TENNIS KINEMATICS TRANSIENT ANALYSIS: A BALL SPIN & RACKET COLLISION DESCRIPTION

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1. Introduction. Brief description of the project.

In some ways tennis has become a truly high tech sport. Advances in racket design and composition have changed the speed of the game from the days of wooden frames, and made the game easier and more enjoyable at the recreational level.

Television coverage of matches makes use of sophisticated statistical analysis to explain the outcome of matches in terms of winners, errors, serving percentages and ball placement Players study the statistical tendencies of opponents in an effort to get an edge.

But at the most basic level of understanding there is no clear picture of what happens to the tennis ball during the course of a tennis match. The radar guns give us an initial velocity of the serves, but beyond that very little is really known about what happens, when players strike the ball in the game. New types of strikes result in complicated rotation of the ball. For example:

- Increasing service speed of ball shooting
- Top spin resulting in maximum upper rotation
- Slice resulting in simultaneous bottom and side rotation

Tennis rackets nowadays need to be constantly re-developed. Design and manufacturing procedures linked with the most essential equipment a tennis player can have, are subjected to aerodynamical change. This book seeks to study tennis from a new perspective – the perspective of design aerodynamics, setting out to determine what we can learn about the flight of the tennis ball. When the ball hits the racket during play, some dynamic stresses and deformations occur with the load periodically changing [1]. This results in oscillations (vibrations) in the racket and under certain conditions the phenomenon “resonance” might occur during which the stress and deformations might suddenly rise to dangerous values. When no resonance conditions exist the periodically changing stress might lead to damages in the racket caused by gradually forming cracks in the material [1].

2. Project Identification and Definition

The wider popularity of tennis as a sport game on a world-wide scale, the increasing quality of the play of both professional and amateur players has set grounds for expanding the production of aids and accessories, such as tennis rackets, for this game.

There is a wide variety of tennis rackets presently available on the market and these could be basically assessed on the basis of the following characteristics:

1. Type of material used for manufacture
2. Size and dimensions of racket head
3. Handle length
4. Racket weight
5. String tensioning
6. Degree of damping and vibrations

The first 5 characteristics are quantitative and could easily be determined and controlled using common measuring equipment. The sixth characteristic, - vibration resistance, is the appealing element. The value of these vibrations is important and is hard to determine with formulas due to the complexity of the friction process, the friction and the air resistance losses [2].

3. Equipment Rules for Tennis Balls

Tennis Ball data such as, the ball's size, the ball speed and the rate at which the ball spins have to be evaluated as well as other distinguishing shape features.

The tennis ball is roughly a 63.5-mm (2.5-inch) sphere. It has a uniform outer surface, a continuous hourglass shaped seam and a felt-like fuzz. The ball has to be white or yellow in colour. It has to be more than 56.7-grams (two ounces) and less than 58.5-grams (two and one-sixteenth ounces) in weight. The average professional tennis player serves the ball at 120kmph and the spin of the ball during a serve can reach around 1000 rpm [2].

The seam of the ball is a very important issue to deal with. International equipment regulations dictate for the minimum seams to appear in the surface of a ball. Furthermore, these should be stitchless. The seam makes the surface of the tennis-ball very porous and non-uniform.

3.1 CFD Seam Simulation

My interest on the seam feature and its consequences led me to start simulating the tennis-ball. Computers are used extensively throughout aeronautics to aid in the design and analysis of aircraft, watercraft, and even sports equipment. Scientists have developed mathematical models, which emulate the physics of fluids [3]. These mathematical fluid models are programmed into software applications, which can be used on the computer.

An engineer can take an object, like an aeroplane or ball, and use the fluid model to analyse how this object would perform in "flight". It is like having a virtual wind tunnel. There is a special name for this type field of work. It's called "Computational Fluid Dynamics" or "CFD" for short. We decided not to include the whole simulation procedure step by step in this section. We would like though, to feature some of the set up made.

Figures 1 and 2 above show two different cases. Comparing them, we could find differences in the ball’s speed and spin.

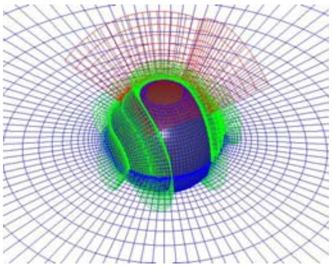
Figure 1

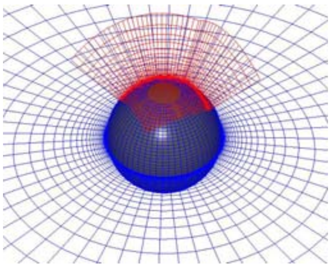
Figure 2

4. Equipment Rules for Tennis Rackets

Rackets failing to comply with the following specifications are not approved for play under the Rules of Tennis:

a. The hitting surface of the racket shall be flat. It should consist of a pattern of crossed strings connected to a frame and alternately interlaced or bonded where they cross. The stringing pattern shall be generally uniform, and in particular not less dense in the centre than in any other area. The strings shall be free of attached objects and protrusions, other than those utilized solely and specifically to limit or prevent wear and tear or vibration, and which are reasonable in size and placement for such purposes [4].

b. For professional play, the frame of the racket shall not exceed 73.66-cm (29 inches) in overall length, including the handle, as from 1st January 1997. For non-professional play, the frame of the racket shall not exceed 73.66-cm (29 inches) in overall length including the handle, as from 1st January 2000. Until 1st January 2000, the maximum length of a racket for non-professional play shall be 81.28-cm (32 inches). The frame of the racket shall not exceed 31.75-cm (12 1/2 inches) in overall width. The strung surface shall not exceed 39.37-cm 15 1/2 inches in overall length, and 29.21-cm (11 ½ inches) in overall width [4].

c. The frame, including the handle, shall be free of attached objects and devices, other than those utilized solely and specifically to limit or prevent wear and tear or vibration, or to distribute weight. Any objects and devises must be reasonable in size and placement for such purposes.

d. The frame, including the handle, and the strings, shall be free of any device, which makes it possible to change materially the shape of the racket. Or to change the weight distribution in the direction of the longitudinal axis of the racket, which would alter the swing moment of inertia, during the playing of a point [5].

4.1 Qualities of modern tennis rackets

Being familiar with the basic performance characteristics of modern tennis rackets contributes to the most suitable choice of a racket for both the beginner and the professional player considering his individual nature (physical characteristics, skills, manner of playing, etc.) and the requirements in the competition (court hardness, ball brand, etc.). This knowledge also contributes to derive the best maximum of a given racket. Or, in the language of “profies” – to “squeeze the maximum capabilities out of a racket” [6]. To achieve this leading players even order specially made rackets with some modifications to the basic model.

On the other hand, the progress in the development of rackets results in changes of the manner and skills of the player. The striking technique for a wooden racket is very much different to that of a racket made of modern composite materials. Every revolutionary change to the rackets results in modifications in striking techniques [6].

Modern rackets are manufactured and tested mainly to provide the following basic mechanical and dynamic customer performance characteristics:

Racket Length

This is the distance from the tip of the racket to the end of the handle. A common tendency is to increase the length of the racket to provide more powerful strike and dynamic inertia. To prevent uncontrolled increase of racket lengths ITF approved a document at its congress in Lozane in 1997 according to which professional players can use rackets of maximum 29 inches. Long Body rackets are made of 28, 28.5 and 29 inches length [6].

This parameter is:

- directly proportional to the length, weight, dynamic inertia and power;
- inversely proportional to body rigidity, manageability and control.

String surface area – head size

This is the surface area of the string flat measured on the inside of the rim. This is measured in square centimetres or square inches. Various companies offer rackets of 500 to 750 sq. inches for this parameter [6].

This characteristic is:

- directly proportional to the length, dynamic inertia, power and control;
- inversely proportional to the rigidity of the string area flat, body rigidity and manageability.

Balance

This is the distribution of the static weight of the racket along its entire length. It is an indication of the distance measured from the low end of the handle to the cross line where the racket would stand horizontally if we supported it at this cross point. Higher values indicate increased weight on the head on the account for the weight on the handle and lower values indicate the opposite balance of weight. The lightest racket heads for adults have a balance figure of 300 and the heaviest heads have a balance of 380-mm [6].

This parameter is:

- directly proportional to the length, weight, dynamic inertia and power;
- inversely proportional to manageability and control.

Weight

This is the static weight of the racket measured in grams. Kid’s rackets are the lightest. Their weight starts from 200 gr. Professional rackets are the heaviest. Their factory weight values come up to 367 – 370 gr [7]. Professional players often attach additional weights to the head of the racket to change its balance and add to the weight of the racket.

This parameter is:

- directly proportional to the length, dynamic inertia and power;
- inversely proportional to manageability and control.

Knit

This is the number and positioning of the string knit openings in the body of the racket, which determine the density and structure of the string area. According to the number of knit openings modern rackets usually have between 16 and 20 longitudinal strings and 18 to 22 transverse strings though there are some exceptions. According to the positioning of the string openings some rackets feature uniform and other, non-uniform and denser in the striking zone (centre) string area [7].

This parameter is:

- directly proportional to the rigidity of the string area, the dynamic inertia and control
- inversely proportional to tensioning and power.

Tensioning

This is the tension applied to the string when knit. Tensioning is usually performed within 18 to 35 kg. Tension is “equal” when longitudinal and transverse strings are identically tensioned and is “differential” when longitudinal strings are tensioned heavier than transverse ones. This difference is usually between 1 and 2 kg and is defined by the shape of the head of the racket [7]. Rackets featuring larger differences in the length of longitudinal and transverse strings are usually knit using different tension.

This parameter is:

- directly proportional to the rigidity of the string area and control
- inversely proportional to knit, dynamic inertia and power.

String area rigidity

This is the pressure pliability of the knit string area not counting the racket body (rim) elasticity. This property depends on the knit, tensioning and the shape and size of racket head. This is resultant characteristic and is an exact indication of the racket knit. It is more important to know the final result of the knit and not the exact value of tensioning applied to the string when knit. The most pliable surface has a figure of 51 for this parameter and the hardest one comes up to 75 kg [7].

This property is:

- directly proportional to the knit, tensioning, body rigidity and control;
- inversely proportional to the surface area of the string flat, the dynamic inertia and power.

Racket body rigidity

This is the pressure pliability of the racket body. This property depends on the manufacturing materials and technology and the shape of the racket body. For professional rackets this figure is between 50 and 75 kg [7].

This property is:

- directly proportional to the dynamic inertia, manageability and control;
- inversely proportional to the length, head size and power.

Dynamic inertia

This is a set of energetic characteristics of the racket indicating how the racket transfers the energy from the hand during the movement. Until very recently this property was disregarded from measurements and was only determined and sensed by the player himself. Now that computer measurement has been introduced into the tennis sport this is a characteristic that is being followed very closely and is the latest feature established so far. It is dependent and functionally incorporates all other racket properties indicating the result of the combination between them. Satisfactory incorporation of opposite parameters is achieved by distributing the mass and elasticity along the racket mainframe. Leading racket brands are made lighter to provide better control and manageability but at the same time they provide much better ball acceleration characteristics due to the improved quality of the dynamic inertia. This makes the racket powerful and precise (control and manageability) simultaneously. This is achieved by improving the balance characteristics and implementing new materials, such as titanium or carbon fibre compounds. This parameter usually varies within 290 and 360 units [8].

This parameter is:

- directly proportional to the length, string surface area, balance, weight, body rigidity and power;
- inversely proportional to the knit, tensioning, string area rigidity, manageability and control.

Manageability

This is the ability of the racket to obey to the movement of the player's hand. The aim is for the player to exercise minimum effort to change the position of the racket and the string area surface. This is measured within 50 and 100 gr [8].

This property is:

– directly proportional to the body rigidity and control;
– inversely proportional to the length, head size, balance, weight and dynamic inertia.

Power

This is indicated by the portion of energy being transmitted from the racket to the ball or at minimum effort from the hand to have the racket transmitting maximum energy to the ball. Modern rackets have figures for this parameter between 25 and 80 units [8].

This property is:

– directly proportional to the length, head size, balance, weight, body rigidity and dynamic inertia;
– inversely proportional to the knit, tensioning, string area rigidity, manageability and control.

Control

This is the ability of the racket to provide precisely (and quickly) the right direction, trajectory and rotation to the ball. Considering the relative share of unprovoked mistakes this is a very essential parameter. For modern racket this parameter varies within 40 and 80 units [8].

This property is proportional to:

– directly proportional to the area and size of the head, to the knit, tensioning, string area rigidity, body rigidity and manageability;
– inversely proportional to the length, balance, weight, dynamic inertia and power.

The following comparative table of the basic characteristic parameters of most commonly used professional rackets indicates how manufacturers achieve the combination between opposite characteristics and what are the trends in the development of these qualities.