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SOLUTION TO THE MYSTERY OF THE EFFECT OF STRING TENSION ON THE ACTUAL IMPACT BETWEEN A TENNIS BALL AND RACKET

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There are many unknowns regarding the relationship between the performance estimated by a player and the physical properties of a tennis racket. The previous paper made clear for the first time the mechanism of actual top spin by a player and its improvement by lubrication of string intersections using 10,000 frames/sec high-speed video analysis, which is contrary to the hypothetical conventional spin theory. It was found that the more the main strings stretch and slide side ways parallel to the string plane and spring back, the more the ball is given spin when the ball is released from the strings. The solution to the mystery of the effect of string tension, gauge or type on the ball spin seems to be in the high-speed video analysis of actual impact by a player. This paper provided the explanation about the strings performance improvement on ball spin and the mechanism of the reduction of shock vibrations of the wrist joint during topspin impact. It also showed the difference in dynamics between the lubricant strings and the looser strings based on the impact analysis, where it is a key factor that the damping coefficient and the stiffness of a ball and also the stiffness of strings radically increase with deformations.

1. Introduction

There are many unknowns regarding the relationship between the performance estimated by a player and the physical properties of a tennis racket. The restitution characteristics between a ball and racket as well as the shock vibrations at the wrist joint can be calculated for a simple forehand swing model at any given swing speed and at any impact location on the string plane if the ball strikes the strings at normal incidence [1]-[16].

However, the ball spin is the mystery. Very little is known about the relationship between the ball spin and the string characteristics both for researchers and players. Players often say that some strings provide a better grip and more spin than others, but ball spin did not depend on string tension, gauge or type and the scatter of data was larger than the difference of strings in the past

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laboratory experiment for oblique impacts on a head-clamped racket or a freely suspended racket. Even recent measurements made by several authors on rebound spin [17]-[23] showed that there still be no significant difference in ball spin off natural and synthetic gut strings, off thin and thick strings, off loose and tight strings, contrary to common belief.

The previous paper [24][25] made clear for the first time the mechanism of actual top spin by a player and its improvement by lubrication of string intersections using 10,000 frames/sec high-speed video analysis, which is contrary to the hypothetical conventional spin theory. It was found that the more the main strings stretch and slide side ways parallel to the string plane and spring back, the more the ball is given spin when the ball is released from the strings. The solution to the mystery of the effect of string tension, gauge or type on the ball spin seems to be in the high-speed video analysis of actual impact by a player.

This paper provides the explanation about the strings performance improvement on ball spin and the mechanism of the reduction of shock vibrations of the wrist joint during topspin impact. It also shows the difference in dynamics between the lubricant strings and the looser strings based on the impact analysis, where it is a key factor that the damping coefficient and the stiffness of a ball and also the stiffness of strings radically increase with deformations [2]-[4][16].

2. Observation of ball spin behavior during topspin forehand stroke by using high-speed video analysis

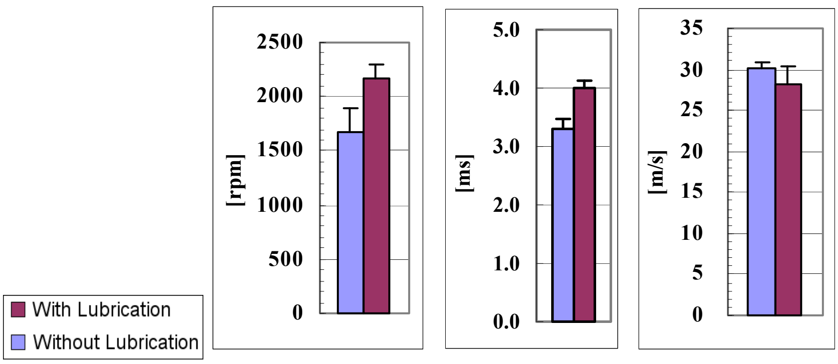
Figure 1 shows the ball spin behaviors viewed from behind the racket, in which (a) the ordinary strings and (b) the lubricated strings at the intersections. The long main strings stretch and slide side ways more across the short cross strings and mains spring back by lubrication at the string intersections in Figure 1(b) compared to the ordinary strings in Figure 1(a), where the mains do not move much and do not recover to their original position. The contact time (dwell time) for the lubricated strings is longer (4.1 ms) than that for ordinary strings (3.4 ms) [24][25]. Figure 2 shows the effect of strings lubrication on the ball spin rate, the contact time and the post-impact ball velocity, which is derived from the average and standard error of three times trials. The ball is given more extra spin (30 % increase) by oil lubrication at the string intersections. More spin produces longer contact time between a ball and strings (21 % increase), reducing the post-impact ball velocity (6 % decrease).

(T405_f196_L) **From contact: 1.7 ms** (T506_f159_L4) **From contact: 1.7 ms**

(T405_f213_L) **End of contact: 3.4 ms** (T506_f183_L4) **End of contact: 4.1 m**

(a) Without strings lubrication **(b) With strings lubrication**

Figure 1. Effect of strings lubrication on the ball spin behaviors (Impact views from behind the racket)



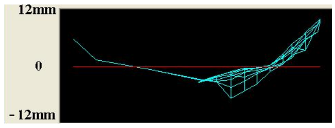
(a) Ball spin rate *ω* **(b) Contact time T_C** **(c) Ball velocity V_B**

Figure 2. Effect of strings lubrication on the ball spin rate and contact time (Average and standard error of three times trials).

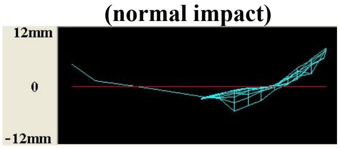
3. Performance of Lubricant Strings and Looser Strings

Figure 3 shows the predicted effect of contact time T_C on the fundamental racket frame vibration, where the impact velocity: 30 m/s under the same impact, hitting location on the string plane: A(top), Racket:MP-1. Figure 4 shows the predicted effect of contact time T_C on the wrist joint shock vibrations.

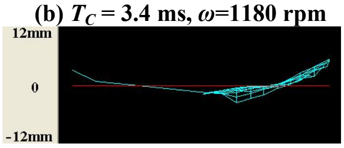
Figure 5 shows the predicted stiffness of the string plane (bed) vs. string deformation relative to the string tension [2]-[4][11][16]. Although the string stiffness markedly increases with the impact velocity, it is not much affected by the initial string tension. The predicted deformations of strings and a ball show



(a) T_C = 2.6 ms, ω= 60 rpm (normal impact)

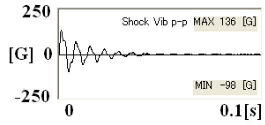


(b) T_C = 3.4 ms, ω=1180 rpm

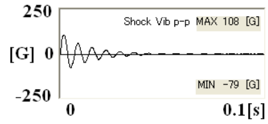


(c) T_C = 4.1 ms, ω=2460 rpm

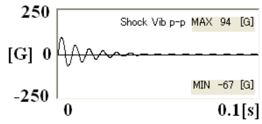
Figure 3. Effect of contact time T_C on the fundamental racket frame vibration. Impact: 30 m/s, hitting location on the string plane: A(top), Racket:MP-1



(a) T_C = 2.6 ms (normal impact)



(b) T_C = 3.4 ms



(c) T_C = 4.1 ms

Figure 4. Effect of contact time T_C on the wrist joint shock vibrations. Impact velocity: 30 m/s, hitting location on the string plane: A(top), Racket:MP-1.

that a lower string tension results in an increase in string deformation but does not result in a decrease in ball deformation at realistic impact velocities. This is the reason why a lower string tension does not result in a significant increase in rebound velocity. Figure 6 shows the predicted contact time, showing that the contact time decreases markedly with increasing the impact velocity and that the

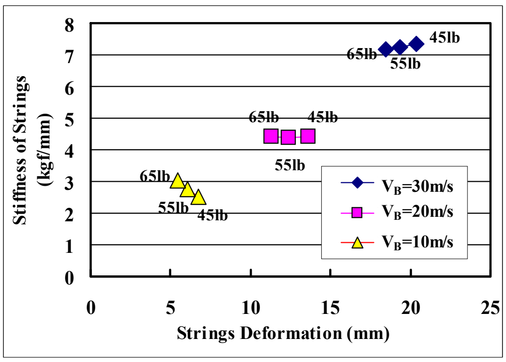


Figure 5. Predicted stiffness of the string bed vs. string deformation relative to the string tension.

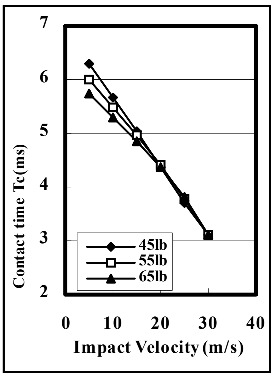


Figure 6. Predicted contact time vs. impact velocity relative to the string tension.

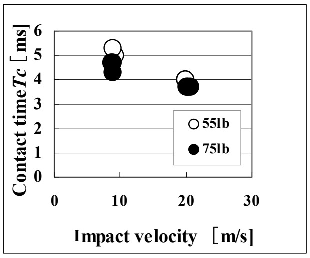


Fig.7 Measured contact time T_C vs. impact velocity, showing the effect of string tensions.

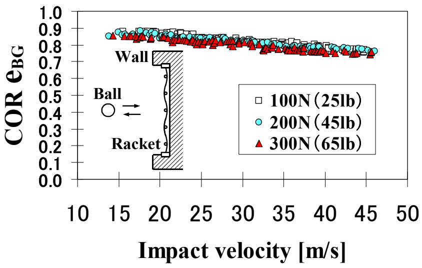


Figure 8. Measured coefficient of restitution e_{BG} between a ball and strings vs. impact velocity, showing the effect of string tensions.

string tension has little effect on the contact time in an actual tennis play[4][11]. The string tension has also little effect on the predicted impact force at realistic impact velocities. Figure 7 is an example of measured contact time vs. impact velocity with the rackets strung at remarkably different tensions (55 lbs and 75 lbs) showing that string tensions have no significant effect on the contact time in the realistic impact velocity of over 20 m/s [4]. Figure 8 shows the effects of string tension on the measured coefficient of restitution e_{BG} when a ball strikes the strings with a racket head (string bed) clamped [11]. String tension for most strings is between 200 N and 300 N; a string tension of 100 N is too loose for play. Impact velocity for most players during real play is between 20 m/s and 30 m/s and between 25 m/s and 35 m/s for an advanced player. The maximum pre-impact velocity (racket head velocity) during the serve of tour pros is 40 m/s. The averaged coefficient of restitution e_{BG} between a ball and strings vs. string tension showed that the 40 % decrease in string tension from 300 N to 200 N results in only a 1.4 % increase in the restitution coefficient e_{BG} at an impact velocity of 20 m/s, and results in almost no increase at 30 m/s. It is shown that the effect of the string tensions on the coefficient of restitution between a ball and strings at realistic impact velocities is very small [4][11].

4. Conclusions

This paper provided the explanation about the strings performance improvement on ball spin and the mechanism of the reduction of shock vibrations of the wrist joint during topspin impact. It also showed the difference in dynamics between the lubricant strings and the looser strings based on the impact analysis. The effect of string tension, gauge or type on the ball spin during topspin stroke by a player is still mystery. The solution to this mystery seems to be in the observation of interaction between a ball and strings using the high-speed video analysis of actual impact by a player in future.

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