post-impact ball velocity V_B when a player hits the ball at the longitudinal axis and off the longitudinal axis (V_{Bo} = 10 m/s, N_s = 56.9 Nm).

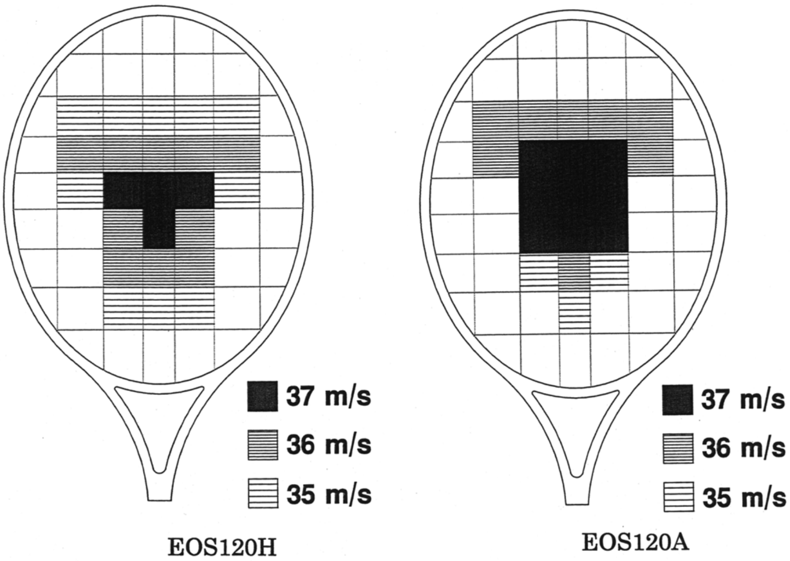

Fig.7 Predicted sweet area with respect to the post-impact ball velocity V_B (V_{Bo} = 10 m/s, N_s = 56.9 Nm).

$$e = -(V_B - V_{Ro}) / (V_{BO} - V_{Ro}) \tag{4}$$

Figure 3 shows the predicted rebound power coefficient e when a player hits the ball at the longitudinal axis and off the longitudinal axis (V_{Bo} = 10 m/s, N_s = 56.9 Nm). Figure 4 shows the sweet area with respect to the rebound power coefficient e.

The post-impact ball velocity V_B could estimate the power of the racket when a player hits the ball. The V_B can be expressed as Eq.(5).

$$V_B = -V_{Ro}\ e + V_{Ro} (1 + e) \tag{5}$$

Figure 5 shows the predicted pre-impact racket head velocity V_{Ro} (N_s = 56.9 Nm). The head velocity V_{Ro} of super light racket is higher than that of a conventional racket.

Figure 6 shows the predicted post-impact ball velocity V_B when a player hits the ball at the longitudinal axis and off the longitudinal axis of the racket (V_{Bo} = 10 m/s, N_s = 56.9 Nm). Figure 7 is the predicted sweet area with respect to the post-impact ball velocity V_B (V_{Bo} = 10 m/s, N_s = 56.9 Nm).

It is seen that the super-light racket is wider than that of a conventionally mass distributed racket with the sweet area in terms of the post-impact ball velocity or power. However, it also showed that the post-impact ball velocity of the former is lower than that of the latter when a player hit the ball at the near side and off the longitudinal axis of the racket head.

CONCLUSIONS

This paper investigates the prediction of the tennis racket performance in terms of the sweet area where the post-impact ball velocity is higher when a player strikes a ball. The prediction is based on the impact analysis by using the experimental identification of the racket and ball with a simple swing model.

The result of the comparison between the two super-large sized rackets with different mass and mass distribution showed that the sweet area of a super-light racket is wider than that of a conventionally mass distributed racket. However, it also showed that the post-impact ball velocity of the former is lower than that of the latter when a player hit the ball at the near side and off the longitudinal axis of the racket head.

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