How To Measure String Tension and What It Means: Part 1

Rod Cross

It is easy to string a racquet at say 60 pounds or 65 pounds and to know that it is strung at that tension, but how do you check the tension after the racquet is strung, say one week later or even one minute later? There are several ways, as experienced stringers will already know. The most common way is to hit the strings with one hand or with another racquet and listen to the sound they make. A high pitch "ping" means the strings are tight and a low pitch means the strings are loose. A better way is to use a racquet diagnostic machine, or a Stringmeter or maybe a fancy electronic gadget such as the ERT700. But how do you know if these devices give the correct answer? The problem is how can they be tested? What else can they be tested against?

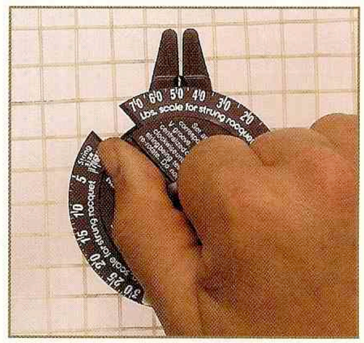
Racquet Diagnostic Machines

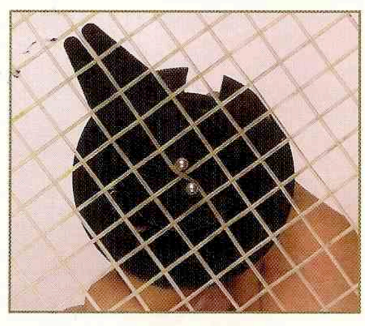
RDC Stringbed Stiffness Test

When you string a racquet, one end of the string is tied down and the other end can be connected to a spring or a strain gauge to measure the tension. But when both ends of the string are tied to the frame, this method of measuring the tension is no longer available.

The next best method is to push the string sideways with a known force to see how far the string bed deflects. That is the method used in Pacific and Babolat racquet diagnostic machines. The answer depends on the string tension as well as several other factors such as the length of each string, the number of strings, the stiffness of each string and the diameter of the object (usually cylindrical) that is used to push the strings sideways. For that reason, a racquet diagnostic machine can't give a reliable measure of the string tension, but it does give a reliable measure of the string bed stiffness. In fact, the string bed stiffness is more important than the tension itself, since the string bed stiffness determines how far the strings will deflect, and how much the ball will squash when you hit a tennis ball. Even so, string bed stiffness is usually quoted in DA or RA units ("made up" units indexed against the machine's zero point), which is just another way of admitting that the actual string bed stiffness is not known. (Another problem, of course, is that the actual string bed stiffness depends on how hard you hit the ball. The string bed gets stiffer the more it stretches, but that is another story.)

The Stringmeter





A racquet diagnostic machine is useful in measuring whether the string tension or the string bed stiffness has decreased over time, and it will indicate roughly by how much, but it still doesn't give an accurate or absolute measurement of the actual string tension because all the other factors are not properly accounted for. That is why the Stringmeter was invented.

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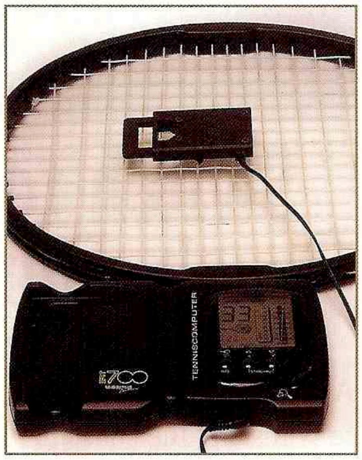
The Stringmeter contains two small cylindrical rods 1/3 of an inch apart that can be inserted anywhere in the string bed to measure the tension of any desired string. The idea is to rotate the rods so that a particular string is pushed on one side and pushed in the other direction on the other side to form a little kink in the string. The rods are connected to a spring-loaded dial that is marked with graduations to read the tension in lb or kg. There is also a small adjustment needed for string diameter, which one does by rotating the position of the scales slightly. The only problem with this is that it is difficult to know whether the answer is correct. One can test the device on a single long string that is pulled to 60 pounds, and it will correctly read 60 pounds, but that is not the same as testing it on a fully strung racquet. In fact, the Stringmeter has three separate scales - one for long straight strings, another in pounds for a strung racquet, and also a kg scale for a strung racquet. The difference is due to the fact that the kink in a single long string has a different shape to the kink when the strings overlap.

Friction between the mains and the cross strings prevents the string kinking over the full length of the string, with the result that the string kinks only over a short section of the string. A bigger force is needed to kink a short string than a long string, by an amount that is difficult to estimate with any accuracy. Consequently, the pounds and kilogram scales on the Stringmeter are difficult to check to determine if they are correct. Nevertheless, a Stringmeter can be used to determine if the tension has dropped with time, and roughly by how much, and it can be used to measure the tension in every single string if you have the patience. A surprising result is that the tension in the cross strings is often a lot less than the tension in the mains. The Stringmeter is the only instrument I know of that can give this particular information. In principle, one could use a strain gauge located on every string to measure the tension in each string, but the Stringmeter is a lot more convenient.

The ERT700



Every other method of measuring string tension measures all the strings at once, so these methods give only the average string tension in all the strings — not the tension in any given string. A high-tech method is used in the ERT700.

It is high-tech since it contains two boxes of electronics and a digital display, but the basic method is fairly simple. The ERT700 forces the strings to vibrate back and forth, in much the same way that they vibrate when you hit them with your hand. The point of doing this is that the vibration frequency depends on the string tension. It is the same as in a piano or guitar or violin. Tuning up a guitar involves adjustment of the tension in each string so that it vibrates at just the right frequency. If you increase the tension it will vibrate faster and the pitch rises. If you drop the tension, the string vibrates more slowly and the pitch drops. The ERT700 detects the frequency of vibration of the whole string plane and assigns a number to the tension. However, the tension indicated by the ERT700 is not the actual tension since the vibration frequency depends on string tension, string length, the area of the string bed, the mass of each string, the number of strings and the actual string pattern. The formula for the actual frequency is too complicated to figure out the actual tension.

The ERT700 uses a small plastic box (which they call a ball simulator) that is clipped onto the strings, preferably in the middle of the string plane. The box has a mass of 34 gm, which is a bit less than a standard 57 gm tennis ball, but bigger than the mass of the strings themselves. The strings have a mass typically about 15 or 16 gm. Without the box in place, the strings themselves will vibrate at about 500 Hz or 600 Hz when you hit them, depending on the string tension. When the box is added, the extra mass of the box slows down the vibration frequency to something between about 140 and 180 Hz, again depending on the string tension. Inside the box is a small brass weight attached to a piezo disk (see November 2000 Racquet Tech for an explanation of piezoelectric materials in the Head Intelligence racquets). When a voltage is applied to the disk, the piezo causes the brass weight to vibrate, in the same way that a piezo buzzer works in a watch or a computer or an alarm to make a buzzing sound. By varying the vibration frequency of the piezo until it matches the frequency of the strings plus the simulator box, a resonance frequency is established and it is used to give readings of string tension, dynamic tension, and percent power vs control. All these numbers are based on one measurement of the frequency, so they are all just different ways of describing the same number.

Provided that one is willing to accept that all the numbers are artificial, then the ERT provides a useful and easy to use guide as to whether string tension has dropped over time and by roughly how much. The power reading varies from 20% to 80%, even though a decrease in 10 pounds in string tension will increase the ball speed by less than

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1%. In other words, the readings need to be taken with a grain of salt.

Artificial Tension Calibration

The manufacturers of racquet diagnostic machines and the ERT700 have decided that the simplest thing to do is to make sure that the tension indicated by their device is nearly the same as the pull tension, at least immediately after a racquet is strung. As time goes by the tension drops, and these devices will indicate that the tension drops, and they agree fairly closely with each other, but they all give a reading that is higher than the actual tension. There are four good reasons why the tension immediately after stringing is in fact a lot lower than the pull tension, as described below. However, stringers and customers are unlikely to be happy about this. If you string a racquet at a pull tension of say 60 pounds, and the actual tension immediately after stringing is only 40 pounds, then what will you tell your customer? If the customer asked for 60 pounds and you give him 40 pounds, then he is not going to be very impressed. That's why these tension measuring devices are calibrated to read the pull tension rather than the actual tension. It keeps everyone happy and no one knows the difference, including the stringer.

Four Reasons for Tension Loss During Stringing

Bond Breaking. If a string is stretched to a tension of 60 pounds, and then clamped at a fixed length, then the tension will immediately start to drop since the chemical bonds in the string keep breaking whenever the string is under tension. The weakest bonds break first, but it takes a longer time to break the stronger bonds. The tension will drop by about 8 pounds in the first 15 minutes. After that, the tension drops at a much slower rate. However, the main point is that the tension drops dramatically while a racquet is being strung. After that, the loss in tension is hardly noticeable. Polyester strings drop the most in the first 15 minutes (see RacquetTech, June 2000).

Frame Distortion. Another problem is that all racquet frames are light and flexible. Even if you clamp the head at 6 or more points, the bits that aren't clamped can move during the stringing process. Graphite racquets are made to be stiff in a direction perpendicular to the string plane, but that is done at the expense of making them soft in a direction parallel to the string plane. Every time you add another string, it pulls the frame inwards in the direction of the string, and stretches the frame outwards in a direction perpendicular to the string. If you add another cross string, the tension in the previous cross strings drops, and the tension in the mains increases. That is why the tension in the cross strings is usually a fair bit less than the tension in the mains. The total pulling force of say 10 strings each at 60 pounds is 600 pounds. That is a huge force on the frame, and it is no wonder that the frame distorts even when it is clamped at 6 or more points. A poorly mounted racquet can expand in width by an inch or more when the mains are strung. That is a terrible thing to do to the frame, but people do it, and then say it doesn't matter since the frame pulls back into shape when the crosses are added.

Friction. Friction is another reason why the string tension after stringing is a lot less than the pull tension. The tension at one end of a string in a racquet is not necessarily the same as the tension at the other end. When the mains are strung, then the tension at each end is the same, since there are no cross strings to interfere along the length of any given string. But when the crosses are installed, they are woven through the mains. Friction between the mains and the crosses then results in the tension at the pulling end of a cross string being higher than the tension at the other end. This is easy to demonstrate. Take a three-foot-long string and weave it across the main strings in a fully strung racquet. Clamp a 2-pound weight on the bottom end of the string. Then, holding the racquet so it can't move, lift the other end of the string. In order to lift the weight at the bottom end, you will need to pull with a force of about 4 pounds. That means the tension in the top end is 4 pounds and the tension in the bottom end is only 2 pounds. Or, if the tension at the pull end is 60 pounds, the tension at the other end will be about 30 pounds.

Pull Angle. The fourth reason has to do with the pull angle. The pulling head on some machines has to be a bit lower than the racquet in order to rotate the racquet. The string makes an angle of about 10 degrees with the horizontal between the pulling head and the edge of the racquet frame. It then passes through a grommet hole. Friction in the hole ensures that the tension after the string passes through hole is less than the pull tension, typically by about 2 pounds.

Conclusion

This all adds up to a total tension loss of at least 10 pounds, and maybe a lot more by the time the racquet is strung, depending on the stringing technique. Next month, some actual tension measurements will be described, and various methods of measuring string tension will be compared using actual data, including the three methods already described above plus two more methods that were hinted at in this article (using a strain gauge and also a microphone).