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IMPACT SHOCK VIBRATIONS OF THE WRIST AND THE ELBOW IN THE TENNIS FOREHAND DRIVE : REMARKS ON THE MEASURED WAVE FORMS CONSIDERING THE RACKET PHYSICAL PROPERTIES

Yoshihiko KAWAZOE: Dept. Mech. Eng., Saitama Inst. of Tech., Okabe, Saitama, Japan
Ryosho TOMOSUE: Institute of Sports Medicine and Science, Aichi, Japan
Akira MIURA: Hiroshima Women's College, Hiroshima, Japan

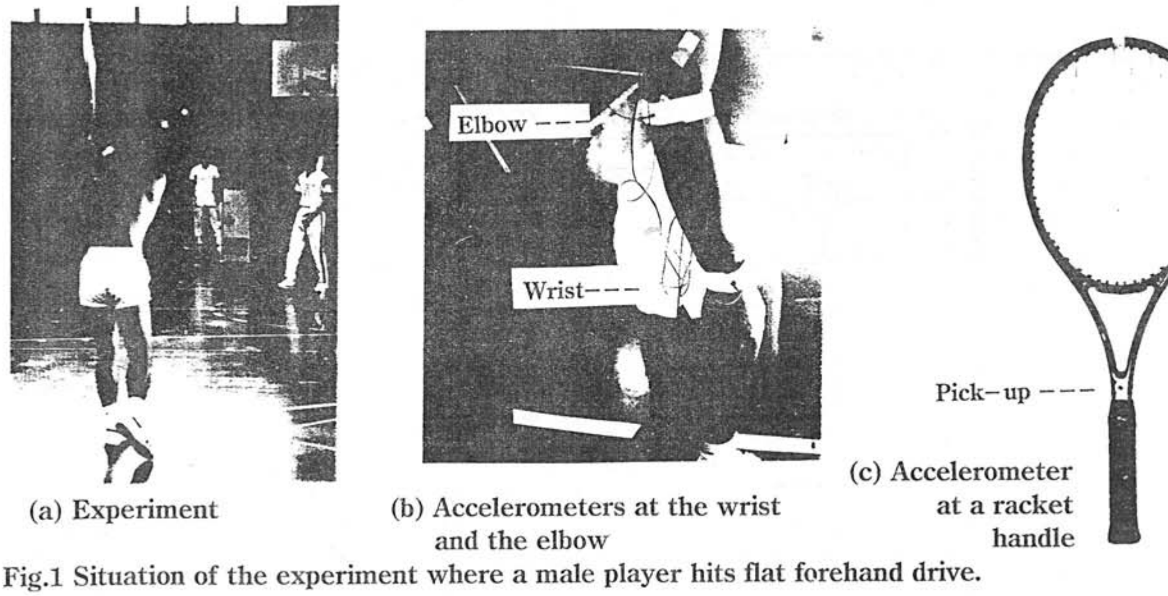
ABSTRACT

This paper has investigated the effect of racket physical properties on the impact shock vibrations of the wrist and the elbow in the tennis forehand drives, and gives physical explanations for the measured acceleration of the racket handle(210 mm from the grip end) and the wrist joint on the basis of the identification of the racket characteristics, the damping of the racket-arm system, the equivalent mass of the arm system and the approximate nonlinear impact analysis. The result shows that the shock vibrations of the wrist joint and the elbow joint are transmitted from the racket with an impulse at the impact location and the several vibration mode components of a racket frame and strings. The predicted wave forms of the shock vibrations with the racket handle and the wrist joint agrees fairly well with the measured ones during actual forehand stroke by a player, although the mechanism of the shock vibrations of the elbow joint is lefft unclarified.

1. INTRODUCTION

Material composites have increased the degree of freedom of design and manufacturing for sports pruducts. At the current stage, very specific design are targeted to match the physical and technical levels of each user.

The performance of a racket can be estimated with regard to physical characteristics such as wight distribution, rigidity distribution, face size, and string tension, if the behavior of the racket and ball is clarified and the residual shock vibrations at the player's arm become known.



(a) Experiment (b) Accelerometers at the wrist and the elbow (c) Accelerometer at a racket handle

Fig.1 Situation of the experiment where a male player hits flat forehand drive.

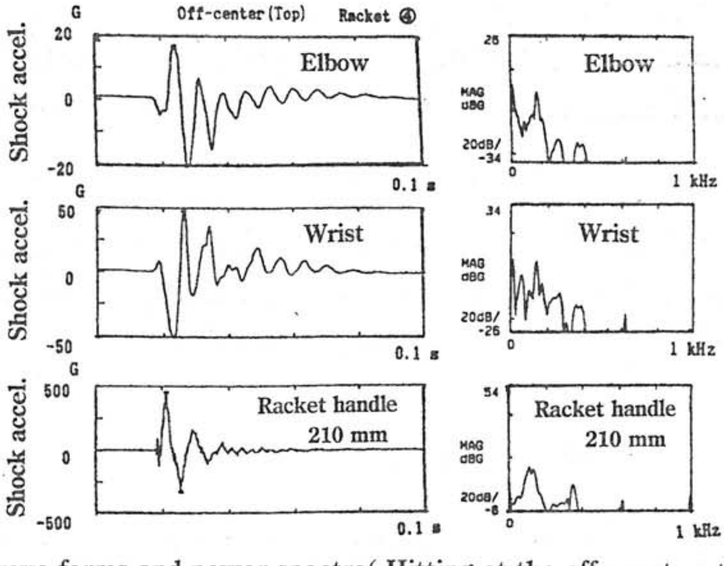


Fig.2 Measured wave forms and power spectra(Hitting at the off−center: top of the racket face).

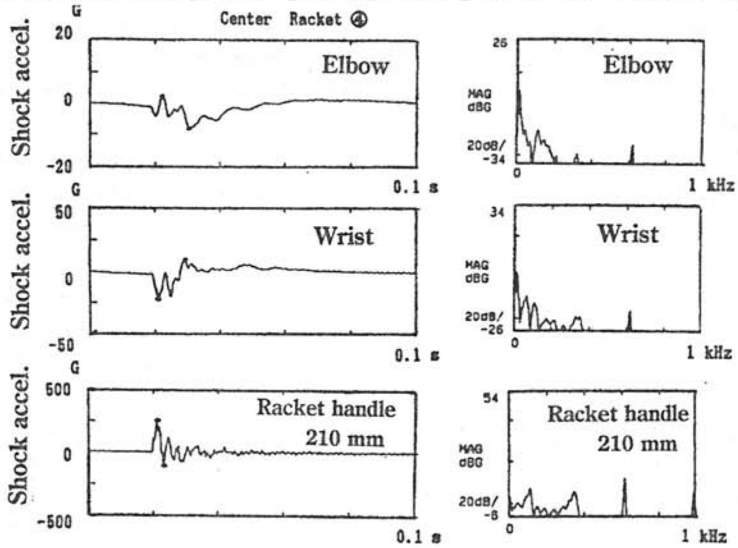


Fig.3 Measured wave forms and power spectra(Hitting at the center of the racket face).

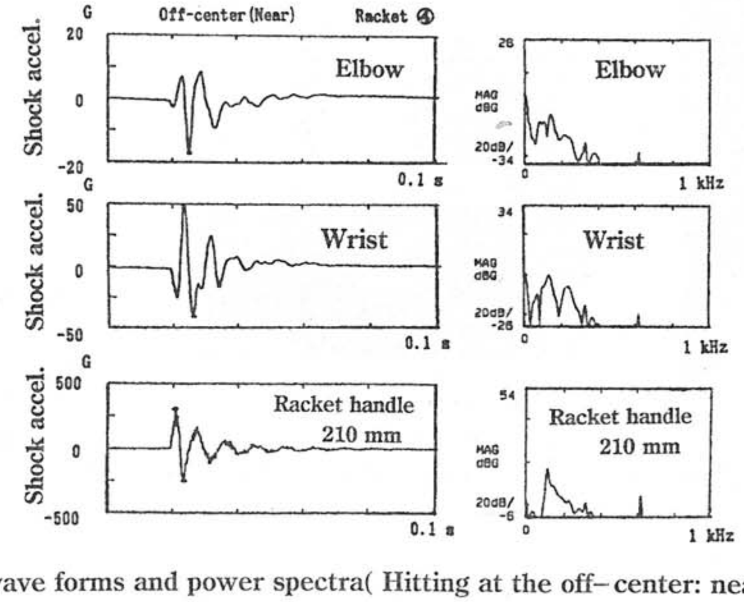


Fig.4 Measured wave forms and power spectra(Hitting at the off−center: near of the racket face).

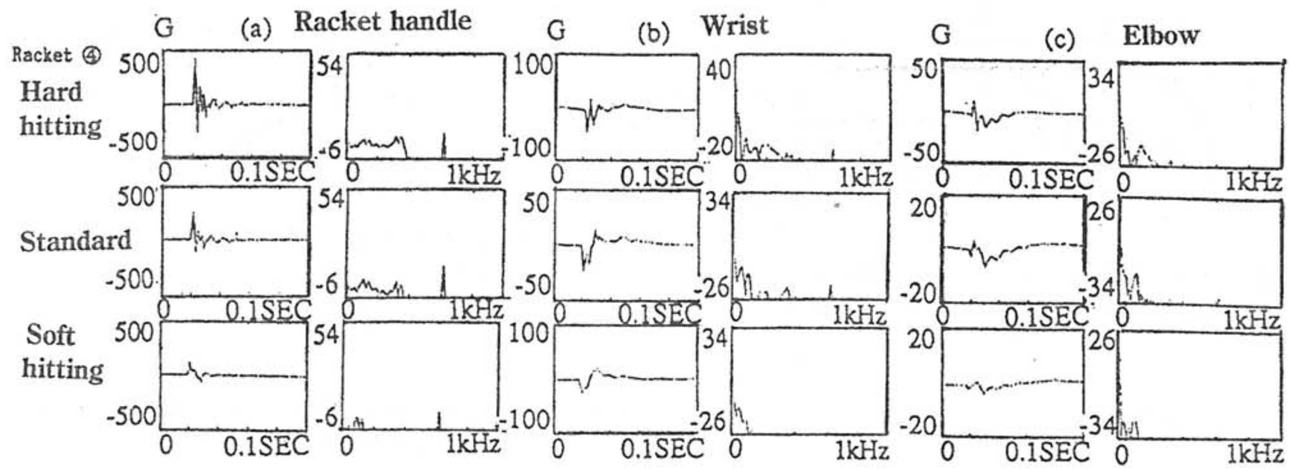


Fig.5 Measured wave forms and power spectra when hitting at the center of a racket face. (Hard hitting and soft hitting).

However, ball and racket impact is an instantaneous non−linear phenomenon(contact time is 6−3 ms, with shorter times at higher impact velocities) creating large deformations in the ball/strings and vibrations in the racket. The problem is further complicated by the involvement of humans in the actual strokes. These problems make analysis extreamely difficult.

This paper investigates the shock vibrations of the wrist joint and the elbow joint caused by the impact when a male tournament player hits flat forehand drive. It gives qualitative physical explanations for the measured wave forms of the shock vibrations acceleration at the racket handle and the wrist jpoint, on the basis of the dynamic characteristics of the ball and racket.

2. MEASURED SHOCK VIBRATIONS OF RACKET HANDLE,WRIST JOINT AND ELBOW JOINT DURING ACTUAL STROKE

Figure 1 shows the situation of the experiment where a male player hits flat forehand drive, the accelerometers at the wrist and elbow, and at a racket handle which is located 210 mm from the grip end.

The measured wave forms of acceleration and power spectra with elbow joint, wrist joint and racket handle are shown in Fig.2(hitting a ball at the top of the racket face), Fig.3(at the center), and Fig.4(at the near). The first lragest peak during the impact was caused by the shock and vibrations of a racket frame, followed by the residual vibrations of the racket frame.

Figure 5 shows the measured acceleration wave forms and power spectra of elbow joint, wrist joint and racket handle when hitting hard, normal and soft at the center of racket face.

Figure 6 indicates vibration modes of a racket which are derived by the experimental modal analysis[1],where the 1st mode is bending with 2 nodes, the 2nd is bending with 3 nodes, the 3rd is tortional and the 4th is vibration of membrane of strings.

Figure 7 shows the center of gravity in a racket−arm system where the equivalent mass of an arm is M_H=1.0 kg[2].

The effect of equivalent mass on the maximum shock acceleration of a racket grip when a ball is struck at each location of the racket face is shown in Fig.8, which is estimated by the approximate nonlinear impact analysis[3].

Figure 9 is a predicted initial acceleration amplitude of 1st mode vibration component 142 Hz, where a ball is struck at the top and the near of the racket face, which is derived on the basis of the impact analysis and the identified characteristics of racket and ball.

Figure 10 shows the predicted shock vibrations of a wrist joint compared with the experimental ones when a ball is struck at the top, the center

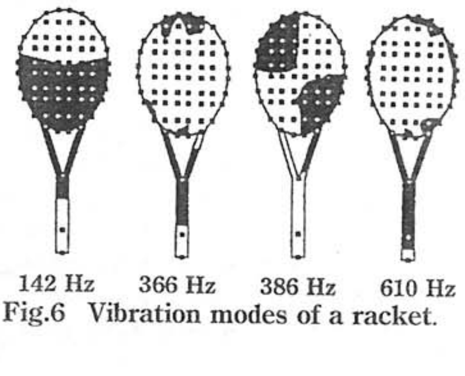


Fig.6 Vibration modes of a racket.

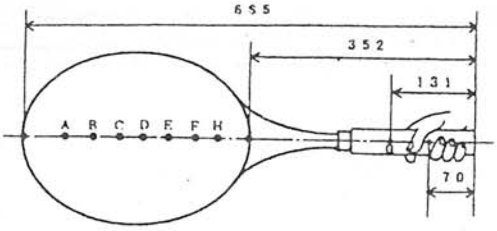


Fig.7 Center of gravity in a racket-arm system. (Equivalent arm mass M_H=1.0 kg)

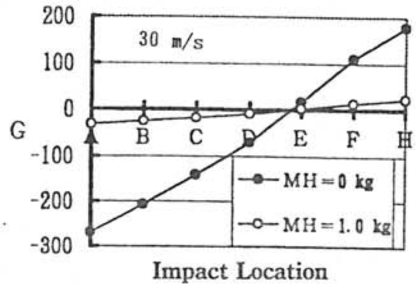


Fig.8 Effect of equivalent mass of an arm on the maximum shock acceleration of a racket grip.

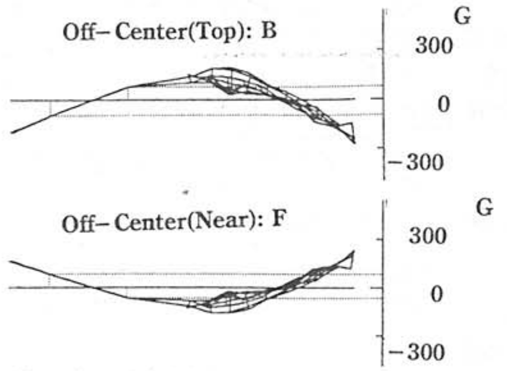
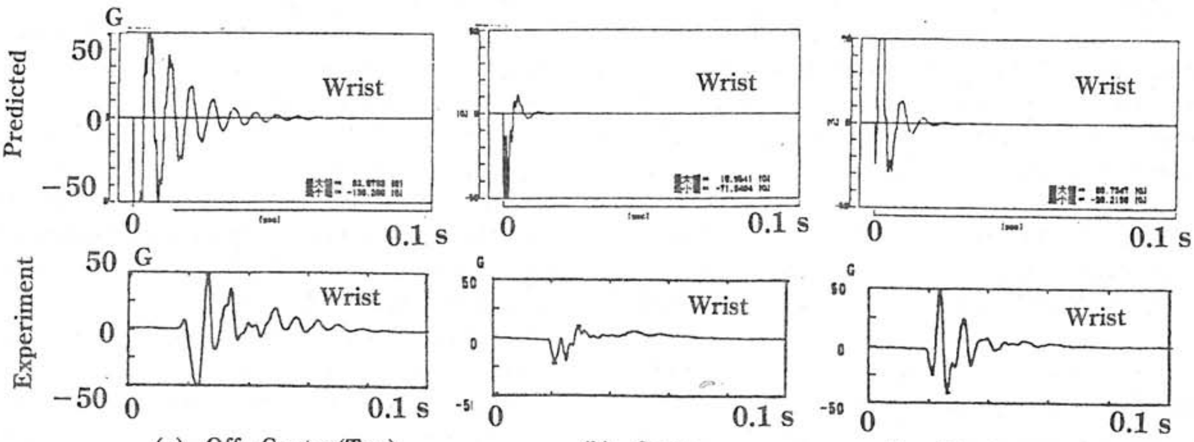


Fig.9 Predicted initial acceleration amplitude of 1st mode vibration component 142 Hz.

and the near of the racket face.

The shock vibrations are composed of the shock acceleration and the racket vibration components, and each copmponent has its own time history and magnitude depending on the impact velocity, impact location, grip location of racket handle and the physical properties of a racket. The damping ratio. of a hand-held racket during actual impact is estimated as about 2.5 times that of the one identified by the experimental modal analysis with small vibration amplitudes. Furthermore, the damping of the wave form at the wrist joint was 3 times that at the grip portion of the racket handle.

The predicted wave forms of the shock vibrations with the racket handle and the wrist joint agrees fairly well with the measured ones during actual forehand stroke by a player. The mechanism of the shock vibrations of the elbow joint, however, is lefft unclarified.



(a) Off-Center(Top) (b) Center (c) Off-Center(Near)

Fig.10 Predicted shock vibrations of a wrist joint compared with the experimental.

3. CONCLUSIONS

The result showed that the shock vibrations of the wrist joint and the elbow joint are transmitted from the racket with an impulse at the impact location and the several vibration mode components of a racket frame and strings. The predicted wave forms of the shock vibrations with the racket handle and the wrist joint agrees fairly well with the measured ones during actual forehand stroke by a player, although the mechanism of the shock vibrations of the elbow joint is lefft unclarified.

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