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TAILORING THE SOUND OF YOUR KEYBOARD INSTRUMENT, PART II

By Paul Y. Irvin

1. Digression - Second Impressions

The reader might well wonder why I probably appear to believe that more effort is yet needed to move us to a more accurate reproduction of early keyboard sound than we already have. This is the explanation:

The rediscovery of early keyboard instruments in the late nineteenth/early twentieth centuries occurred in the context of at least three modern keyboard practices which were so ingrained that they were not really questioned or even noticed, and so were imposed on antique restoration and copying. These 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. The first practice concerned the use of modern music wire, the second the use of a′=440 Hz, and the third involved modern expectations and approaches to dampers.

Modern steel music wire was the only ferrous wire commonly available for musical instruments during the rediscovery time and so was used initially for stringing antique keyboard instruments and their copies. Modern wire, however, has mechanical properties quite different from historical wire, and this results in many sound properties differing. Furthermore, the kind of sound produced by modern wire on these instruments created a sonic model that was used, both consciously and unconsciously, when other decisions about set-up were made. These subsequent decisions moved the produced sound further from the historical intention, and subsequently this modern sound idea encouraged a less historical approach to using these instruments.

It took a while for the early re-discoverers of historical keyboards to realize that 440 Hz was not really the appropriate pitch for all of the extant antique instruments. A major problem was frequent string breakage when brought up to modern pitch, and this experience created the belief that the amount of tension that wire could withstand was the primary criterion for choosing which type of wire to use, and where, in an instrument. This focus on string tension and strength has resulted in confusing and misdirecting the application of tension for uses not considered by historical makers, in promoting the use of wire with unhistorical properties and sound, and in distracting attention from the musical qualities of the wire that the historical makers exploited in their musical instrument design.

Firm, modern dampers that completely and quickly quiet a tone produce drier sounding instruments with higher maintenance requirements than were experienced historically. I have discussed this topic for harpsichords in the Spring 2010 issue of this journal.

Since the sound of modern music wire in early keyboard instruments (both antiques and copies) produces markedly different timbre, speech, sustain, and tuning characteristics than were experienced historically we are now going to explore the first Tone Control listed above, and discover what kind of sound is produced from the unique properties of historical wire and how its particular musical qualities encourage historical use of the instruments.[1]

The Musical Importance of Wire

All keyboard instruments from about the fifteenth century to at least the 1820s were designed around the sonic and working properties of the wire available at the time, which certainly makes sense. 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 harpsichord, fortepiano, or clavichord.[2] A steel wire suitable for use in musical instruments was not even developed until 1823. That new type of wire, and the subsequent steel wires that were developed later, had a different composition, different manufacturing process, and very different properties that governed how it vibrated and stretched, compared to the iron wire that had been used for centuries. So, it should make sense that using wire with non-historical properties in an historical keyboard design will not produce historical sound or performance qualities, any more than using strings designed for a modern violin on a Baroque style violin will produce Baroque sound and playing characteristics, no matter how accurately its other features were copied.

The vast majority of iron poduction is made into steels, and there are many, many different kinds of steel because very small amounts of other elements present, and small changes to the quantities of those elements, affect strongly the working properties of iron compounds, from soft and very workable to extremely hard and brittle, from weak to extremely strong.[3] Phosphorus was the crucial component of historical iron wire which made it soft yet very tough, but steel with the same amount of phosphorus cannot be made into wire or many other things, so steel makers now go to a lot of trouble to reduce phosphorus to only trace levels. The two approaches are quite different as are the resulting metal properties and their sounds.

The properties of brass do not appear to be as sensitive to changes of composition as iron and steel alloys are. In fact, much modern yellow brass wire has essentially the same composition as historical yellow brass.[4] However, the musical properties of many modern brasses are still often very different than historical brass, because the particular manufacturing processes used to produce any wire (whether brass, iron or steel) strongly influence the final properties that determine how it vibrates and stretches.

Stephen Birkett, an Associate Professor and researcher in physical systems, organology, and wire at the University of Waterloo, Canada, has done more work to try to recreate historical iron wire than anybody else of whom I am aware, and he has gained true first hand appreciation for just how sophisticated and skilled the historical wire drawers actually were. They were working on the cutting edge of technology at that time. Duplication of their results has certainly not been as easy to achieve as most people today would expect, given the centuries of industrial development that have occurred since. Unfortunately most of that attention has been on steel and not iron, since the numerous varieties of steels available have many uses and most of them are less expensive to produce than iron compounds.

To reproduce fully the sound and playing characteristics of historical wire, in addition to having the correct composition, it may also be necessary to come rather close to replicating the historical manufacturing processes. Since there are no extant manuals sufficiently detailed to explain adequately these processing steps, it will be necessary to know just what the historical properties are, so that a reasonable reproduction of historical wire can finally be achieved.[5]

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

Musical consequences of wire properties

There are at least four properties of wire that can affect the timbre, focus, clarity, sustain and tuning of your instrument.

Inharmonicity refers to how "in tune" the overtones of a note are with the harmonic series based on the fundamental pitch of the note. All real world wire has some stiffness and this property sharpens the overtones of the strings to varying degrees. Steel is stiffer than iron, which is stiffer than yellow brass, which in turn is stiffer than red brass. The stiffer a metal is, the greater its inharmonicity. Historical iron and brass wires are softer than their modern substitutes and therefore have less inharmonicity and a purer sound.

Inharmonicity is not generally noticed as a separate feature of a keyboard's sound, although it can become quite obvious as a fuzzy, even somewhat coarse sound quality 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.[6 7]

The presence of small amounts of inharmonicity does not change the essential timbre of a note. A muselaar still sounds like a muselaar, and a lute register like a lute register, but smaller amounts of inharmonicity in a note will give a purer sound.

Less inharmonicity usually increases clarity, and we can decrease the inharmonicity in keyboard instruments by using the longest, thinnest, most flexible strings available (yellow brass, or even red brass perhaps). But (issues of power and balance across the compass aside) the goal is not really to have no inharmonicity in an instrument since various 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.[8]

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 best not to mix wire from different manufacturers without carefully listening for changes in the tonal colour (and other differences), to switch as soon as possible to the next softest wire as one strings down into the tenor and bass (in order to reduce the increasing inharmonicity due to thicker strings), and to avoid stringing too thickly in the treble so as not to exceed the ear's preferred amount of inharmonicity in that range. It would also seem preferable to use wire with historical inharmonicity levels rather than increasing those levels by using harder modern substitutes.

(While wire material contributes to the inharmonicity of a note, so do a string's length, diameter, and pitch, which will be discussed with different Tone Control factors. Additionally, the same string used in two different instruments can produce significantly different amounts of inharmonicity due to how it relates to the different resonances of the instruments, but that is largely out of our control after the instrument is made.).

Another property of the metal that contributes to tonal colour comes from the Young's modulus (modulus of elasticity), which is a measurement of how flexible a string material is, and as such is a contributor to the wire material inharmonicity discussed above. But this property also contributes to the formation of a **longitudinal mode**, that is, a vibration that travels back and forth along the length of the string rather than the sideways vibration (at right angle to the string direction) that we usually see and hear. This longitudinal vibration can be heard by itself when a violinist or guitarist sometimes accidentally causes a high pitched squeal by sliding fingers along a string. Unlike the vibrations with which we are more familiar, 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 particular modulus and the sounding length of that string. Because of this property, this longitudinal frequency will stay constant regardless of the string's pitch. The only way to change this frequency is to change the length of the string or change to a wire with a different modulus of elasticity.[9]

Having the frequency of this mode coincide with one of the overtone frequencies of the transverse vibrations would promote the clarity of the note, and this possibility has been exploited in modern pianos.[10] However, for harpsichords at least, the randomness of the frequency that a note might need to be tuned to for whichever pitch level and temperament is desired at any particular time, would produce a random, unrelated frequency relationship that just contributes a particular "colour" to the note. If a string with a different flexibility were substituted, the "colour" of the note would change. Because of these differences in elastic modulus, historical wire would give a different tonal colour to an instrument than would modern iron substitute wires.

Probably the wire property with the greatest number of musical consequences is **internal damping**, also known as **viscosity**, which, as the name implies, affects how quickly the wire damps its own vibrations. The greater damping level of historical wires has at least two major musical effects. One affects the initial transient sound, and the other affects overall timbre.

All musical sounds start with a burst of mixed, unrelated frequencies that then settle down into a set of overtone frequencies defining pitch and timbre, as already mentioned. Increased internal damping in the vibrating material reduces the time it takes for the jumble of frequencies to settle into their harmonic sound[11] and this focuses the tone more quickly, allowing notes to be more clearly and quickly recognised, especially when they are played rapidly or very staccato.

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

This internal damping also suppresses higher frequencies proportionally more than it does lower frequencies. Thus, the higher damping of historical wires gives them a more mellow sound than the brighter sound of the significantly less damped modern 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 makes the known historical use of bare wooden hammers in fortepianos more attractive.

Reducing higher harmonics also increases clarity of pitch by reducing the contribution of frequencies that are dissonant to the fundamental pitch[12], reduces the "tinkling" character that many (especially older) harpsichords exhibit, makes tuning easier, and reduces the obviousness of slight mistunings in an instrument.

An illustration of the effects of damping on the speech qualities, timbre and sustain of a sound can be heard from a lute. Here the much 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 *Lautenwerk* instruments.

Similarly, when compared to the sound from less damped modern wires the more damped historical wire will provide a more quickly focused sound with a smoother start and more prominent lower overtones.

Since keyboard instruments strung with historical wire are less bright and spiky sounding than when strung with modern substitute wire, their sounds will blend more smoothly across their compass and between registers, and with other instruments, due to sharing more similar timbre and vocal qualities.

The brighter and more abrupt sound of modern wire might very well explain why it is so difficult to get harpsichord sound nowadays to blend in a group of musicians. And why so many recording engineers reduce harpsichord playing levels in ensemble to unrealistically low levels so that their brightness does not mask or overwhelm the musical lines of the other instruments, which makes them sound like they are playing at a distance from the rest of the instruments.

This extra brightness quality of modern wire also often seems to be associated with a lot of the energy of the plucked or struck string being released very rapidly at the beginning of the tone and then the volume reducing at a slower decay rate. This feature gives a rather pronounced "pop" to their sound, resulting in the two part diphthong and staccato effects discussed earlier. It seems (all other factors being equal) that the less bright the wire sound, 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".

There is one more property of wire to discuss here that has significant practical musical consequences. All strings stretch when brought up to playing tension, but once a string has stabilised to the desired pitch it should ideally be able to maintain that pitch over time (given constant conditions), and then return to its original slack length when the tension is removed.

With increasing tension all strings will eventually reach a point where they begin to stretch irreversibly and will no longer return all the way to their original length after tension is released. If 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 have any slow stretching over time when it is at its playing tension, otherwise its tuning will need frequent attention. Slow stretching over time at playing tension is called **creep**. A wire's resistance to 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 wires exhibit continuous stretching below their usual historical playing tension, 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 wire compositions and processes used to make them.[13] (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.

Wire Section Summary

Few makers of early keyboards now use the modern steel music wire, modern hardened yellow brass, or phosphor bronze used on these types of instruments when they were first rediscovered in the twentieth century, and which formed our first impression of their sound. They have been mostly replaced with wire that, by some characteristic or other, is specifically intended to be more suitable for early keyboard instruments. While an improvement over the earlier wire used, most, if not all, of the "iron" wire being sold and used in historical keyboard instruments is actually steel wire which apparently has been somehow modified, possibly through mild annealing, to reduce its strength so as to be closer to that found in historical wire. There is little evidence, however, that weakening this property does anything to bring the wire properties responsible for its sound to the levels of historical wire.

Many of the brass wires currently available for early keyboards are stronger, harder, and stiffer than historical brasses, and these characteristics naturally result in timbre, focus, colour, and sustain different from that of historical brass wire.

When measurements of the damping, inharmonicity, and creep characteristics of wire become available we may be able to use them to choose the wire with the best fit for historical properties (or to choose wire to tailor the sound of an instrument in a desired direction). Until that happens, however, it will be necessary to listen to the sound of wire from different manufacturers to find the ones that have less brightness and a less pronounced beginning to their sound if we wish to move closer to historical sound and performance qualities. It is best if these wire comparisons are conducted as blind listening comparisons, where the wire is unseen and unnamed, since this knowledge will always create conscious and/or subconscious expectations in the mind before the ears can assess the sound without prejudice.

Additionally, the bright sound and pronounced speech qualities of the modern wires that were initially used during the rediscovery of early keyboard instruments established a sound model for these instruments that then influenced other decisions in the set-up process, resulting in a sound that is quite different than the keyboard sound for which the music was composed, or with which other contemporary instruments were expected to blend and contrast. In order to regain these lost historical relationships, using wire that produces more accurate historical sound would seem to be an excellent start.

Reality Check Addendum

While much of this discussion of the musical properties of historical wire has probably seemed quite theoretical in nature, recent events indicate that it does quite describe the properties of historical sound. Since the above text was first submitted for publication July 2011, Stephen Birkett has managed to draw his historically-based, phosphorous-iron wire to sizes small enough to use on harpsichords and supplied several very experienced builders with it for testing. One of the makers, Owen Daly, gave a brief description of his impressions of this phosphorus-iron wire on an instrument of his that he has played for many years:

"I will share some of my impressions after having restrung my own "Vaudry" in the material last Friday and Saturday. I make no claims to scientific comparisons and I make no apology for that. I have been playing as much music as I can, and waiting for global impressions to impinge themselves upon me. Remember that this is an instrument which I have played steadily for 16 years, and so my 'feel' for it is well-established and intimate. So, in no particular order:

There is indeed a darker sweetness than before. It's as though the lower partials, which we use in tuning and immediate impressions of pitch-centre and timbre, are stronger than before, and exhibiting even less inharmonicity than on the previous wire (which was already very good in this regard) [Voss wire, pyi], while the nastier higher transient stuff is less intrusive.

I'm finding, playing the Cinquieme Ordre of Francois Couperin, that all sorts of inner-voice lines, those around the high tenor and middle octaves, have more overt musical presence. I have been *taught* to pay attention to those lines, but it is always an effort not to be treble-centric; yesterday I was hearing them, and consequently able to pay attention to their shapes, as if I were noticing the viola part in a string quartet as a fully-formed contributor.

The 4' locks-in and blends with the 8's with a fusion I've not experienced before, save on some of my brass-strung Italian instruments with 4' registers. There is little or no vestige of the common 'yappiness' and squealing of a French 4'. After tuning my 4' carefully yesterday, I had to stop and check to make sure I had engaged it, it blended so well. It was not by any means inaudible, though, because when I turned it *off*, the character darkened considerably. I was using it in a movement whose affect is supposed to be tender and gracious, and it was not out-of place.

I have found that, consistent with prior claims coming from Stephen, the stuff has stabilised more quickly in terms of holding pitch (that is, not stretching dramatically) than any other wire I have dealt with. By 24 hours, instead of around a semitone, the instrument had dropped maybe about 4 Hz. Some days later, needing a new tuning (less than a week after stringing) I had to bring things up no more than that yet again. Whether the actual character of the timbre will change and mature gradually, or will achieve its full voice almost immediately, I can't yet say. My inclination is to say that each day it seems warmer and more cohesive, so I think it *will* undergo the usual "improvement" with settling. But when it gets brighter, as my top octave has done this week, it seems not to become at the same time strident." [14]

Paul Poletti has also reported his experiences with restringing an antique harpsichord, 30 December 2011 to fortepiano@yahoogroups.com :

"Just finished restringing the Barcelona Zell with P wire. It had Rose A on it. I have to say the difference is amazing. I did some recordings of the same notes before and after, and several things are noticeable. First, the sound is not as aggressive, a touch more mellow and round, lacking a nasty sort of scratchy sparkle which the Rose has. More interesting is that the envelope is different. The Rose drops rather quickly in volume before settling down to a gradually diminishing sustain which lasts longer, while the P wire has a much more legato envelope, a smoother, flatter, not as precipitous drop from the first moment, and it seems to go on and on. I have to say that I had always found the Zell to be a bit disappointing, nothing special, despite its Famous Brand status. But now, it's a totally different instrument, a big and full voice despite its small size, really rich and almost luscious in a way approaching what I would have more readily expected from a French instrument."

By September 2011 Stephen Birkett had already had six fortepianos restrung with his reproduction of historical phosphorus-iron wire. One of these fortepianos can be heard on a recording of Beethoven Rondos and Bagatelles played by Natalia Valentin on an anonymous antique, beautifully restored by Christopher Clarke (Paraty 109.104). To my ears, and a broad range of other ones, the very singing nature of this instrument's sound seems to eliminate many people's objections to the more frequently-encountered sound of fortepianos, to the point that many remark that, "it sounds like a modern piano". While this observation might seem to make the sound result suspicious, it actually confirms the likelihood of it being historically accurate when viewed against the basic nature of historical and modern wires and the usual direction of evolving designs:

As explained earlier the more highly damped historical wires naturally produce a mellower tone with more bloom, while the less damped modern wires naturally produce a brighter sound with a quicker initial release of energy. Given the sound qualities of other Baroque instruments and the vocal ideal of the time, there would have been little motivation for the historical keyboard makers to work against the basic nature of the historical wire to design instruments that would be brighter and more incisive than the other instruments of the period. Once steel music wire was developed for use on musical instruments, it would seem unlikely that piano builders of that time would decide to work against its basic sound to make it more mellow and sustaining —unless they were just naturally continuing an already established, and very musically useful sound passed on from the fortepiano.

Christopher Clarke also shared his impressions of this wire in a private communication of 4 January 2012:

"I've had the privilege of stringing three grands (the anon. S. German you heard, the 1802 Erard copy, my Big Ham (an 1825-ish Wiener fantasie) and a Viennese-action square (Schiedmayer, c. 1835) with Stephen's wire, and as you probably gathered, I'm absolutely convinced by it." . . . "generally, the stuff behaves just like old wire; it comes straight up to pitch and stays there, the sound is "open" and generous right from the start (good sustain, good clean development of harmonics) and gets even better as the wire settles, which it does very quickly. It's very easy to tune. In spite of the merciless beating the Erard took during the inauguration, no strings broke (though some unisons were knocked right out). I think Stephen's wire had a lot to do with the good musical qualities of our copy."

The musically beneficial sound qualities described above from harpsichords and fortepianos using wire with more historical properties will undoubtedly also be heard from clavichords that use it. And that particular balance of sound qualities can be, and doubtless historically was, reinforced by other choices that affect the sound of keyboard instruments, such as soundboard design, case materials and dimensions, etc., as well as by factors that can be changed after the instrument is built, such as instrument pitch, stringing schedule, bridge and nut pin materials and installation details, and voicing approaches and materials.

This article explored only one of the tone controls influencing the timbre and vocal qualities of the final sound coming from a keyboard instrument. In future articles I hope to explore other factors that contribute to producing a sound with more historical qualities, even without using historical wire.

I wish to thank very much Stephen Birkett, Gregory Crowell, Carol Linne, Paul Poletti, and Richard Troeger for their suggestions and help in writing this article.

Endnotes

1 Paul Irvin, "An Approach to Recreating Historical Sound", Part I and Part II, *Harpsichord & Fortepiano* 12/2 (Spring 2008):33-38 and 13/1 (Aut 2008):21-27.

2 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: n.p, 2010), 334-5.

3 While some of these modern substitute wires may call themselves "iron" or "high carbon iron", they are all more accurately defined by industry standards as steel due to the amount of carbon they contain.

4 Martha Goodway and Jay Scott Odell, "The Metallurgy of 17th- and 18th-Century Music Wire", in *The Historical Harpsichord*, Volume Two (General Editor, Howard Schott), a part of the monograph series in honor of Frank Hubbard. (Pendragon Press, Stuyvesant NY, 1987), 29.

5 Knowing the measured levels of the various physical properties of historical wire makes possible another approach to reproducing historical sound by designing strings with whatever composition and processing steps are needed to produce the necessary levels of those physical properties of historical wire. With those levels reproduced the strings would then produce the same essential sound as the target wire. See Jean Louchet, *The Keyboard Stringing Guide – for the restoration of pianos, harpsichords and clavichords* (ISBN 978-1-4457-1033-4, pub. Lulu.com, 2010; 2nd edition) 1st ed, 21. However, I do not yet know of any stringmaker pursuing this particular approach for early keyboard instruments.

While this approach of manufacturing a string to have particular tonal characteristics may seem unusual, it does not appear much different in concept than the approach of string designers who manipulate various materials and string winding methods in order to create the inharmonicity and damping characteristics that will result in the timbre and tone production desired by their guitar and bowed string instrument customers. See Fan Tao, "Strings: The (Often) Forgotten Accessory", *Guild of American Luthiers Journal 101* (Spring 2010), 28-36.

6 The amount of inharmonicity in the strings of harpsichords and clavichords is often assumed to be negligible because they are so thin, but there are no studies of which I am aware to confirm that the levels found are below audibility. Measurements made in the 1970s of a harpsichord and a modern piano string of appropriate sizes playing the "A" below Middle C showed quite similar inharmonicity levels. (See Goodway, 96). Many (admittedly informal) measurements that I have taken of antique harpsichords and modern copies show significantly less inharmonicity than measured in this earlier study (although a similar amount appears in the top octave of instruments). This difference in measured levels might be due to the fact that the earlier researchers used modern steel music wire while most of the instruments I measured were probably using the substitute wire developed later specifically for early keyboard instruments. If so, this difference points to an improvement in inharmonicity over the earlier harder steel wire, which raises the question of how much more improvement might be heard by using the softer historical iron wire.

7 It might be worth noting that it has been rare to find a note on any instrument that had a degree of inharmonicity that would be deemed "negligible" by any audiophile who was auditioning sound equipment (but many measurements that would have been deemed "unacceptable"). While the numbers used in measuring inharmonicity appear very small, this does not mean that their effect is also necessarily small. The ears are very sensitive, able to hear at the limit of audibility one millionth the energy they receive at the threshold of pain, and under certain conditions able to detect variations between two signals down to 30 millionths of a second. (See Benade, 210.). Formal study of inharmonicity in early keyboard instruments could help to determine if it actually has, or has not, influenced instrument design, and if so, how.

8 Goodway, 101-103.

9 Louchet, 75-9.

10 Harold A. Conklin Jr., "Piano Design Factors:their influence on tone and acoustical performance", in Weinreich, *Five Lectures on the Acoustics of the Piano* no. 64: 34-36.

11 Benade, 154.

12 Helmholtz, 22-3, 118-9.

13 Birkett, 329-45.

14 From 4 November 2011, HPSCHD-L posting