Hybrid Wire Scales for Pianos

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Ed's model for determining tone is determined primarily by impact and sustain, for each of the three sections of the piano: the vocal section in the middle, the bird song section at the top end, and the gong or wind instrument section at the bottom.

With three strings together, the mix of frequencies on the bridge is shifted. This coupling integrates the fundamentals. In the bass there is a psycho-acoustical effect of the fundamental coming out of the lower notes. The longitudinal tone has an effect itself; there is even a longitudinal mode in the treble with very high frequencies. Jim Elliot worked with the monochord with pick-ups and drivers to look at transverse couplings. There is a complex mix between these approaches. On the back page of his book he compares the longitudinal wave velocities of different materials of wire. The longitudinal frequencies are the lowest of all the samples. On some pianos it is easy to do an A and B comparison in the high notes.

The origin: the molecules are minutely stretched apart and then come in. This wave goes in two directions. The key to using a hybrid wire is an analysis of break-point percent, which can correlate to a great degree to tone quality of the piano. In each section of each piano (bass, tenor, treble), the tension is in around 60 at the upper part of the section and around 40 at the low end. All piano wire will break at the same pitch. To determine break point, they hang a wire and add weights to it until it breaks. The elasticity of a wire is how much the string stretches before it breaks.

Ed played notes on some of his pianos with hybrid wires. We listened to a Chickering, a Baldwin, a Steinway and a Baldwin SD26. We particularly listened to the changes between sections.
The angled relationship between the strings and the bridge is a vector. When a bridge goes to 90 degrees of the string, there will be more longitudinal momentum. Ed made a piece of laminated spruce as a stiffener attached to the bottom of his Steinway A; this modification really improved the sound at the break. The bridge doesn't move just up-and-down. The horizontal vector creates longitudinal vibration. Weird whistling sounds can be re-ignited longitudinal motion. Ed wants to make titanium bridge pins. It is preferable to have leverage over mass, and a stiffener over . Impedence is roughly synonymous with sustain. If you drive the mass up, coupling goes down. If you drive stiffening up, coupling doesn't change as much. Couple takes energy that would normally be distributed in mass and takes it out so it sustains longer. Stainless wraps don't corrode like copper, and are lighter. Winding 6000 copper is so tiny it is nearly impossible to wrap, whereas stainless can go that small to create mass on a string. Ed played single-wrapped strings and compared them to double-wrapped. Strike points also make a big difference if they are too far forward or back. A good board can make up for a bad strike point, but having both is best.

Piano wire of any size will break at the same pitch. Smaller sizes of wire have more tensile strength and can stretch a little farther but not much. Most wires go up to 70%, and should be tuned up to about 65%. Take a look at the break-point chart. It doesn't make much sense to go to fatter wires at the bottom of the tenor, so go with the thinner. Treat stainless wire carefully because it is more fragile than carbon fiber wire. Ed is advocating using these wires for only two or three notes in a piano. Piano wire is really like a tube, with all the strength of the wire in the circumference.
The termination of strings has a significant effect on longitudinal mode. Shaping the V-bar can eliminate buzzing. Hard termination can cause string fatigue. Typically V-bars are case-hardened and are easy to

file. When looking at Steinways, check the V-bar to hear if it has over-hardened. Listen to the pure sound in the bass.

Hand-Out Notes

Terms to know include: Inharmonicity (IH), Unison Coupling (UC), Longitudinal mode (L-Mode), Transvers Mode (T-Mode), Breakpoint (BP), Elastic Limit (EL), Young's Modulus of Elasticity (YM).

This class is a presentation and demonstration of how to improve the musical utility of a piano by placing Pure Sound stainless steel alloy and Paulello high-carbon steel piano wire in the portions of a piano scale that are at a low BP percent.

Please note: I am not compensated in any way for mentioning these products.

The standard for wire scale modification practice since the late 1970's has been to convert low BP plain tri-chord unisons to high BP wound bi-chord unisons. This is usually done with the goal of reducing the IH of the low BP plain strings at the scale break between the treble and bass bridges.

I have done a number of plain tri-chord to wound bi-chord conversions and while the volume, tenability and tuning stability are improved, the musical utility is often not improved or even worsened.

I have found that there are two main reasons why this is so. One is that a significant part of the proper tonal character of a piano comes from the full effect of three unison strings coupling together in phase and frequency due to the influence of the piano soundboard/bridge. The other is that L-Mode is at least as significantly as IH in our perception of piano tone quality.

The plain wire types I have used to improve scale breaks in pianos are Pure Sound stainless steel alloy and type O Stephen Paulello piano wire.

BP percent can be determined by calculating the tension of a given string and dividing that by the BP for that diameter of modern piano wire.

Tension formula for determining pounds of tension from inch lengths and diameter is as follows:
(FxLxD)squared, times 2.303x10 to the -3 exponent = T in pounds
F = frequency
L = speaking length
D= string diameter

Low BP portions of a piano scale are between 20% and 45%.
Desirable BP for great piano scales is from 45% to 62%.
All piano wire (of the same type) breaks at the same pitch.

The EL of modern piano wire is at 70% BP. To have a robust piano scale there needs to be a margin of safety for the wire. Best practice is not to exceed 65% BP.

The BP across the compass of a typical concert grand scale starts at nearly 60% at note 88 and descends gradually to around 43% at note 21. Then note 20, the first wound string, is at around 60%, descending to the lowest bi-chord at around 45%. The highest monochord is around 60%, descending to around 45% at the lowest A.

Gauge	Diameter in Inches	Breaking Point
12	.029	247-257
12.5	.030	262-272
13	.031	273-285
13.5	.032	286-299
14	.033	303-318
14.5	.034	319-332
15	.035	333-348
15.5	.036	351-368
16	.037	366-382
16.5	.038	380-396
17	.039	398-416
17.5	.040	416-435
18	.041	433-452
18.5	.042	451-472
19	.043	470-491
19.5	.044	490-511
20	.045	509-531
20.5	.046	529-554
21	.047	550-578
21.5	.048	570-598
22	.049	590-620
22.5	.050	610-641
23	.051	635-667
24	.055	734
25	.059	839
26	.063	951
27	.067	1,025
28	.071	1,155
29	.075	1,270
30	.080	1,425

(Breaking point = pounds in tension)

In calculating BP% I use the lowest BP from the ranges given in the chart. For example, diameter .042 BP is 451 pounds in tension. Strained at 140 pounds tension, this wire is at 31% BP.

The BP protocol I follow in creating a hybrid wire scale for the plain strings is at 35% BP or less, using stainless alloy wire of similar diameter to the original.

When the BP is between 33% and 45% I use Paulello type O of similar diameter to the original.

Some scales increase the wire diameter every two to four notes in the low BP area. I don't see any advantage to duplicating that. No piano needs 21 gauge wire at note 24. It is my opinion that the smoother, warmer sound heard when Pure Sound and type O Paulello wire is used in place of low BP modern piano wire is mostly the result of reduced production of L-Modes. It does seem to my ear, by comparing beat rates when tuning a hybrid wire scale, that the IH is reduced. I don't hear the 6-4 partial pair of a 5^{th} beat, and the 3rds and 6ths seem to run faster than modern piano wire would produce in a scale with low BP above the wound-to-plain scale break.

The PTG foundation should hire a testing lab to test selected sizes of all piano wire currently produced for BP, EL, L-Mode, YM, and size tolerances. This would give us more assurances regarding the limits of these hybrid wire protocols.

We have many new choices in designing a hybrid wire scale than we have ever had before. The new types of wire choices that I am aware of include:

- Paulello type M, which is a fully modern wire
- Paulello type O, which I treat as being about 10% less BP than modern wire
- Paulello type I, which I treat as being about 20% less BP than modern wire
- Paulello type II, which I treat as being about 30% less BP than modern wire
- Pure Sound stainless alloy, which I treat as being about 25% less BP than modern wire

All three Paulello wire is high-carbon steel and can be had with nickel plating. Paulello also makes nickel-plated iron wrapping wire.
Mapes makes both copper and stainless steel alloy wrapped strings. Mapes will use Paulello Type O core for wound strings buy you must provide the core wire.

The Pure Sound stainless wire is significantly more fragile than high-carbon steel wire. Extra care must be used when installing it so as not to bend it any more than is needed. Do not raise it above pitch to make it settle quicker. It stabilizes very quickly at pitch. I would not use it in pianos that have agraffes with steel inserts in them. I would not use it for wound string core wires. I am prepared for these hybrid wire scale protocols to result in early failure for the stainless notes. But the tonal result worth the risk. Most hybrid wire scales would have two to maybe as many as six notes with stainless, and these would be placed in the compass at the bottom of the treble bridge where string breakage is rare. If they last ten years at a minimum it is not a serious service burden to replace them all when the first stainless string breaks.

I am very excited about all the wire choices we have today to solve tonal problems in pianos that we service and rebuild. Many new or newer pianos with clanging L-Modes in the tenor could have just a few consecutive notes restrung with hybrid wire at a very low service cost. Clanging wound scales and ill-defined low notes could also be redone in new or newer pianos with modest additional service cost.

The worst (to me, anyway) L-Modes are usually in the highest monochords.

The protocol for wound strings is to use type O core for the lowest bi-chord and the first two to five monochords. Make the lowest bi-chord string the same wrap as the note above, but switch to type O core of the same size. Load the highest monochord to about 58% BP and drop BP in graduated way as you descent in the scale. When you reach the largest diameters of wrap possible, and BP has dropped to around 47%, use type O cores and continue with BP's of 45%.

My Baldwin R grand has Pure Sound stainless on the lowest 4 plain wire notes: #'s 30, 31, 32, and 33. It has Paulello Type O on plain wire notes #'s 34, 35, 36, and 37. It has Type O core wire on notes #'s 1, 2, 3, 4, and 11.

My Steinway B grand has Pure Sound stainless on the lowest plain wire notes #21 and 22. It has Paulello Type O on plain wire notes #'s 23, 24, 25, and 26. It has Type O core wire on notes #'s 1, 2, 3, and 9. Notes #'s 18, 19 and 20 have been converted from bi-chord copper wrapped strings to tri-chord stainless wrapped strings from Mapes.

Fully Tempered Duplex Scale

One day when tuning, Ed found a de-tuned duplex scale in the piano and noticed a little whistle in it. Instead of voicing, he realized that he actually heard a longitudinal beat that was going under the V-bar. Since there are three strings per note, each of which is a different length, that means there are six different longitudinal modes on each note. Ed found a piece of sepal co-plymer that can act as a damping string rest material.

Tone-regulate a piano to improve the weakest section. The Steinway patent talks about longitudinal mode going across the bridge, which is not possible. They also talk about a pin termination for the string. L Bosendorfer didn't agree in the 1850's about these modes. These pianos were designed with a lot of monochords, which are designed with the bridge at 90 degrees to the strings. Ed started doing some experiments with brass rails, brass duplex supports, and other designs. The arrangement he prefers is a graduated change.

Matching to the compass for the duplex ratio is important, and this was not well done by most companies. Piano wire is very stiff and we drive it right next to the termination point. Because of the stiffness there is communication beyond the V-Bar. The V-bar allows the string to pivot, so the string can flex but not ring or sustain the vibration. The shorter your speaking length, the closer to this effect the string becomes. An agraffe will damp elmo as a component of a string-bearing termination ridge. The pivot termination allows the wire to flex longer, which is very important in the duplex pattern. As we go down to the tenor this becomes less important. How close the string felt is to the agraffe can alter the effect of the agraffe as well. Steinway B's are known for their metal ring in the high tenor. A monotone duplex can be open or damped.

In the upper treble, use the lowest duplex ratio and have the longest duplex lengths. Just don't be resonant with the transverse mode. In most pianos they are too short in the treble and too long in the tenor and are too loud. These distances should be graduated from long to short from the treble to the tenor. In other words, the front duplex should be longest for the shortest strings and increasingly shorter as the strings get longer.

Hitching lengths should be very close to the length of the top 40 notes of the piano. This is to prevent the reflection of the speaking length; since they will be going in opposite directions and will cancel. In the low frequency there is just one area. We can have phase cancellation in the air: two notes at the same pitch but at opposite phase. If these were in phase the power would kill it; consequently they should be in opposite phase. False beats will result from transverse motion. The fundamental note in the treble should resonate in the soundboard. A piano is a study in damping. The soundboard is a damper. If we didn't want it to damp, we could use titanium. Soft titanium bridge pins would help. The bridge grabs the copper bridge pin softens the vibration. Hardened pins would cause the string to ride up and down on the pin. There is a lot of weight in bridge pins. The pianos with additional bridge pins create a nasal tone; more mass creates more heat. Mass reduces coupling.

The ratio matching starts with the lowest ratios in the upper treble and cascades down. Matching to the compass (the range/frequency) is the guide. Brass doesn't transfer enough. The polymer damps more. The trouble with wood is that is creates corrosion. Ebony and rosewood are good, but are now endangered species.

The construction of capo bars effects longitudinal motion. Most do not do well in a horizontal vector. Capos made with dampening material can eliminate the whack noise. There is a whole host of materials that could be used.

Roger asked about completely redesigning the bridge. For example, use some other material than wood, eliminate bridge pins, use grooves or slots, etc. The goal would be to create a piano without false beats, most of which are caused by bridge pins. We want the string to stay in a horizontal plane. Place a strobe on a vibrating string and you can see there is more horizontal than vertical motion. Another contributor of false beats is how straight the string comes up from the hitch pin to the tuning pin, rather than left or right. The angle could be increased so there would be no clamping.

Ed uses size 6 bridge pins. He often goes down the next size smaller. The high pitch helix is the best drill. In the old days they used a high torque slow speed dentist drill. Generally the back bridge is closer, and as you go farther down they get farther apart. Angle a different lentgth speaking length on the back side. Set the top note at 52 mm. Go down and look at the end of the sections, find a multiplier that will increase the speaking lengths in each section, then lay it out. He takes a pattern with a piece of masking tape trimmed off from the bridge. Any time you use a pattern you lose some accuracy. Using a pattern introduces error. When drilling a bridge it is important to be controlled and stable with the drill.

At the hitching length for the rear duplex scale, should it be made as long as possible to keep it from damping? This back-scale on tiny pianos is much too short. Would the board be dampened more as the back-scale is shortened, since it becomes stiffer. Del Fandrich demonstrated this with his jig at the last PTG conference.

Since there are only two modes of string vibration – transverse and longitudinal – then we can experiment by stiffening or softening termination points to find various results. Increased stiffness in the treble keeps the hammer from doing any side-wobble. WNG tube-wall shanks come in three different diameters; Ed chooses the thickest because they are the stiffest. He puts the tightest in the treble and the loosest in the bass. Ed likes installing as few adjustment points as possible in a piano; for example, he doesn't like spoons. When Ed installs a new back action in a piano, he puts the pin close to the flange rotation point. This avoids the big flop with the up-stop rail. Keep it simple.

Ryan Sowers played a Beethoven sonata.