STRETCH TESTS ON STRINGS

by Rod Cross

INTRODUCTION

The June 2000, Dec 2000 and Feb 2001 issues of Racquet Tech contain the results of laboratory tests on about 140 different strings. Each string took about an hour to test. I have since found a faster way to get similar results using a method that stringers themselves could use if they have a suitable stringing machine (one that allows the tension to be altered while the string is still under tension). They are still only laboratory tests, but laboratory tests at least give real numbers. Play tests give only imaginary numbers thought up by the players. Laboratory tests are useless by themselves since they don't reveal if a string feels good or bad. But if two strings test out the same in the lab, then they ought to feel the same. If they don't, then something is missing from the tests, and that is something that we could learn from. If there is a magic ingredient that makes a good string? If so, then we'd all like to know what it is.

The most important property of a string, in terms of lab tests, is its stiffness. If you tension a certain length of kevlar to say 60 lb, it won't stretch as far as the same length of nylon. A kevlar string is very stiff and nylon is stretchy. However, a stretch or stiffness test like this is not as easy as it sounds. One problem is that all strings change their stiffness as they stretch. At low tensions they might be relatively stiff, but nylon strings soften in the range from about 20 to 30 lb, then they get stiffer again above 30 lb. Even worse, in terms of measuring a string, is the fact that the stiffness drops during the first few seconds when you first stretch a string. If you take a new piece of string, tension it to 60 lb and try to measure how far it stretched, it will stretch a bit further while you are trying to measure it. This is called creep. It might stretch by only a small amount while you are measuring it, or it might stretch a relatively large amount, but if you are looking for small differences between different strings, then the effect of creep can make a big difference.

AVOIDING CREEP

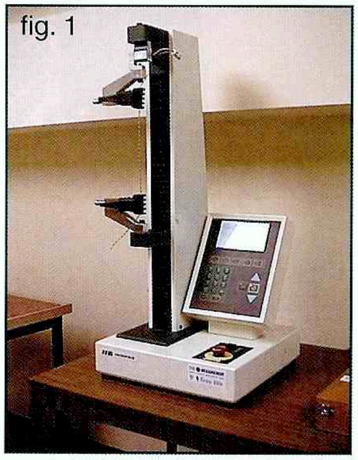
A string creeps whenever it is under tension since chemical bonds in the string break, especially during the first 10 seconds. We can't wait hours in the lab for the string to stop creeping, especially if we want to test a lot of strings. In any case, the string will start creeping again as soon as it is stretched a bit further to measure its elongation. There are two tricks that can be used to get around this problem. Method 1 is to stretch the string very rapidly by hitting it sideways with a hammer. That is how the test results described previously in Racquet Tech were done. The string was stretched in 0.03 seconds, which was too short to break many bonds. This is also what happens when a racquet is used to hit a ball. In fact, the strings in a racquet stretch for only about 0.005 seconds during the impact with a ball.

There is another way to avoid creep. If a string is stretched for any length of time, then most of the bonds that can break will break in the first 10 or 20 seconds. The trick is to stretch a string for at least 10 and preferably 100 seconds to break all the weakest bonds and then decrease the tension to measure how far it "unstretches." After 100 seconds, the rate of creep is very small. If the tension is decreased, then there is a further reduction in the rate at which bonds break and creep is effectively eliminated from the measurement. So, Method 2 is to stretch a string for 10 seconds or more and then measure the decrease in length when the tension is decreased. This gives almost the same answer as measuring the increase in length when the string is stretched rapidly. The test can be done on a stringing machine using a ruler to measure the distance between two marks initially about 200 mm apart. My own tests were done on a machine especially engineered for this type of measurement in order to get more accurate results.

TEST RESULT

The machine that I used to test out Method 2 is shown in Fig. 1. It is a small but expensive computer-controlled device that can be used to stretch a string (or compress a tennis ball) at a controlled rate, and the tension vs extension curve is displayed on the computer. A bracket was made to hold each end of a length of string using standard stringer's clamps since they are much better and cheaper than any of the clamps that can be bought for use with the test machine. The result for one string (Prince DNA Helix 17, 1.25 mm diameter) is shown in Fig. 2. The free length of string between the clamps was 200 mm, and this was the standard length I used to test all the strings shown in this article.

fig. 1



The computer was programmed with the following three steps:

1. Stretch the string at a rate of 50 mm/min until the tension reaches 63.0 lb (280 N in metric units): then hold the string at this length for 100 seconds. During the 100 seconds the tension dropped by several lbs depending on what string I tested. This step simulates what happens when a stringer installs a string.

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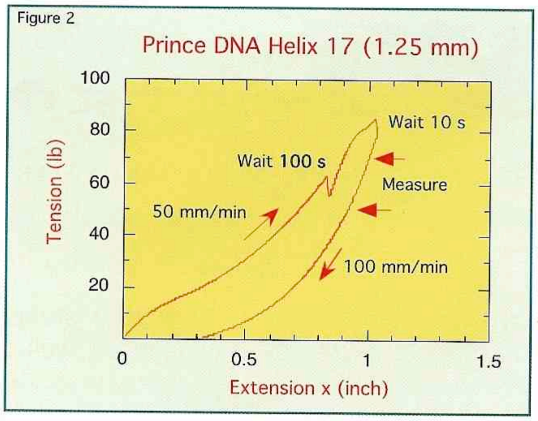
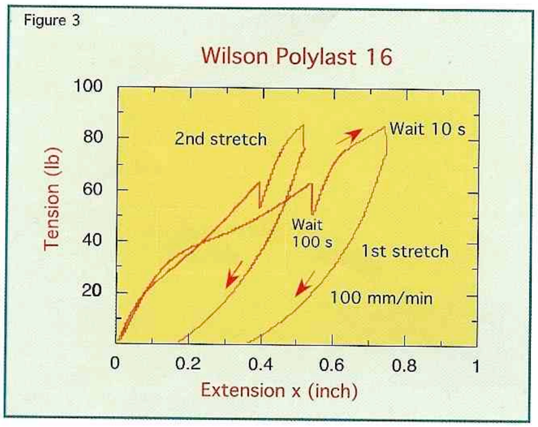
Figure 2



2. Stretch a bit further at 50 mm/min until the tension reaches 85.5 lb (380 N), then hold at the new length for 10 seconds. During the 10 sec wait, the tension dropped a few more lbs. This step simulates hitting a ball a few thousand times. Each time a ball is hit, the strings stretch and the tension increases to about 80 lb or more, depending on the type of string and how hard the ball is hit. When a ball is hit, the tension might start at 60 lb (the pull tension) rise to 80 lb and fall to 59.98 lb due to the fact that a few bonds will break during the impact. One hit lasts only 0.005 seconds. But if a ball is hit 2000 times, then the tension will drop by a total of a few lbs.

Figure 3



3. Decrease the tension back to zero at 100 mm/min. The last step is the important part since one can measure the decrease in length without any significant creep effects occuring. A convenient and standard way to do this is to measure the decrease in length when the tension drops from say 70.0 lb to 50.0 lb. If one measured the change in length from say 40 lb to 20 lb, then the answer would be different and it would not be very relevant since strings are used in the range from about 50 lb to 70 lb or a bit higher. In Fig. 2, the extension dropped from 1.002 inch at 70 lb to 0.915 inch at 50 lb. The string stiffness, k, is the change in tension divided by the change in length. In this case, we get k = (70 - 50)/(1.002 - 0.915) = 230 lb/in.

The Method 1 hammer tests reported in Dec 2000 on this string gave a different value for k, namely 192 lb/in. However, we tested 320 mm long strings then. Longer strings stretch further than short strings at the same tension so long strings have a smaller value of k. My 230 lb/in for a 200 mm string would translate to 230 x 200/320 = 144 lb/in for a 320 mm long string. It looks like Method 2 and Method 1 disagree. But the hammer tests increased the tension, not from 50 to 70 lb but from 50 lb to 88 lb since that is what happens in a 120 mph serve. The further a string stretches the stiffer it gets. The value k = 144 lb/in for a 320 mm string represents a medium pace groundstroke stretch and the value k = 192 lb/in for a 320 mm long string represents a very fast serve stretch. You can see how this happens by looking at the curve in Fig. 2. As the tension increases the curve gets steeper (both sides of the curve get steeper) meaning that k gets bigger.

I also tested a steel extension spring to see how it performed in the test machine. It had zero creep and the decreasing tension curve lay exactly on top of the increasing tension curve. Both curves were exactly straight lines, apart from the beginning since extension springs need some initial tension before they start to move. That is because the coils are wound so tightly (unlike a compression spring) but noone can tell me how or why this initial tension might be useful. I think it's just that springs are easier to wind when each coil is pulled tight against the next.

RESULTS FOR OTHER STRINGS

Fig. 3 shows the stretch test results for a typical polyester string. Polyester strings lose tension faster than other strings and they are stiffer than nylon. This string was tested twice, first using a fresh sample. The pre stretched sample was then tested again. It didn't stretch as far the second time, but a surprising result is that k = 397 lb/in for the first stretch and k = 394 lb/in for the second stretch (measuring between the 50 lb and 70 lb points). The stiffness between 50 and 70 lb hardly changed at all.

Figure 4

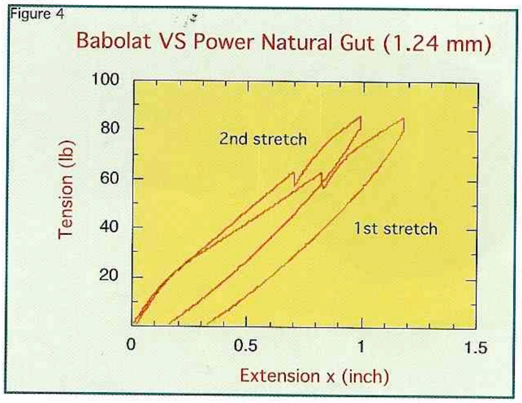


Fig. 4 shows what happens when natural gut (17G) is tested twice. It also gets stiffer after pre-stretching, but the stiffness between 50 and 70 lb is hardly affected. It increased from k = 115 lb/in to 117 lb/in.

Fig. 5 compares two different gauges of Tecnifibre NRG^2, 16 gauge (1.34 mm) and 17 gauge (1.23 mm). The 17G version is

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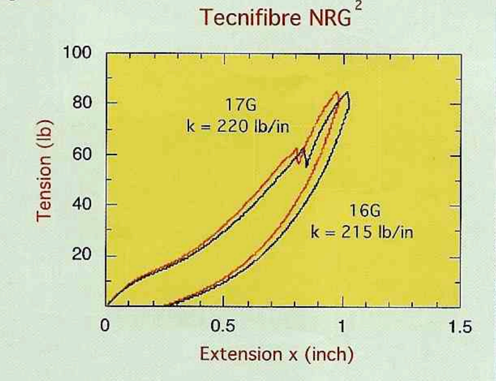
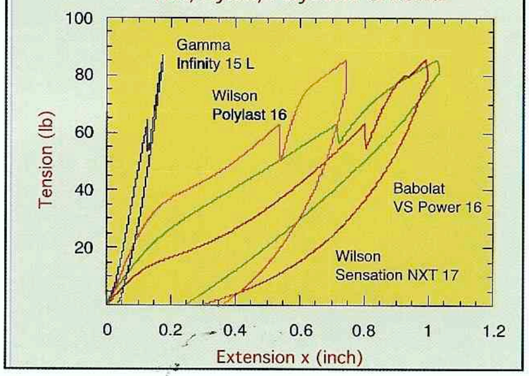
Figure 5



slightly stiffer than the 16G version, even though one would normally expect a thin string to be easier to stretch. It is the expected way around with natural gut. The 16G version of Babolat VS Power had k = 125 lb/in.

Fig. 6 shows a comparison between gut, nylon, polyester and kevlar. Kevlar is very stiff and stretches only a tiny amount. Nylon stretches the most at tensions up to 60 lb, but it is stiffer in the region from 50 lb to 70 lb than natural gut. All nylon strings have about the same stiffness, so it is a mystery to me why different nylons are reported to feel different. It might be the crispness of the sound they make, not the crispness of the "feel." In other words if something sounds better, it might be perceived as feeling better. That is presumably why some players use string dampeners and some don't. I have the same problem as Andre Agassi in this respect. He can't play without a string dampener and neither can I, even though I know it makes no difference to the ball speed or angle off the strings.

Figure 6



STIFFNESS VALUES

Method 2 (200 mm string) gives higher values of k than Method 1 (320 mm string) but both methods give the same answers regarding the relative stiffness of different strings, even when the differences are fairly small. The values of k (lb/in) obtained by both methods are given in Table 1 for a sample of 11 different strings.

Table 1. Comparison of both methods

String	Dia (mm)	Method 1	Method 2
Babolat VS Power 17	1.24	100	115
Babolat VS Power 16	1.29	108	125
Tecnifibre NRG2 16	1.34	170	215
Tecnifibre NRG2 17	1.23	184	220
Prince DNA Helix 17	1.25	192	230
Wilson eXtreme Control 17	1.23	196	239
Wilson Sensation NXT 17	1.24	202	244
Wilson Syn eXtreme Gut 17	1.25	218	260
Wilson Polylast 16	1.28	276	397
Prince Control Freak 16	1.27	499	629
Infinity 15L	1.38	734	797

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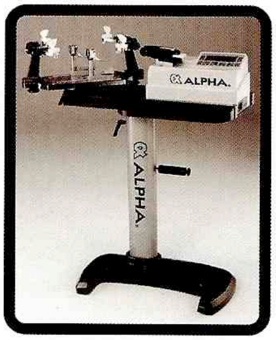

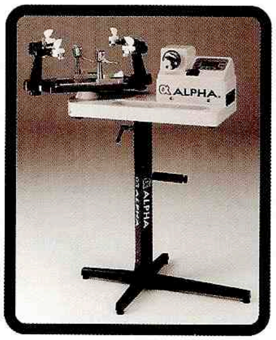

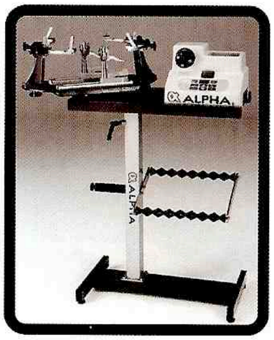

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DO STRINGS LOSE ENERGY?

All the graphs in this article indicate that strings lose a lot of energy when they are stretched. Any graph that shows force or tension vs distance can be used to calculate the work done in moving through that distance. The same is true of a string. Work has to be done to stretch a string, and that work is stored as elastic energy in the string. The string gives back some of that energy when it returns back to its original length, but it doesn't give back all the energy since some of it is used up in breaking chemical bonds in the string. The amount of energy lost is represented by the area enclosed by each of the curves. The fattest curves are the polyester curves. They have the biggest area so they lose more energy than other strings. As a result, the drop in tension during the 100 second pause at 63 lb, and also the drop in tension during the 10 second pause is larger than that for any other string. The polyester curves are so fat that about 70% of the stored energy is lost when the tension drops back to zero. The area of each curve is in fact of very little relevance to what happens when a string is used to hit a ball. In that case, the tension rises from about 50 lb to about 80 lb and then back to 50 lb (or maybe 49.98 lb) in only 0.005 seconds. This happens so fast that only a few bonds are broken. As a result, very little energy is lost.

Fig. 7 shows a very fast stretch for the Wilson Polylast string. It was stretched at 20,000 mm/min using a hammer impact, starting at a tension of 50 lb. The tension rose in 0.015 sec to 100 lb and then dropped back to 45 lb in the next 0.015 sec. This was the first impact on a fresh string and it broke a few bonds. The next impact broke fewer bonds and the extension curve was narrower than the one shown in Fig. 7. After 10 impacts, the forward and return parts of the curve were almost identical, meaning that almost no energy was lost in breaking bonds. After 10 impacts, a polyester string will therefore be just as powerful as any other string since the

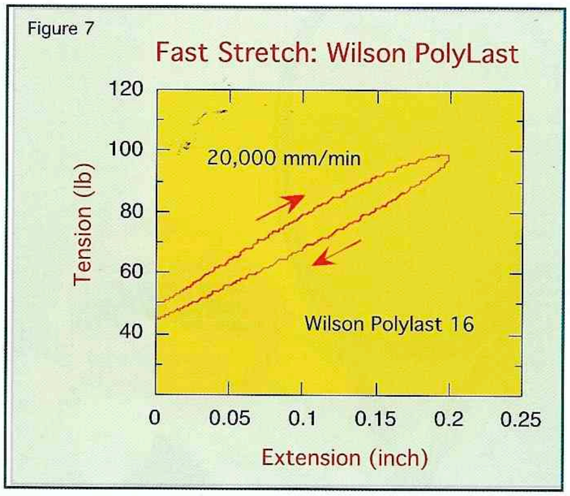
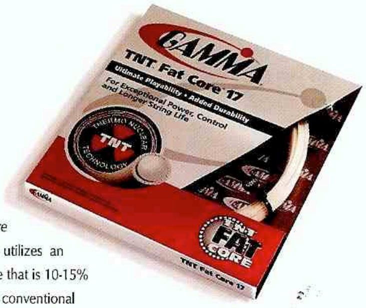
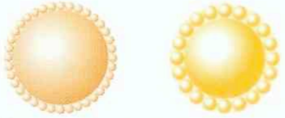


Figure 7





energy loss in each impact is negligible.

The curves in this article were all obtained at a stretch rate of 50 mm/min. A 0.03 seconds hammer impact stretches the string at 24,000 mm/min. A tennis ball stretches it at 140,000 mm/min during a fast serve. The hammer tests described in June 2000 Racquet Tech showed that only about 4 or 5% of the stored elastic energy is lost when a string is stretched rapidly by a sudden impact.

The tests here were all very slow by comparison, giving enough time for many more bonds to break. As a result, somewhere between 20% and 70% of the stored energy is lost, depending on the type of string.

It is interesting that the opposite situation occurs for a tennis ball. If a ball is squashed slowly it will store some elastic energy. If the force on it is slowly released, only about 15% of the energy is lost. But when a ball bounces, it squashes rapidly and returns rapidly back to its original shape. In the process it loses 45% of its stored energy. That is easy to measure from the bounce height. The difference is due to the fact that a ball is made from rubber and it loses energy by compressing and bending rather than by stretching. A ball can be squashed slowly by applying a force on opposite sides of the ball. When a ball bounces, a force is applied on only the bottom side, and the bottom bends more than in a slow squash.

DO STRINGS LOSE RESILIENCE?

In Figs. 1 - 6, each string was stretched, left stretched for a while, and then the tension was allowed to drop back to zero. As a result, the string was plastically deformed and ended up being longer than the original length. This means that strings are not resilient under these conditions — i.e., they do not return to their original length after stretching. The longer they are left under tension, the less resilient they become because more bonds get broken over long periods of time. However, strings are 100% resilient when they are used under normal playing conditions and they remain so for many years. When a string is installed, it is stretched to a certain length. Suppose that a main string is 12 inches long when it is installed. When it is used to hit a ball, it will stretch by about 1/4 inch during the impact, and then it returns to being 12 inches long. It doesn't become any longer than 12 inches otherwise all the strings would be loose and floppy like a butterfly net. All that happens is that the tension drops slowly over long periods of time. ■