THEORETICAL MODEL AND EXPERIMENTAL TESTS FOR TENNIS IMPACT DYNAMICS

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INTRODUGTION

In order to investigate the health problems connected with tennis and to develop and test new equipment, the theoretical and experimental analyses of the ball–racket impact phase are fundamental. Therefore only this critical phase, lasting less than one hundredth of seconds, is here analyzed. It is influenced by the initial conditions such as the racket's and ball's position and velocity right before their impact; it is also related to the dynamic characteristics of the racket.

Aim of this research is that of verifying a mathematical model (Casolo, Ruggieri 1991) which is simple enough to show the influence of each single racket parameter on the impact and to set up correct procedures for the experimental tests and the design of the equipment.

Both in the model and in the experimental tests, we take into account the limited inertia of the player's arm. Unlike other researchers, we do not clamp the racket handle at a fixed frame, because it is too unprecise and it means to attribute infinite mass and moment of inertia to the hand.

BACKGROUND

Strictly referring to the impact phase, the main forces transmitted by the system's components (Fig.1, 2) from the ball to the shoulder are S_0, S_1, S_2, S_3. Obviously, the speed variations of the body segments are proportional to the impulses of the respective forces and inversely proportional to the masses which they are subjected to. All the other forces and couples, as for instance the ones due to the muscular actions, are negligible during the impact; they are in fact one or more orders of magnitude as low as the previous ones.

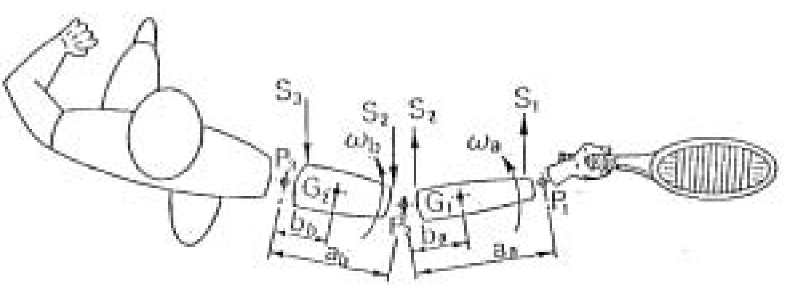


Fig.1: Racket + player model

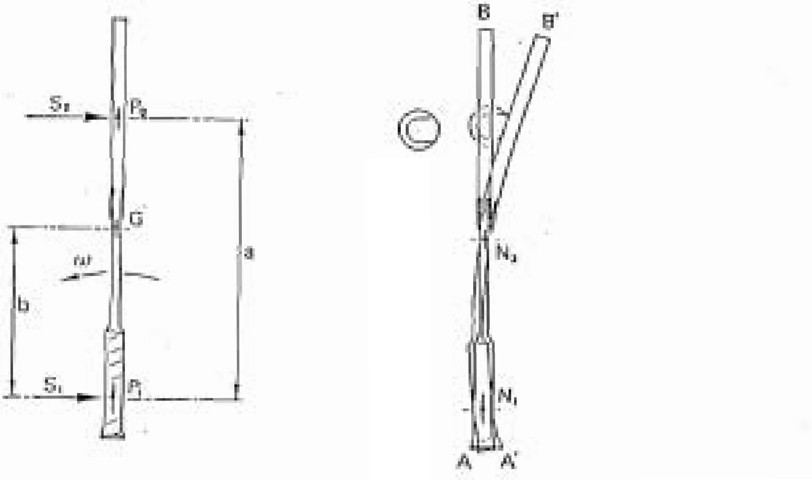


Fig.2: Racket external load and frame deformation

By manipulating the dynamic equilibrium equations (Casolo 1991) it' is possible to write the equation $dV_1/dt = S_1/M_1$ where S_1 is the force transmitted by the racket to the hand, V_1 the instant speed of the hand; therefore M_1 can be seen as an equivalent mass, taking into accaunt the whole mass of the player, hypothetically applied to the racket handle.

The impact can thus be analyzed by means of the simple model of fig.2. The values of M_1 depends on the masses m, m_a, m_b, of the hand, the forearm, and the arm, whereas do not depend on the lengths a_a and a_b.

Let us assume $m = .5kg$, $m_a = 1.5kg$, $m_b = 2kg$, we obtain $M_1 = .946kg$. The precision required in the estimation of the masses can be deducted by the following: $\Delta M_1 = .276\Delta m + \Delta m_a + .015\Delta m_b$ which shows the incidence on M_1 of the errors Δ of the evaluations of hand, forearm and arm masses. So, as explained in the previous work, is linked to the elasticity of the ball and the racket and is in function of the sinking x of the ball into the mesh according to the law: $S_0 = kx\,(1 + hx^2)$; where h and k can be obtained from a series of simple static measurements on ball and racket increasing the load applied onto them.

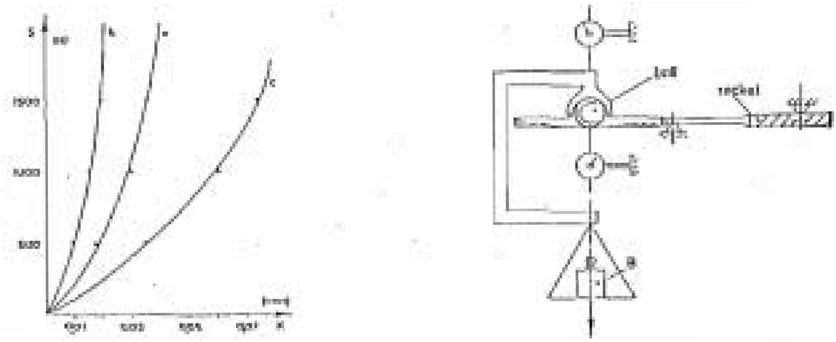


Fig.3: A static test on a racket:
c) sinking x of the ball pressed on the net by the force S (mass B);
b) deformation of the ball; a)deformation of net plus ball

It is than possible to write the equation of motion of the ball during the penetration phase and to predict the sinking time and the rebound speed of the ball when the dynamic and the elastic parameters of racket and the the initial condition of the impact are known.

MATERIALS

The equipment for the rebound experimental tests consists of three major devices: a cannon to throw the ball toward the racket; a trestle to hold the racket in its position before the impact; a set of laser photo-barriers and respective timers to measure velocities. The cannon (Fig.4) consists mainly of a tubular air tank ending up with a gun. Between the latter and the former a calibrated ring, that can be substituted, defines the speed range of the ball.

The upper part of the trestle is a rectangular frame; beside the racket, it holds the photo-barriers for the racket speed measure. The frame is connected to the racket by means of two electro-magnets driven by the ball through another photo-barrier in order to free the racket few milliseconds before the impact. The adoption of the equivalent mass M_1 [obtained linking to the handle a lead ring) allows to neglect any constraint to the racket during the impact phase.

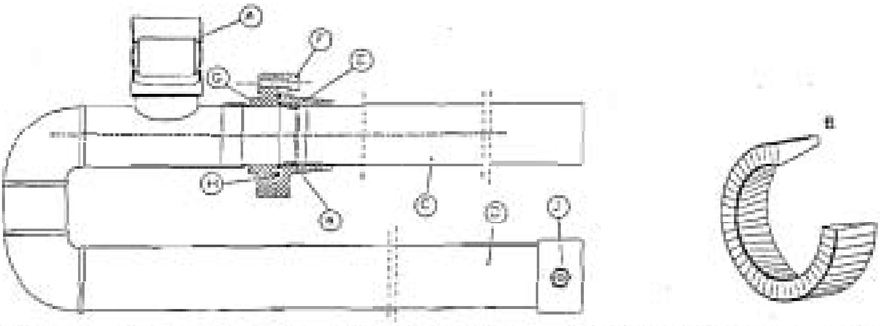


Fig. 4: Ball cannon : A) ball loading, B) interchangeable narrow ring, C) gun, D) air tank

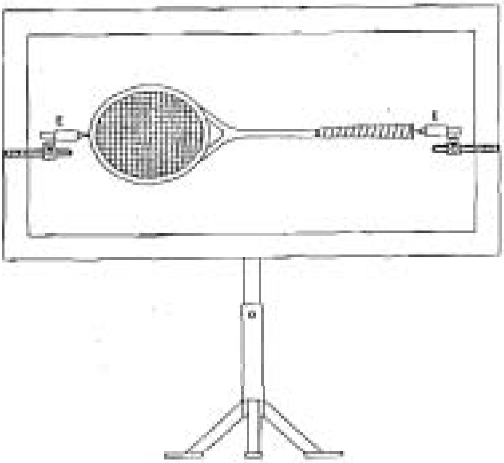
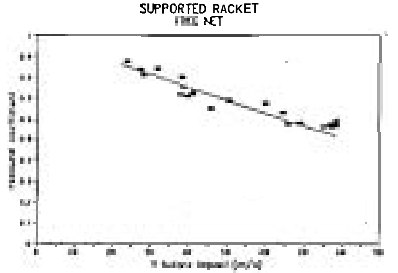


Fig. 5: racket holder ; E)electro-magnets

Two photo-barriers are needed to measure the speed of any point of interest: one makes the clock (10Mhz quartz oscillator) start and the other stops it. A logic circuit drives the counters, allowing for instance to use the same two barriers for the measurement of both the ball's initial and rebound-speed.

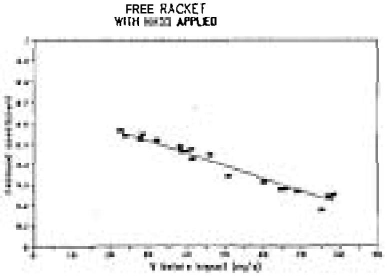
RESULTS AND CONCLUDING REMARKS

Preliminary tests have been taken in order to prove the equivalence of the described model (with the equivalent mass) to a held-by-player racket. Therefore three sets of data have been collected for the following cases:
1) Racket frame wholly constrained, to test net and ball stiffness actions (Fig.6 a) - 2) Racket free with equivalent mass (Fig.6 b) -3) Racket held by the player (Fig.6 c).

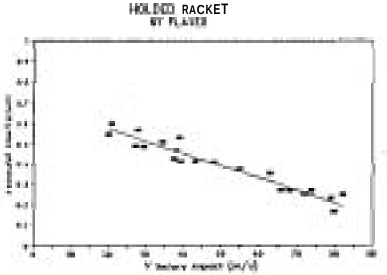


a. Rebound speed vs initial speed for totally constrained racket and free net

Fig. 6 a, b, c



b. Rebound speed vs initial speed for free racket with equivalent mass applied



c. Rebound sped vs initial speed for holded-by-player racket

Thee preliminary results prove the testing apparatus adequacy as well as the correctness of the evaluation of the equivalent mass.
Therefore in futher experiments it should be possible to test rackets simply by applying a proper mass to the handle and expecting them to behave exactly as if they where held by player. These and other sets of measures show that the rebound coefficient depends mainly on ball characteristics, which affect the interpolating line slope, and on inertial characteristics of the racket, which make the line shift up and down.

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