Extra Extra Light Steel Strings on Old Banjos

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Musical taste and authenticity aside, owners of 100+ year-old banjos are admonished not to use steel strings because of the threat of irreversible damage to those fine antiques resulting from tensions higher than the original design. The purpose here is to offer sound samples of extra extra light steel strings whose tensions at standard pitches are no greater than those of commonly used nylon. There is also a sketch of how to understand and estimate tensions for various choices of material, scale length, and pitch. While these are things that many people know, there are many more who don't but might enjoy trying. A related bit explains why different strings sound different. But the discussion of the actual damage peril is inconclusive.

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INTRODUCTION

Playing period music on period instruments is a legitimate endeavor. But so is using the instruments at hand to play the music you like. And there are always a few people who push existing instruments to create totally new sounds. But the concern is often raised about a mechanical incompatibility of fine old banjos with what became a common (though not universal) sense of how banjos should sound with the adoption of steel strings. The five-string banjos of the mid-19th Century had gut strings and rims made from grain measures or comparably light weight fabrications. By the late 19th Century, the U.S. had become enthralled with the banjo. Skilled and thoughtful builders were joined by furniture and drum manufacturers eager to cash in. Typical construction was only slightly more substantial than earlier. Silk was occasionally an alternative to gut as a string material. And pitches were mostly lower than is common today. In the ensuing decades, heavier construction and steel strings dominated new construction. The new sound put much greater tension into the strings. What was the consequence of many people's impulse to put steel strings, tuned to higher pitches, on the many older instruments that were still around? Some of those instruments have survived to this day in good shape. But there are others with warped necks, rims, and/or dowel sticks, with heel cracks, with worn ivoroid tuners, and with worn frets. If the culprit is, indeed, the tension of steel strings, one can ask what would happen if steel strings were chosen thin enough that the total tension matches commonly available nylon string sets that are deemed acceptably safe. So the first order of business is to listen to steel that thin. Later sections in this note address the physics of string tension and timber and some of the potential physical damage issues.

THE SOUND OF SKINNY STEEL

A commonly available packaged set of nylon strings comes as 19, 22, 28, 25w, 19. Those are diameters in thousandths of an inch, with "w" designating a wound string. As discussed below, a steel set of 7, 8, 10, 17w, 7 has nearly the same tension. These can be found as "singles." (Often, a collection of singles is no more expensive than a packed set of five.) This comparison is of practical interest because both sets are easy to obtain. (The tensions discussed are for the same tuning and scale length.) A nylon set of 17, 19, 23, 24w, 17 is often recommended as offering more of the 19th Century mojo. Its total tension is about 20% lower than the 19 set, but you'd have to search a bit harder to find the singles to make it up. There is no uniform labeling convention as to what is "light" or "extra light" in steel strings, but packed steel sets of 9, 10, 13, 20w, 9 produce about 60% higher tension than the steel 7 set. These are the four sets included in sound samples below. (A common choice for modern open-back banjos of 10, 12, 16, 23w, 10 would give a bit more than double the tension of the steel 7's and nylon 19's.)

Here are some short sound samples. The banjo is a 27″ scale, c.1898 Stewart with an 11″ skin head. I made two identical 1.8 gm bridges, with one with wider slots for nylon strings. The finger-picked tune comes via Rev. Gary Davis, a giant of the guitar, who often related that he heard it first in 1905.

1) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/nylon17.mp3 for the nylon 0.017″ set.

2) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/nylon19.mp3 for the nylon 0.019″ set.

3) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/steel7.mp3 for the steel 0.007″ set.

4) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/steel9.mp3 for the steel 0.009″ set.

The feel of the thin steel strings was surprising at first, but, after all, they're no floppier than the nylons. Even once I was used to picking them, frailing seemed additionally odd. You can judge the sound for yourself with a snippet inspired by a tune from Taj Mahal.

1) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/nylon17-f.mp3 for the nylon 0.017″ set.

2) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/nylon19-f.mp3 for the nylon 0.019″ set.

3) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/steel7-f.mp3 for the steel 0.007″ set.

4) Click or go to http://www.its.caltech.edu/~politzer/xtra-xtra/steel9-f.mp3 for the steel 0.009″ set.

A FAIR COMPARISON?

Beside the vagaries of my inconsistent, mediocre playing, there is a more serious issue. Many of my previous investigations involved changing one item and keeping everything else as the same as possible. Hearing the result was an important component, but there was usually an attempt to quantify the expected change and to measure it. In the present context, the issue is purely aesthetic. Do extra extra light strings produce an acceptable sound? However, no attempt was made to optimize the head tension or bridge weight for each different set of strings. (And, of course, "optimize" is only with respect to some aesthetic judgment.) Hence, each of the sets demonstrated might be made to sound "better" by its own choice of set-up.

THE IDEALIZED EQUATIONS

As long as the "chime" (aka harmonic) at half the string length is close to an octave and the chime at one third the length is close to a pitch interval of a fifth, corrections to the ideal string equations are negligibly small. The first tiny correction is due to string stiffness. It makes the successive harmonics slightly sharp and is the reason that really thick solid strings sound a bit funky. But that's not a worry here because we just want rough estimates of relative string tensions.

Simple physics considerations[1] connect the speed v that transverse disturbances travel along the string to the tension T and linear density ρ. (ρ is the mass per unit length of the uniform string.) In particular

$$v^2 = T/\rho \ .$$

The pitch frequency f of a string fixed at both ends separated by length L is the inverse of the total back-and-forth travel time of a pulse or disturbance. That means that

$$f = v/L \ .$$

This is all that's needed to connect ρ, f, and L to T:

$$T = \rho f^2 L^2$$

Tune down instead of thinner strings? For a given material of volume density σ, the linear density ρ is proportional to the string diameter D: $\rho \propto D^2$. In that case, decreasing D has the same impact on T as decreasing f. For example, tuning down from a C to the G below reduces the tension by a factor of 2/3. That's about the same as going from a steel $0.010''$ string to a steel $0.007''$.

THE STRETCH CORRECTION & THE VALUE OF ρ

The various materials used to make strings each have an equilibrium (volume) density; call it σ. That's the mass per unit volume when the material is not under any stress. For ordinary nylon, it's about the same was water, 1 gm/cc. It can be just a bit less so that it floats. Fluorocarbon is nearly double that; so fluorocarbon fishing line sinks. Steel is typically around 8 gm/cc. Actually, just using these approximate densities in the formulae above will give a reasonable estimate of the relative tensions produced by different sets of strings.

When a string is under tension, its volume density might differ from the equilibrium value. (Which way it goes, if at all, depends on the way the atoms hold together.) One can measure σ by taking a long length of string, measuring its length and diameter and weighing it. (Sometimes there's an annoying conversion between weight and mass — having to do with 32 ft/sec/sec.)

All strings stretch under tension — more so the greater the tension. That means that ρ definitely gets smaller with increasing tension. The question is by how much, and do we care in the present context?

Among the strings tested, the stretch is the biggest for the nylon 1$^{\text{st}}$ strings, here tuned to D with a 69.0 cm scale. To measure it, I marked a 0.019″ string at 1 cm intervals starting at the nut when the string was just barely taut. (It vibrated at about 55 Hz.) I noted how many marks went past the nut as the string was tuned up to D and settled over a day or two. The 10.5 cm of string between the bridge and tailpiece also stretches and must be included in the evaluation. The final stretch, starting from 79.5 cm of unstretched string, was 5.8 cm worth of (unstretched) string. That implies, for a nylon string tuned to D with a 69 cm scale, $\rho_{\text{stretched}}/\rho_{\text{equilibrium}} = 0.92$. This ratio should not depend on the diameter of the nylon string. In particular, it would be the same for a 0.017″, when using the same pitch and scale.

This inevitable stretching has a somewhat counter-intuitive consequence. As a stretchy string settles in, each time it is tuned up again to the proper pitch, the resulting tension is slightly *less* that it was at the previous tuning.

For the same material, the fatter strings tuned to lower pitches will have less stretch in as much as they were chosen to have pretty much the same tension as the first string. In particular, for the same tension, a string with a diameter D_{bigger} has

$$\rho_{\text{stretched}}/\rho_{\text{equilibrium}} = 1 - \tfrac{5.8}{79.5}(\tfrac{D_{.019''}}{D_{\text{bigger}}})^2$$

The decrease in estimated tension for the full nylon set of five strings is only about 5% (in contrast to 8% for the 1st string itself).

The major string manufacturer D'Addario posts on-line the linear weights of all of their strings and encourages people to use precisely the ideal formulae given above. For the arithmetic-challenged, they also offer an on-line interactive tool at http://stringtensionpro.com/, which does the math to estimate the tension for any string, pitch, and scale length you enter. A quick perusal of their numbers reveals that they ignore stretch and simply use the equilibrium weight of their strings. No direct tension measurement of actual strings enters their calculations. For steel strings, the stretch correction is genuinely tiny. As shown above, it's pretty small for nylon in the context of estimating total tension. I have not included the very popular Aquila synthetic strings in this investigation simply because their molecular formulations, stretchiness, and diameters are a moving target. However, one could certainly weigh some measured lengths and also measure the (substantial) stretch to estimate the tension when brought up to pitch.

TONE & STRING DIAMETER

Non-zero thickness of strings introduces non-deal behavior, i.e. deviations from the simple formulae. And these deviations increase with increasing thickness. When a string bends, the material to the outside of the ideal centerline has to stretch, and the material inside has to compress. Thus, the elastic nature of the material contributes to stiffness of the string. The higher harmonics successively go sharper and sharper because each successive harmonic entails sharper and sharper bends. One solution for lower notes that require more string mass is to wind a thin core with wire. The winding adds appreciable mass without adding much stiffness. (A downside of wound strings for players who choose non-metal strings for the high pitches is that the wound ones typically wear out much faster.)

The stretching and compression also contribute to frequency-dependent damping. Thicker strings have less over-all sustain. But, in addition, the increasing dissipation with increasing harmonic frequency effects the tone. The very high harmonics that contribute to sharpness of the attack sound are seriously reduced. And the modest harmonics die off proportionately faster and resolve to a purer fundamental tone more quickly. Most versions of plucked string aesthetics welcome some suppression of high harmonics. Banjos are likely in the extreme regarding embracing some of that high-frequency-rich tone.

When considering a denser material, a compromise can be reached between making the strings thinner and increasing the tension. That is how fluorocarbon is used in place of nylon and obviously with steel versus nylon or gut. When there is worry about the integrity of the instrument, the advice is often given, “If you must use steel, at least use light gauge.” But they never say how light.

STEEL STRING DAMAGE

So what about actual permanent damage due to steel strings and higher-than-original tension?

Fret wear is inevitable if you play a lot with steel strings. Some people just live with it and do a re-fret when necessary.

FIG. 1. ivoroid pegs

Charming ivoroid tuners appeared on banjos in the late 19th Century. My own ill-informed impression is that the relevant period was only something like 1885 to 1890. In any case, not many have survived to this day. But some of those that did are badly chewed up by steel strings. Inexpensive ebony or rosewood violin tuners are practical replacements. By 1890, there were metal-shafted friction tuners. With their smaller shaft diameters, they are easier to tune. (Of course, geared tuners are a huge improvement for steel strings — because the strings stretch so little.)

Cracked heels afflict many old banjos. And many of those cracks have been successfully repaired. It is hard to imagine addressing the causal contribution of excessive string tension just from theory or experiment. What we have instead is epidemiological and anecdotal evidence. I reached out to a few people who have very substantial experience. Two, who likely have over seventy five years of professional repair and restoration experience between them, ventured specific opinions. Their take was that accidents rather than strings are the culprits. Old banjos have been around longer than newer ones and are likely to have sustained more accidents, and they are inherently more fragile.

The most serious issue is actual neck warping. But again, the evidence is only epidemiological and anecdotal. A tension-balanced set is desirable in terms of feel and tone but it's not obvious what to make of absolute tension values. Experience of the whole banjo community suggests that a particular total tension is generally safe. (Rare odd quirks always arise for things made of wood, and warp can occur for no apparent reason.) One exceeds that safe value substantially at one's own risk. (But we still have no idea of what's "substantial.")

On the other hand, it's not completely clear that the many warped old necks got that way because of steel strings. There certainly exist individual old instruments that have survived with straight necks and very worn frets. And again, "old" means that there has been a lot of time and opportunity for climate abuse and for peculiarities of the wood and construction to show up. So who knows?

I'm still looking for a set of strings that will make me sound like J.D. Crowe. Seriously, though, there are all sorts of reasons why individuals prefer one sound over another. For myself, I find that the style of music, the style of playing, and the particular banjo all influence what sounds best. And my preference is not even the same from week to week. Many people do not prefer steel strings, at least for some music, irrespective of mechanical issues. I believe that, if you pick the strings that sound best to you, you'll play your best

— and sound best to your listeners, who don't hear what you hear anyway.

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[1] This is derived in any college physics textbook that covers Vibrations & Waves. Morse gave a neat derivation that avoids explicit mention of calculus or differential equations in his classic *Vibration and Sound*, McGraw-Hill (1936); see §III.8.