Where the Sound Begins . . . .[1]

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The rediscovery of early keyboard instruments in the late nineteenth/early twentieth centuries occurred in the context of at least four modern keyboard practices which were so ingrained that they were not really questioned or even largely recognized, and thus were applied to antique restorations and to copying. This caused many inappropriate conclusions to be made about the sound and playing characteristics of early keyboards that have continued in various forms and degrees to the present day. In my assessment, several assumptions that diverted attention from the historical intentions are:

1. the use of modern music wire,
2. the modern idea that the sound an instrument makes is categorized by how the sound is started (bowed, plucked, struck, blown, etc.),
3. the application of a'=440 Hz pitch level to historical instruments,
4. modern expectations and approaches to dampers.

The 20th-century view of putting plucking instruments in one category and striking instruments in another category very likely hinders understanding the type of sound that was desired and achieved from keyboard instruments. Historically, for instance, clavichords, lutes, harps, and vihuelas were often grouped together because the qualities of their sounds were considered to be so much alike.[2] Different sounds are bound to occur if one maker's expectation is that a harpsichord should sound like strings being plucked, while another builder expects it to have smooth, vocal qualities similar to those of a lute, harp or other Baroque instrument.

How modern, firm harpsichord dampers completely and quickly quiet a tone, producing drier-sounding instruments with higher maintenance requirements than were experienced historically was explained in an article of mine in the Fall 2009 WEKA Newsletter (and in an online Appendix to that article, referenced in the Spring 2010 edition), so we won't revisit that issue now.

Using a pitch level different than the one originally intended for an instrument design has several significant sonic and structural consequences that will have to wait until another article for a fuller explanation. However, one of the most obvious consequences of the early modern practice of tuning antique instruments to modern pitch when they were intended for lower pitches was strings breaking. This practical problem led to a 20th century focus on tension and wire strength when working out stringing schedules that has resulted in confusing and misdirecting the application of string tensions for uses not considered by historical builders, in distracting attention away from the musical qualities of the wire that the historical builders were exploiting in designing their musical instruments, and subsequently promoting the use of stronger wire with unhistorical properties and sound. In turn, this change from the historical expectation of what harpsichords, clavichords and fortepianos should sound like has not only affected the kind of sound we try to produce when we build them, but also the way they are played and used. This article will explore the very starting point of where an instrument's sound begins – the wire.

Modern versus historical wire

Modern steel music wire was the only ferrous (iron containing) wire commonly available for musical instruments during the rediscovery of early keyboards and so was naturally used initially for stringing the antique keyboard instruments and their copies. Modern wire, however, has mechanical properties quite different from historical wire and these differences result in markedly different timbre, speech, sustain, and tuning characteristics than were experienced historically. Furthermore, the kind of sound produced from using modern wire on these instruments created a sonic model that was used, both consciously and unconsciously, when other decisions about set-up choices needed to be made. These subsequent decisions moved the produced sound even further from the historical intention, and subsequently this modern sound idea encouraged a less-historical approach to playing and using these instruments.

Modern wire intended to be used as substitutes for historical wire in keyboard instruments eventually became available. The reduction in brightness that this wire brought was generally welcomed, but the basic idea of what the instruments should sound like remained only slightly modified, and little research seems to have been done to examine if the change had gone far enough. While this substitute wire is an improvement over the "piano" wire used earlier in the 20th century, most, if not all, of the "iron" wire being sold and used in historical keyboard instruments is actually steel wire that apparently has been somehow modified to reduce its strength so as to be closer to the strength of historical wire. There is little evidence, however, that reproducing this single property does anything to match the actual sound of these wires to that produced by historical wire, and there is mounting evidence that it does not.[3] In fact, many of the more recent substitute wire products state greater strength than historical wire had probably to reassure customers that it will be less likely to break. As we will see, deliberately making wire harder and stronger moves it further away from historical sound.

Additionally, many of the brass wires currently available for early keyboards are stronger, harder, and stiffer than historical brasses, and these characteristics naturally also result in timbre, focus, color, and sustain different than historical brass wire.

It probably makes very good sense that all keyboard instruments from about the 15th century to the 1820's were designed around the sonic and working properties of the wire available at the time. What might be surprising, though, is that throughout this entire period all of the non-brass wire was made from essentially the same iron material, whether for use in harpsichord, fortepiano, or clavichord.[4] A steel wire suitable for use in musical instruments wasn't even developed until 1823. That new type of wire, and the various steel wires that were developed afterward used different compositions and manufacturing processes, and consequently had very different properties that governed how they vibrated and stretched, compared to the iron wire that had been the starting point of instrument designs for so many centuries. Consequently, it should be no surprise that using steel wire and its non-historical properties in an historical keyboard design is no more likely to produce historical sound or performance qualities than using Modern violin strings in a Baroque violin will produce Baroque sound and playing characteristics from that instrument.

When steel production developed in the 19th century it became quickly obvious that steel was cheaper to produce than the pure iron compounds. This cost factor and the many types of steels that can be made for different applications has resulted in at least 95% of iron ore being used for steel. Additionally, the phosphorus absolutely crucial for historical iron wire makes steel unworkable, so phosphorus is routinely removed in the early stages of iron production. This has made it very difficult to conveniently reproduce historical iron wire.

The properties of brass do not appear to be as sensitive to changes of composition as iron and steel alloys are. However, the musical properties of many modern brasses are often still very different than historical brass, and this is because the particular manufacturing processes used to produce any wire (whether brass or iron or steel) also strongly influence the final properties that determine how it vibrates and stretches.

So, let's take a look at how different levels of various wire properties produce different musical qualities and consequences for the player and listener.

Wire and its musical consequences

There are several physical properties of metal that can affect the timbre, focus, clarity, sustain and tuning of strings made from it.

Only in theory do strings vibrate "purely". All real-world wire has some **stiffness** and this causes the harmonic overtones of a note to be progressively sharper as they get higher. The stiffer that a metal is, the greater is this **inharmonicity** in strings made from it. Considering the various types of wire used on early keyboard instruments, red brass is the least stiff, yellow brass is stiffer, iron is yet more stiff, and steel is the stiffest. There is also a range of stiffness, and therefore inharmonicity, within each wire type depending on details of its composition and the processes used to manufacture it. Historical iron and brasses are softer than their modern substitutes and therefore have less inharmonicity and produce a purer sound.

Inharmonicity is not usually noticed as a separate feature of a keyboard's sound, although it can become quite obvious as a fuzzy, even somewhat coarse, quality in the sound when strings get too short and too thick, or short and very high-pitched. Using a thick, steel wire for a short bass string in a compact harpsichord will make this quality very obvious.

Inharmonicity does not change the pitch, timbre, loudness, stability, or sustain of a note, but small amounts of inharmonicity in a note (along with other factors) contribute to the "color" of a tone.

Reducing inharmonicity usually increases clarity of tone. It can also be decreased in keyboard instruments by using the longest, thinnest, most flexible strings available (yellow brass instead of iron or steel perhaps). However, (issues of power and balance across the compass aside) the goal of designing is not really to have no inharmonicity in an instrument since research has shown cross-cultural preferences for a certain amount of it in particular patterns across the musical range anyway, with a particular dislike of it in the bass, and a preference for a rising amount of it ascending into the treble.[5]

What is musically important with inharmonicity is to control the amounts of it so that it can progress smoothly and unobtrusively. Because of this, it seems usually best,

1. to not mix wire from different manufacturers without carefully listening for changes in the tonal color (as well as other differences),
2. to switch as soon as possible to the next softest type of wire as one strings down into the tenor and bass in order to help counter the increasing inharmonicity due to thicker strings,
3. to not string too thickly in the treble (in an attempt for more volume, for example) so as not to exceed the ear's preferred amount of inharmonicity in that range,
4. to use wire with inharmonicity closer to historical levels rather than increasing those levels by using harder modern substitutes.

While the specific wire material contributes inharmonicity to a note, so does a string's length, diameter, and pitch. Additionally, the same string used in two different instruments can produce significantly different amounts of inharmonicity due to how it relates with the different resonances of the instruments, but that is largely out of our control after the instrument is built.

The stiffness of a metal also influences the frequency of a string's **longitudinal mode**, that is, a vibration that travels back and forth the length of the string rather than the sideways vibration that we usually see and hear. This longitudinal vibration can be heard clearly by itself when a violinist or guitarist sometimes accidentally causes a high-pitched squeal by their fingers sliding along a string (usually it is only heard at much quieter levels). Unlike the vibrations we are more familiar with, the frequency of this longitudinal mode does not change when the string's tension is increased or decreased. Its frequency is completely determined by the degree of stiffness and the sounding length of that string. Due to this characteristic, the longitudinal frequency will stay the same no matter what pitch a string is tuned to. The only way to change this frequency is to change the length of the string or change to a wire with a different stiffness.[6]

Having the frequency of this mode near one of the overtone frequencies of the dominant transverse vibrations helps the clarity of the pitch, and this possibility has been exploited in modern pianos.[7] If the longitudinal frequency of a string is too different from any of its overtone frequencies then a "strange" quality will sometimes be attributed to that note. When it is near enough to an overtone, its frequency just adds to the "color" of the note. If a string with a different flexibility were substituted, the "color" of the note would change. Because of its increased stiffness, modern steel substitute wires give a different tonal color to an instrument than does the historical wire that all historical instruments were designed around.

Probably the wire property with the greatest number of musical consequences is **internal damping** (also known as **viscosity)** that, as the name implies, affects how quickly the wire damps its own vibrations. The larger damping level of historical wires, compared to modern substitutes, has musical benefits for an instrument's initial transient sound, its overall timbre, and the nature of its sustain.

All sounds from musical instruments start with a burst of mixed, unrelated frequencies that then settle down into a set of harmonically related frequencies that determine the pitch and timbre of the note. Greater internal damping in the vibrating material reduces the time it takes for the starting jumble of frequencies to settle into a defined pitch and tone[8] and this gives a **faster focus** to the tone, allowing notes to be more clearly and quickly recognized, especially when they are played rapidly or very staccato.

Since internal damping also affects how each overtone frequency develops, as well as decays, the **speech quality** of notes will change when wire with a different level of damping is substituted.

The increased internal damping also suppresses higher frequencies proportionally more than it does lower frequencies. Thus, the higher damping of historical wires give them a **more mellow sound** than the brighter sound of the significantly less-damped modern substitutes for historical wires. This mellower sound makes the 4' and front 8' harpsichord registers more useful as solo stops, reduces the high-end intensity of clavichords, and would make the known historical use of bare wooden hammers in fortepianos more attractive.

Reducing the higher harmonics also **increases clarity of pitch** by reducing the contribution of frequencies that are dissonant to the fundamental pitch[9], reduces the "tinkling" character that many (especially older) harpsichords exhibit, makes tunings quicker, and makes mistunings less obvious.

The sound qualities of historical wire also permit **voicing** for a fuller, more projecting tone with much less harshness than is usually possible with the steel-type wires.

An illustration of the effects of internal damping on the speech qualities, timbre and sustain of a sound can be heard from a lute. Here the even more highly damped property of gut gives an immediately focused, **very rounded start** to a sound that is very mellow due to its lack of higher harmonics, even when plucked with a plectrum rather than a finger, as in lautenwercks.

Similarly, the **less bright and spiky** sound from historical iron wire permits a keyboard instrument to blend more smoothly across its compass and between registers, and for its tones to blend much better with other instruments it plays with, due to sharing more similar timbre and vocal qualities with those other instruments.

In contrast to historical wire, modern soft steel wires and hardened brasses produce a tone with a prominent transient sound with a much higher proportion of higher frequencies that sustain longer. When an instrument using these types of wire is played fast the slower focusing, decreased clarity, and higher frequencies can give an impression of a jangle of sound. When an instrument with these modern strings is played slowly their more rapid release of energy makes it more difficult to link notes and phrases together which encourages a faster tempo.

All other factors being equal, it appears that the less bright the wire sound is, the more likely it is to produce a more rounded start and a smoother sustain envelope, which in turn provides a wider range of possibilities for phrasing and articulation. In my experience, the most popularly used modern wires are unfortunately some of the ones with a greater amount of brightness and "pop".

A recording has been released using reproduction phosphorus iron wire on an anonymous South German 18th century fortepiano restored by Christopher Clarke. On it Natalia Valentin plays Beethoven Rondos & Bagatelles (Paraty 109.104). Everybody I have had listen to it has had similar reactions: the sound seems to just appear without being obviously started by an impact, it suspends in the air and very smoothly seems to evaporate without an obvious change in its character - very much a vocal kind of sound.

Practical advantages of historical wire

There are also several practical advantages of historical wire which reduce maintenance:

All strings stretch when brought up to playing tension, but, once a string has stabilized to the desired pitch, under constant conditions it should ideally be able to maintain that pitch over time, and then return to its original slack length when the tension is removed.

With increasing tension all strings will eventually get to a point where they begin to stretch irreversibly and will no longer return all the way to their original length when tension is released. When tension is continuously increased, the string will continue to stretch until it eventually breaks. What is naturally desirable in a wire for a musical application is that it not stretch slowly over time when it is at its playing tension, otherwise tuning will need frequent attention. Interestingly, a wire's resistance to long-term **creep** over time is independent of its overall strength. Testing by Stephen Birkett has revealed that historical iron wire uniquely has no creep until it is beyond its usual playing tension and very close to breaking. Unfortunately, despite their greater overall strength all the modern substitute steel wires appear to exhibit continuous stretching within the usual historical playing tension range, and most of them at well below those tensions. This difference in creep between historical and modern ferrous wires is a consequence of the different compositions and processes used to make them.[10] (I have not yet discovered if this creep resistance is also true of historical brasses, but this is being researched now.)

Because of historical iron's very different "creep" properties compared to modern substitute wires, a **new string** made from it can be installed on an instrument and once it is tuned to pitch it will be **stable virtually immediately**[11].

Another very practical feature of the historical phosphorus iron wire is that it is **very resistant to rusting**. Several builders and collectors have noticed that the original strings on some of their antiques look fine, but the 19th and 20th century steel replacements exhibit significant rust. Stephen Birkett has also confirmed this characteristic with samples that he has made of historical iron wire.

Summary

Few, if any, serious Baroque violin players would consider using anything other than catgut on their violins since that was the historical string material around which their instruments were designed. Lute and theorbo players do have some synthetic choices to use on their instruments, but these substitutes were designed with the knowledge and intention of sounding as similar as possible to the original string material.[12] The substitute wires offered for keyboard instruments for the last several decades were designed without knowledge of what the original strings of historical keyboards actually sounded like, so it would have been a matter of extreme luck for them to happen to reproduce the historical sound. Information about the physical differences between historical and modern substitute wires has been around since the 1980's, but nobody seems to have taken the known sonic consequences of those different properties to model a more accurate understanding of the sonic characteristics of historical wire, or to attempt to create a more historically accurate substitute wire.

With an understanding now of the more rounded beginning, fuller, more unified tone, and the decay characteristics provided by historical wire we have several options:

1. Listen carefully to the sound of different wire to choose the one closest to the historical properties of smooth vocal beginning, fullness, and a blooming decay, as exhibited by other Baroque instruments as well as vocalists.
2. Make adjustments to various features of our keyboard instruments (bridge and nut pins, pitch level, stringing schedule, voicing, etc.) to move closer to the smoother, mellower, more vocal and sustaining sound.
3. Encourage wire makers that there is a desire for more accurate reproductions of historical wire so that we can move much closer to using and enjoying the sound and playing properties of what was actually experienced historically.

Perhaps all of the above.

10-09-11

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1 This article is a much reworked section of a larger, more detailed article, "Tailoring the Sound of Your Keyboard Instrument" to appear in the Fall 2011 issue of Harpsichord & Fortepiano magazine, for which I received much valuable from Stephen Birkett, Gregory Crowell, Carol Linne, and Richard Troeger.

[2] Gregory Crowell, "The Clavichord as a Plucked String Instrument", De Clavicordio VII, The Clavichord and the Lute., edited by Bernard Brauchli, Alberto Galazzo, Judith Wardman. Musica Antica a Magnano 2006, p181-194.

[3] Martha Goodway and Scott O'Dell, "The Metallurgy of 17th and 18th Century Music Wire", The Historical Harpsichord Volume Two, Pendragon Press, New York, 1987.

Stephen Birkett and Paul Poletti, "Reproduction of Authentic Historical Soft Iron Wire for Musical Instruments", Instruments a claviers – expressivite et flexibilite sonore, Proceedings of the 2002 Harmoniques Conference , Lausanne, Peter Lang (publisher).

Stephen Birkett, "The Physical Characteristics of Historical Iron Wire and a Report on Its Replication as a Viable Modern Product", Cordes et clavier au temps de

Mozart, or Bowed and Keyboard Instruments in the Age of Mozart, Proceedings of the harmoniques International Congress, Lausanne 2006. Peter Lang (publisher)

[Stephen Birkett, an associate professor and researcher in physical systems, organology, and wire at the University of Waterloo, Canada, has done more research to try to recreate the actual composition and production steps of manufacturing historical iron wire than anybody else I am aware of, and he has gained true first-hand appreciation, the hard way, of just how sophisticated and skilled the historical wire drawers actually were.]

[4] Stephen Birkett, 334-5.

[5] Goodway, 101-103.

[6] Jean Louchet, The Keyboard Stringing Guide – for the restoration of pianos, harpsichords and clavichords. 2009 (First edition). 75-79.

[7] Harold A. Conklin Jr., "Piano Design Factors – their influence on tone and acoustical performance", Weinreich, Five Lectures on the Acoustics of the Piano, edited by Anders Askenfelt (Publication issued by the Royal Swedish Academy of Music No. 64, Stockholm 1990)], 34-36.

[8] Arthur H. Benade, Fundamentals of Musical Acoustics. Oxford University Press, New York 1976, 154.

[9] Hermann Helmholtz, On the Sensations of Tone., Dover Publications, New York, 1954. 22-3, 118-9.

[10] Birkett, 329-45.

[11] once the tuning pin coils have been adjusted.

[12] These synthetic string options do not respond to rosin so are not a choice for bowed instruments.