The set-up of 4- and 6-course 18th century mandolins: a few considerations

When faced with the problem of what kind of strings were used on18th century Mandolins of six and four courses, the first thing that stands out is the great heterogeneity of their set up—if we follow the two surviving instructions, by Fouchetti and Corrette, discussed here. What is especially hard to understand is the stringing of the 4-course Neapolitan mandolin: here we find together gut strings, single and twisted metal wires, and wound strings on gut/silk. To complete the already heterogeneous picture, for the fourth course there are also two choices between unison and octave.

Here is the first question: why was a gut first course used, and not a metal wire like the other courses, already available in the first half of the 19th century? This question is logical: the average breaking load stress (Breaking Point) of the gut is 'only' 34 Kg/mm2, much lower than the average of iron and bronze of the time, which easily exceeded 100 Kg/mm2.

To understand the reason, we must first start from the mechanical and acoustic behaviour of the string. In this way we will be able to try to figure out what were the guiding criteria used to determine the vibrating lengths of plucked and bowed instruments, including mandolins.

Strings and their characteristics

Musical strings follow the rules that are summarised in the string equations of Taylor-Mersenne or indeed Hook's Law (although the first to mention it was Vincenzo Galilei around 1580), which relates frequency, vibrating string length, diameter and density of the string.

However, when the gauge of a string increases, another consideration is not included in this equation: with the increasing string diameters comes also a progressive loss of its acoustic properties until reaching the point where, over a certain gauge, the string has clearly lost most of its musical performance. This is caused by the progressive increasing of the stiffness of the string. This phenomenon is called inharmonicity: before the appearance of the wound strings (on the second half of the 17th century) it was the main problem with which all the makers of plucked, bowed and keyboard instruments had to deal with.[1]

Inharmonicity clearly determines a limit to the total number of bass strings that an instrument can have, i.e. the open range. There is a second problem: a poor elasticity, i.e. a high elastic modulus, this also produces an unwanted sharpening of the note when pushed down onto the frets; this phenomenon is particularly noticeable on short vibrating length instruments ('pitch distortion').

The best solutions, in order to keep the inharmonicity within limits and the string still sounding 'good', is to limit the diameter increase by some means (or, alternatively, keeping a thicker gauge but increasing the elasticity of the string to reduce the stiffness). Our main interest is represented by these relationships:

—Diameter and vibrating length are inversely proportional.
—Diameter and tension are inversely proportional.
—Diameter and density are inversely proportional.

The solutions that, at the same frequency, can contribute to reduce the diameter are the following:

1) Reduction of working tension
2) Increase in the vibrating string length

However, there are other implementable actions:

3) Increasing the elasticity of the string (this does not affect the diameter reduction)
4) Increase the density of the string (affects the diameter reduction)

Point 1 is exclusively a decision of the player: according to the ancients the right string tension (which I argue is better called the right feel of tension) is when the strings are not too stiff, nor too slack under the finger pressure. There is, however, a lower tension limit otherwise not only you can lose the finger control on the strings but also the acoustic power, its 'fire', along with the increase of what is commonly called 'pitch distortion' due to the fact that the strings are too slack and so out of the control of the performer.

Point 2 depends only by the luthier. This solution was adopted from ancient times on the harp, but later also for keyboards, theorboes/archlutes etc, where the vibrating string length increases, step by step, towards the bottom strings making them, step by step, thinner than they would otherwise have to be; proceeding in this way, the inharmonicity is under control.

Points 3 and 4 depend on the string maker: the appearance of the wound strings in the middle of the 17th century can be considered a good example of point 4; a roped gut string/a very high twist string an example of point 3.

At the end of the day, the only point on which the luthier can act is point 2, where vibrating length and diameter are inversely proportional (assuming that the performer has already done his or her job in the choice of the right feel of tension).

In the 16th, 17th and (maybe) the first half of the 18 century, the problem of string inharmonicity was well-known to luthiers: it can be seen, for example, from the still existing bowed and plucked instruments, whose vibrating string lengths are all related to the frequency of the note on the highest string and the hypothetical standard pitch: in practice we are speaking of the well-known rule of those times to tune the first string as high as possible just before it broke.

In order to optimise the sound performance of a musical instrument luthiers therefore followed the rule of using the maximum vibrating length possible for a given treble note indicated by the customers (depending on the region and its related pitch standard) only in that way could all the strings have the minimum gauge at the right feel of tension for the benefit of the overall acoustic performance.

However, the vibrating length cannot be increased as desired because of the limit imposed by the breaking load of the first string: there is a limit that we call upper limit. At the same time, it is not possible to increase the number of bass strings (i.e. increasing the open range) because there is another boundary called the lower limit. In other words, the full open range of a musical instrument is enclosed within these two borders.

The so-called lower limit, however, using pure gut strings, begins to heavily manifest itself when the frequency range between the first string and the last reach, more or less, two octaves. Only the 6-course mandolin has this range; the 4-course instrument does not. Generally speaking, the problem was, however, partially solved after the middle of the 16th century by the introduction of a kind of very elastic and/or denser bass gut strings and then totally solved by the introduction of wound bass strings in the second half of the 17th century. In the second half of the 18th century, the wound strings were probably in universal use.

The upper limit

When a string of any material is progressively stretched between two fixed points (i.e., the vibrating string length), it will at some point reach a frequency where it will instantly break (breaking point). In the case of a modern gut string, the average value of this frequency for a vibrating length of one metre is about 260 Hz (actually, after several tests, I have found a range of 250-280 Hz), which is a slightly low C.

The value of such a limit frequency, known as the 'breaking frequency', is completely independent —as strange as it may seem—of the diameter and this can easily be verified both by mathematics (applying the general formula for strings) and empirically. By changing the diameters, the only changing parameter is the tension value always corresponding to the breaking point (i.e. the breaking frequency). The breaking frequency is inversely proportional to the vibrating length at which the string is stretched.So, if the string length is cut down to a half the frequency doubles and vice versa.

This means that the product of the vibrating length (in m) and the breaking frequency (in Hz) is a constant defined as the 'breaking index', or more simply FL product (i.e. vibrating length x breaking frequency).
By introducing the breaking index into the string formula, considering a unit section of 1 mm^2 (that is equal to 1.18 mm in diameter) at 1.0 m of vibrating string length, at the corresponding breaking frequency value in Hz we obtain (of course) the breaking load stress value of 34 Kg/mm^2. In other words, a string of 1.18 mm gauge, 1.3 of density, 1.0m, length, under 34 kg of breaking tension will reach a music pitch limit of 260 Hz. In short: the breaking point of a modern gut string, according to our practical tests, ranges from 33 to 38 Kg mm^2, which is equivalent to a breaking index of 250-280 Hz/m (mean value: 260 Hz/m).[2]

Breaking vibrating length

Going back to our main topic, a luthier thinks the other way round from what has been just explained; it is the frequency of the first string which is the first parameter to be fixed when designing a musical instrument such as a mandolin, lute, etc. By dividing the breaking index for the desired first string frequency, you will obtain the theoretical vibrating length limit where the string will break when reaching the desired note (breaking point):

This is a simple proportion: 260: 1 meter = 1st string's frequency: X (were X is the vibrating length to be attributed in metres). In the case of a 6-course mandolin whose first string is a G: 698.5 Hz (at 18th-century French pitch of 392 Hz)[3] we obtain a result of 260/698.5 = 0.37 m. This is therefore the vibrating limit length where we know that the string will break reaching the note G (here we are referring to the ancient French pitch standard of 392 Hz).

The choice of vibrating 'working' length should therefore consider a prudential shortening of this limiting length. But how much? The more the are shortened, the thicker the strings are with the risk of losing acoustic performance.

Prudential shortening or working index

Examining the vibrating string lengths of the plucked and bowed instruments of the tables of Michael Praetorius (*Syntagma Musicum*, 1619) makes it possible to calculate their working index and put them in correlation to the gut breaking index. This allows us to understand the security margin adopted in those times.[4 and 5]

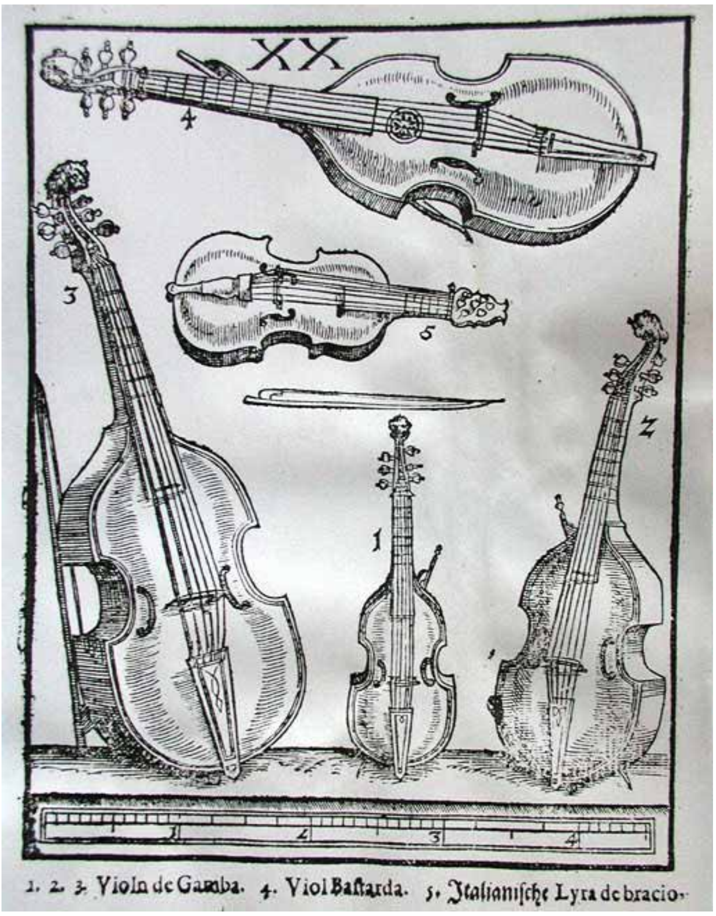
However, in the various calculations, unfortunately the scholar Ephraim Segerman has taken as a reference the average breaking load value—or breaking point—of a modern gut string found in the literature: 32 kg mm^2 (which is equivalent to a breaking index of 240 Hz/m) that is actually lower than the reality.

So, this value can be placed on a 'lower quadrant' of the range of breaking loads that we have found in today's commercial strings during our experiments (we will here suggest the average value of a breaking point of 34 kg/mm2, equal to 260 Hz/m of breaking index).

However, comparing the breaking index of 240 Hz/m with all the other working indexes, he found that the choice of the vibrating working length of the lute family and some gambas (viola bastarda for example) was about 2-3 semitones below the breaking index (and hence also of the theoretical vibrating length that we calculated before).

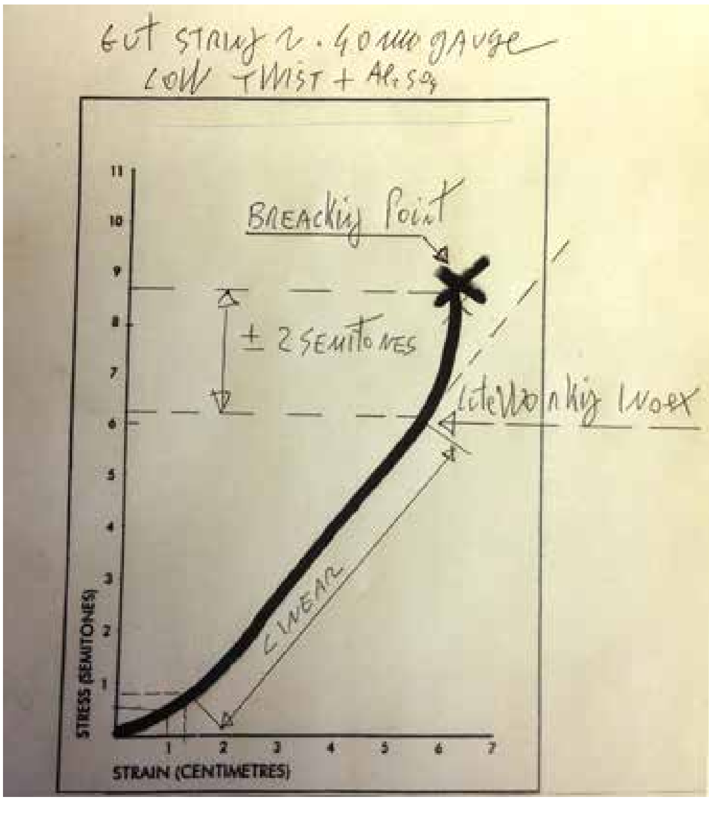
Considering our example, therefore, shortening of the strings by two / three semitones would represent the real vibrating length to be adopted (corresponding to a G of 392 Hz): 32.9 / 31.1 cm, values that are actually found in the 6-course mandolins of the time.

To give concrete evidence of what has been said so far, we have subjected a gut string to a progressively increasing tension (stress) and measured the related stretching (strain).



Drawing from *Syntagma Musicum*, Michael Praetorius (1619)

Examining the resultant stress/strain diagram, the initial proportional variation that emerges follows the Hook's Law (also called Tyler / Mersenne). At a certain point, the proportional variation stops and you reach a condition where the stretching (and therefore the corresponding tension) suddenly rises for very small further peg turns imposed on the string:



The string therefore maintains its linear stretching behaviour until about 2-3 semitones from the breaking point; beyond this value, it enters the critical phase. This is different from the typical behaviour of metals and nylon/nylgut/fluorocarbon strings. From this point gut almost completely loses its ability to stretch itself reaching rapidly its breaking point.

It is therefore concluded that the use of the maximum vibrating length can only work in the upper point of the linearity just before that the line on the chart starts to bent up to reach final breakage. The maximum acoustic performance (given by the maximum reduction of the diameter of all strings = maximum control on the inharmonicity) is determined by the fact that the instrument is working on the upper limit of where it is still stretching proportionally, just before it changes, and this is exactly two to three semitones from the final exitus, as shown on the graph. This behaviour of the gut string was well known even to the ancients and was therefore applied as one of the basic rules in the design and construction of musical instruments.

For Example, Marin Mersenne was aware of the right proportions that a musical instrument must have (*Harmonie Universelle*, 1636, Livre Troisième, Proposition X, 129) :

ment par la cognoiſſance des premieres tenſions que l'on a experimentées
aux chordes, ſi quant & quant l'on ne ſçait de combien l'extenſion de cha-
que chorde doit eſtre plus grande à la 2, 3, ou 5 fois, qu'à la premiere : c'eſt
pourquoy il ſuffit icy de remarquer combien chaque chorde s'eſtend depuis
ſon ton plus graue iuſques à ſon plus aigu, auant qu'elle rompe, afin que l'on
puiſſe conclure par la diuiſion de l'extenſion en eſgales parties, combien cha-
que ton ou demy-ton fait plus, ou moins eſtendre la chorde : toutes-fois les
extenſions ne ſont pas touſiours eſgales, encore que l'on y adiouſte des for-
ces eſgales, car les dernieres ſont quaſi touſiours plus grandes que les premie-
res. L'experience fait voir que les chordes de Luth s'eſtendent pour le moins
d'vne vingtieſme partie, auant qu'elles rompent, car la chanterelle qui a cinq
pieds de long, & que l'on tend auec vne demie liure, s'eſtend de trois poul-
ces ou enuiron, depuis l'extenſion qu'elle reçoit de cette demie liure iuſques
à ce qu'elle rompe par la force de trois liures & demie. Et apres qu'elle eſt ten-
duë par vne demie liure, la ſeconde demie liure que l'on y adiouſte la faict
alonger d'vn demy poulce, & la troiſieſme la fait encore alonger d'vn autre
demy poulce, & ainſi conſequemment iuſques à ce qu'elle ſe rompe, n'y ayant
point d'autre difference, ſinon que les derniers alongemens ſont vn peu plus
grands que les premiers.

And here is what Bartoli wrote at the end of 17th century:[6] 'Una corda strapparsi allora che non può più allungarsi . . .' (a string breaks when it cannot stretch furthermore).

Hor venendo alla propoſitione poſta di ſopra, Vna corda
ſtrapparſi allora che non puo piu allungarſi: ella contien due
parti, l'vna delle quali mi pare hauer ſicura: cioè, Che finche
puo allungarſi, non puo ſtrapparſi: e mi par tanto vera, quan-
to è, Il non venirſi nelle operation naturali e neceſſarie, all'
eſtremo, che prima non ſi ſien paſſati tutti i mezzi, e vinte
le lor reſiſtenze, che ſi truouano ſempre minori. Ma lo ſtrap-
parſi, è l'eſtremo dello ſtiramento, adunque non ſi viene ad
eſſo, mentre la corda, coll' allungarſi puo non ſtrapparſi.
Che poi ſi habbia a ſtrappare quando non ſi puo piu allunga-
re, mel perſuade il diſcorrer così. Poniamo, che la graueza-
za del peſo ſia creſciuta a tal miſura che per eſſa la corda ſi
Z 4 truoui

Daniello Bartoli: *Del suono, de' tremori armonici e dell'udito* (1679).

Meanwhile, the rule of those times of tuning the lute and even some bowed instruments beginning at the highest open note and stop immediately before the breaking of the first string is well known: this is the ultimate proof of what we have already showed graphically.

The example of the lute

The vibrating lengths that were chosen for some of the old, surviving lutes impart valuable information. The main problem is that in order to make an evaluation we have to find and use instruments in their intial state, not modified to later tastes, and instruments whose standard pitches can be determined with a relative certainty. This is the case of with at least some unmodified renaissance Venetian lutes, German D-minor baroque lutes, and French baroque guitars.

Starting from hypothetical standard pitches (for their times and places of origin) and from what has emerged from the study of their vibrating string lengths, the research on the various 5-course French guitars (at the 17th century French pitch standard close to 390 Hz) as well as the German 13-course D-minor lutes tuned at the Kamerton of 410-420 Hz (see Baron 1727: his Kammerton F note for the first course) and finally including even some surviving renaissance Venetian lutes whose scale lengths of 56-58 cm, probably related related to Venetian standard *mezzo punto* pitch of 460 Hz more or less, researches have allowed us to establish a working index between 225 and 235 Hz/m with an average of 230 Hz/mt: this can be considered the lute working index of past times (theorboes generally speaking worked with a bit more safety; some Magno Graill or Buechenberg large theorboes have vibrating string lengths around 95 cm; at the Roman pitch standard of 390 Hz/m, the related working index range is 210-220 Hz/m). We are very close to what we calculated for example from Segerman: 210 Hz/m.

If we consider true that the working index of these examined original instruments presents a safety margin of two or three semitones from the breaking point (as we have seen on our stress/strain graph), it is even therefore possible to estimate the average breaking point in kg of lute first strings of those centuries. This can be obtained by increasing the working index that we have deduced of two or three semitones.

From this simple reverse calculation, it is possible to determine that the average breaking load of the gut chanterelles of the 16th, 17th and 18th centuries would be between 33.7 and 35.1 kg/mm^2 (corresponding to a breaking index range of 256-268 Hz/m) in the case of two semitones of safety margin and 35.7-37.3 kg/mm2 (breaking index 273-285 Hz/m) if the safety margin was instead of three semitones.

As we can see, the range of all these values is perfectly in line with that of the current treble lute gut strings of 0.36-0.46 mm gauge (34-38 kg / mm2).

Going back to the 6-course mandolin with a first string at G, a prudential shortening of two semitones in the average value of the breaking index of 260 Hz/m determines a vibrating length of 32.9 cm; it will be 31.1 cm if we are considering three semitones as a safety margin: these are the typical vibrating lengths found in the surviving instruments.

The range of working index (the product of the frequency of the first string, times vibrating length in metres) is as follows:

G/Sol (at the standard pitch 392 Hz);	32.9 cm	31.1 cm
	230 Hz/m	217 Hz/m
G/Sol (at the standard pitch of 415 Hz);	32.9 cm	31.1 cm
	244 Hz/m	230 Hz/m

As can be seen, a 6-courses mandolin exceeds the typical working index of the surviving lutes and 5-course guitars only if the safety margin is two semitones, with a pitch standard of 415 Hz.

In the case of the 4-course Neapolitan mandolin with a vibrating length of 33 cm (a string length typical of the violin) the following figure is obtained:

E / Mi (at 392 Hz reference pitch); 33.0 cm
194 Hz/m

E / Mi (at 415 Hz reference pitch); 33.0 cm
205 Hz/m

The conclusion is that both these working indices are within the breaking index of a gut treble. The 6-course mandolin in particular works exactly like a lute while the 4-course Neapolitan mandolin has a lower tension on the first string, just like a violin. A plausible explanation would be that while on the 6-course mandolin the range between the open first and the last strings is two octaves (24 semitones), on the 4-course instrument this range is reduced to 18 semitones, so it is not strictly necessary for the strings to be working at their highest possible acoustic performance, i.e. close to their breaking point, as is the case on those instruments with open range of two full octaves like the lute, in order to preserve the acoustic performance of the bottom strings.

However, our initial question is still unanswered: why not use a metal treble whose sound would be much brighter and quicker speaking, would have had less wear and tear and even a higher breaking load than gut?[7]

The breaking load stress of 17th century iron wire for the harpsichord can reach up to 100 Kg / mm^2. For old brass this value is lower but always much higher than the average breaking load stress of gut. The explanation is that the highest note is certainly directly proportional to the breaking load but also inversely proportional to the specific weight of the material, which is very high in metals: 7.0 g / cm^3 for iron, 8.5 g / cm^3 for brass; but only 1.3g / cm^3 for gut.

From simple calculations, taking into account the ancient pieces of wire for keyboard instruments discussed in some essays of those times, we can list a series of breaking indices. According to Mersenne:[8]

Silver: 155 Hz/m
Iron: 160 Hz/m
Brass: 150 Hz/m

The typical high density of metals affects quite strongly the limit of the breaking index: an 'ancient' steel string with a breaking load of 100 kg/mm^2 for example (which is one of the higher values found among the absolute values of old keyboard strings), however, has a breaking index of just 178 Hz/m.

This clearly explains why the battente guitar, fitted with robust metal strings can have a vibrating string length limited to just 55–58 cm, while those with less strong gut strings can reach 68–73 cm (at the same historic pitch standard).[9]

A lot has been discovered concering metal strings' breaking load stress in the past.[10] Here are some breaking indices found for old metal strings on spinets or harpsichords:

'Old' harpsicord iron: 158–188 Hz/m; mean 173 Hz/m.[11]
'Old' spinet and harpsicord iron: 164-187 Hz/m; mean 175 Hz/m.[12]
Old' spinet iron from the second half of the 17th century: 159–195 Hz/m; mean 177 Hz/m.[13]

Other metals:

'Old' copper alloys: 112–138 Hz/m; mean 125 Hz/m.[14]
'Old' brass: 101–155 Hz/m; mean 128 Hz/m.[15]
'Old' brass: 148–153 Hz/m; mean 150 Hz/m.[16]

It can be easily seen that the difference between Mersenne's data and the average measured values is not particularly relevant.

The reason why the nandolins used the gut for the highest string is therefore clear: they did not have pure metals and/or metal alloys that could reach a breaking index similar to that of gut (260-280 Hz/m). Considering, iron (the metal with the highest breaking index) this would correspond to a breaking load of 145-160 kg / mm^2.

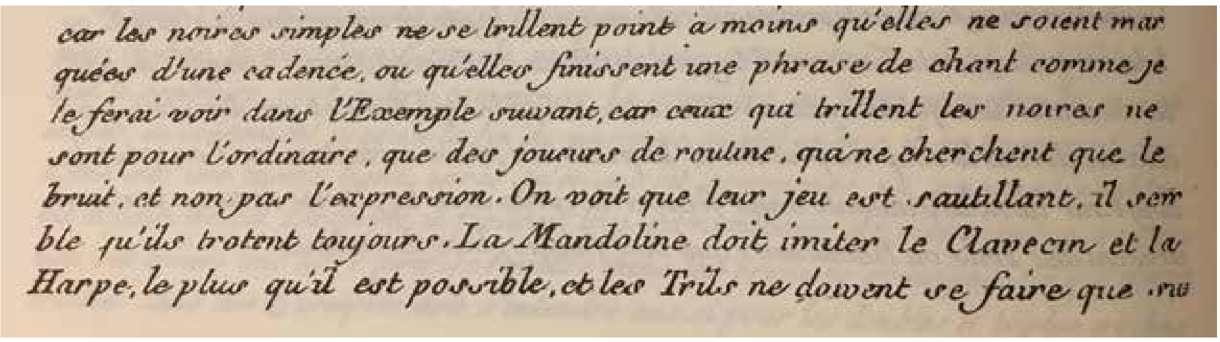
The evidence of the use of gut trebles on the mandolin is a clear demonstration that strong metal strings were not available in the 18th century and even the first decades of the 19th. A metal wire with these values would have been employed immediately, as actually happened for a time at the turn of the 16th and 17th centuries and after 1830.[17] The mandolin was therefore inevitably forced to use gut string for the first course due to lack of alternatives.

Historical sources

There are few historical sources from the 18th century containing information regarding the string set-ups of 4- or 6-course mandolind; these few are, at the end of the day, only Fouchetti and Corrette.[18, 19] Let's see what they wrote and what can be deduced.

Fouchetti

What Fouchetti wrote about the 4-courses Neapolitan mandolin set-up, generally speaking, is considered unreliable, if not fanciful. A set of strings like those he described appears to be the most bizarre and heterogeneous among those of all the plucked and bowed instruments of his time: different materials on a set of just four courses: gut string, brass wires, twisted brass wires, and wound gut/silk strings. This degree of heterogeneity is absolutely amazing. By looking more closely and by making some calculations, we realise that this set-up gives about the highest perfection possible for that time both from a mechanical point of view and from the acoustic point of view, and indeed with very few other alternatives, if we consider what was available in those times to make strings—keeping in mind that the most desired feature in this instrument was brightness and prompt speaking, as it had to imitate the harpsichord:[20]


car les noires simples ne se trillent point à moins qu'elles ne soient mar
quées d'une cadence, ou qu'elles finissent une phrase de chant comme je
le ferai voir dans l'Exemple suivant, car ceux qui trillent les noires ne
sont pour l'ordinaire, que des joueurs de routine, qu'ne cherchent que le
bruit, et non pas l'expression. On voit que leur jeu est sautillant, il sem
ble qu'ils trotent toujours. La Mandoline doit imiter le Clavecin et la
Harpe, le plus qu'il est possible, et les Trils ne doivent se faire que su

As far as vibrating lengths are concerned the sizes used conforms with clear evidence, especially on the 6-course mandolins, that we are considering an instrument that, like the lute, had the maximum vibrating length possible in order to ensure the best acoustic performance.

Here is the set for the Neapolitan 4-course mandolin (Fouchetti says nothing about the 6 -course mandolin):

1. a pardessus gut treble
2. a harpsichord gauge 5 yellow brass
3. two harpsicord gauges 6 yellow brass twisted together
4. a light G violin wound fourth. The core can also be silk. As an octave pair you can use 5-gauge yellow brass as on the second course. Sometimes the fourth courses are strung in unison.

J'ai parlé de la Mandoline à quatre cordes, c'est-à-dire à quatre cordes doubles, car elles sont accordées de deux en deux à l'unisson, c'est-à-dire, du même son, excepté la grosse corde, ou Sol, à laquelle on met une octave. On se sert pour cela d'une corde semblable à celle de La, que l'on accorde à l'Octave au dessus de la grosse corde Sol. Quelque fois l'on met deux bourdons ensemble, alors on les accorde à l'unisson comme les trois autres cordes.

A l'egard des cordes elles doivent être de laiton. L'on prend pour les La, des cordes de Clavecin du numéro 5. Les Re sont du numero 6, mais l'on en met deux tordues ensemble pour chaque Ré. A l'égard des Mi, l'on se sert de cordes de boyeau l'on prend des chanterelles de Pardessus de Viole. Les bourdons, ou Sol, sont aussi des cordes de Boyeau, mais filées; l'on prend des bourdons de Violon, mais plus petits. On fait quelque fois filler des cordes de soye, pour servir de bourdons; elles sonnent très bien.

First string: considering the range of the working index that we determined, the first string must be of gut due to the lack of possible alternatives: Fouchetti suggests a first pardessus string. According to the data provided by De Lalande,[21] and other sources, we know that the treble for pardessus and also mandolin was made up of two whole lamb guts, and the violin first string of three. There are numerous researches,[22, 23, 23] that associate three whole lamb-guts with a gauge of .68 to .73 mm. By simple proportions, the mandolin/pardesssus first string had a diameter of .56-.59 mm.

Second string: Fouchetti says you should use a yellow brass wire of gauge 5. The second course's working index is around 129 Hz/m so the brass wire available (for harpsichord) was not going to break. The use of a brass string and not of a more robust iron has only one explanation, of an exclusively acoustic nature: brass, due to its specific weight higher than iron, is brighter: this fits quite well with the criteria of those time were mandolin should imitate the sound of the harpsichord. According to the Cryseul gauge scale,[25] the gauge 5 corresponds to a diameter of about 0.30 mm.[26] The yellow brass had a specific weight around 8.5 g /cm^3 (red brass: around 8.7 g /cm^3).

Third string: Fouchetti says to take two yellow brass harpsichord of gauge 6 twisted together. The purpose is clear: the strings twisted together become more elastic than a single strand of the same gauge, so they minimise the 'pitch distortion' effect on the frets which with a simple single wire would be very evident even for small pressure variations and / or lateral displacements on the string. With a single metal wire, there would also be a considerable difficulty in tuning and keeping it stable over time because even an imperceptible rotation of the tuning peg would produce significant variations. By twisting two wires together, the abovementioned problems are solved; the use of the brass still guarantees the best acoustic performance in terms of tonal brightness and projection even though it is still a little less 'round' than a single wire. The gauge 6, always according to the Cryeseul scale, corresponds to .29-.30 mm in diameter. The problem here is to determine the strings' degree of twist and the behaviour of the yellow brass, as Fouchetti says nothing about it.

We can find a solution by realising different types of twisting and checking the mechanical strength, sound, and especially the resulting working index, and compare it to the working indices of the other courses. Thus by experiment we have found that two .30 mm brass strings twisted together with a low twist produced a string of .39 mm diameter (1.30 times the diameter of the starting wire) or .46 mm (1.54 times the diameter of the starting line) if the twisting ratio is very high. In this second case, however, we found the sound was far better: the working tension, tuned to D of 262 Hz (Parisian pitch standard of 392 Hz) is around 3.4 Kg.

Fourth string: For the fourth string a violin G wound string was used, but a bit thinner than normal (in those times they were made using a medium second violin stringwe as the core: we have employed a thin second one) Considering a gut-core wound string, it is evident that you lose the characteristic brightness of the three top strings.

This problem is greatly mitigated by the fact that a yellow brass octave (and not a gut) string is added, whose obvious purpose was to add brightness to obtain an acoustic alignment with the higher ones. This course was also sometimes strung in unison but Fouchetti tells us that this was seldom done.
The author suggests, alternatively, the use of silk as the core of the fourth, thus anticipating what would then become the standard for the bass of six-course guitars in the 19th century. With the use of a silk core the sound became even a little brighter. Indeed, the use of silk core basses for five-courses guitar had already been described by Juan Guerrero in 1760.[27]

> On doit faire un choix des Cordes et bien observer les proportions qu'il faut qu'elle aient entre elles: Une Guitarre n'est bien montée que lors que les troisiemes et la cinquieme Corde, egales en grosseur, sont moins fortes qu'une Chanterelle de Violon; Les secondes doivent être plus fines que les troisiemes; la Chanterelle et la quatrieme sont egales, mais plus fines que les secondes; le Bourdon de Re filé en plein doit être un peu plus fort que les troisiemes; Et celuy de La plus fort encore que l'autre Bourdon. en Espagne on se sert de Cordes filées sur de la Soye qui n'est pas torse et telle qu'on s'en sert chéz les Fabriquans de Bas: Cet usage rend l'Instrument beaucoup plus Sonnore, on jouë mieux et avec moins de peine.
>
> Tablature

But how was a wound violin G string made in those times? Some sources wrote that a second string of the same instrument was taken for the core and then covered with a thin silver wire or silver copper wire (see Francesco Galeazzi, 1792). The equivalent gut string to ensure a balanced setup (with scaled tension) for this instrument, ranged from 1.70 to 1.90 mm. Fouchetti writes, however, that this string has to be a bit thinner than normal, but by how much? We must calculate its equivalent gut from the mandolin scale length, the presumed pitch standard and the gauges of all the other strings (and so, by calculation, the related working tensions).

Thus, with a vibrating string of length 33 cm, the diameters and the density of the materials, it is possible to obtain the working indices values of all the strings at the supposed Parisian itch standard of 392 Hz with the following results.

First course: 5.44 kg (average tension value between .56 and.59 mm; diameter = .575 mm)
Second: 5.3 kg (gauge 5 = .34 mm)
Third: 3.4 Kg (two gauge 6 low twist wires = .30 mm)
Fourth, octave: 4.46 Kg (.34 mm)
Fourth, wound bass: the tension should be the same as the paired octave string: 4.46 Kg

Some remarks

1) at 'Parisian' 392 Hz pitch standard, the working index of the yellow brass wire for the octave of the fourth string is about 115 Hz/m (122 Hz/m at 415 Hz): a yellow brass wire can therefore be safely used.

2) The set-up presents a scaled tension profile which would probably lead to a situation of equal tactile feel if were it not for the third course where we have abnormally low tension. In reality, it is possible to balance the situation if we consider a thinner gauge for the first string, always made, however, from two guts.

3) Then, in order to have the same working tension as its paired octave, the equivalent gut of the fourth string should be 1.75-1.80 mm: in fact, we have a fourth violin string which tends to be in the lighter end of the tension range.

Fouchetti's stringing: conclusion

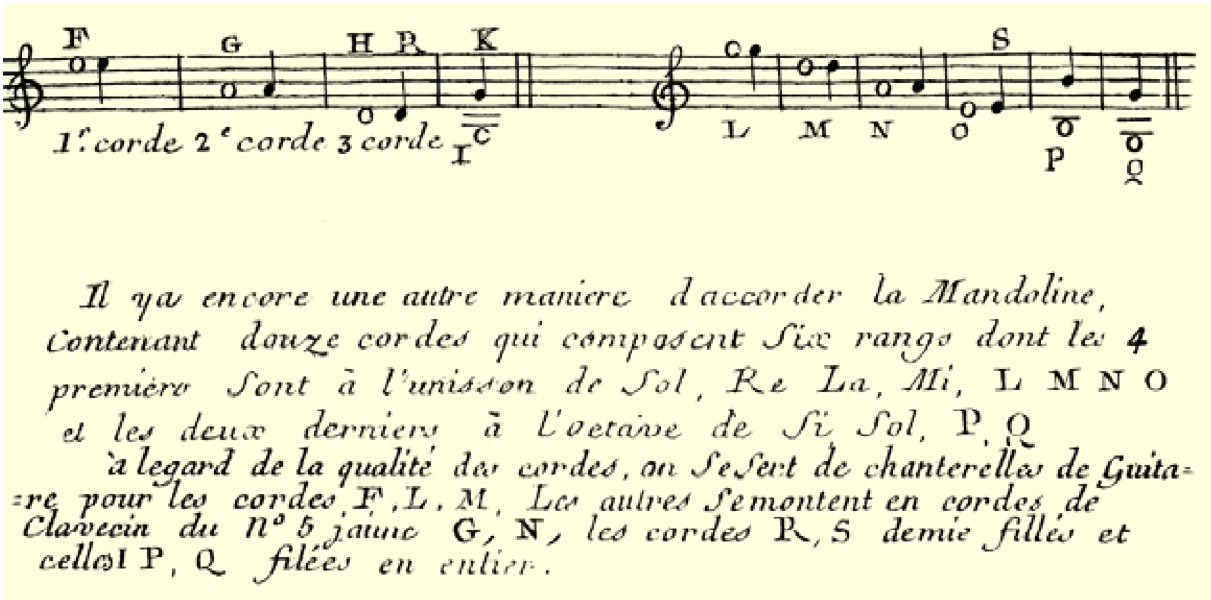
The setup described by Fouchetti presents almost perfect coherence in tension values between the various strings and on the acoustic side; due to the careful choice of materials and string types, it achieves the highest performance that results in powerful projection and brightness.

It should be noted, however, that there were not many alternatives available at the time: the first string had to be gut, while the fourth had to be a wound gut/silk-core string. Most likely, on the second and third courses, iron wires for harpsichord could be used but this would be at the expense of brightness (though wires of this material providing the same working tension as gauge 5 and 6 yellow brass would probably not be available) as there was no intermediate gauge between n ° 5 and n ° 6.

The octave of the fourth course could be unisons, adding another violin G wound string instead of a brass wire, but here too, there would have been a loss of brightness, a factor which is emphasised by Fouchetti, who points out, as already said, that the mandolin must imitate the harpsichord and harp.

Corrette

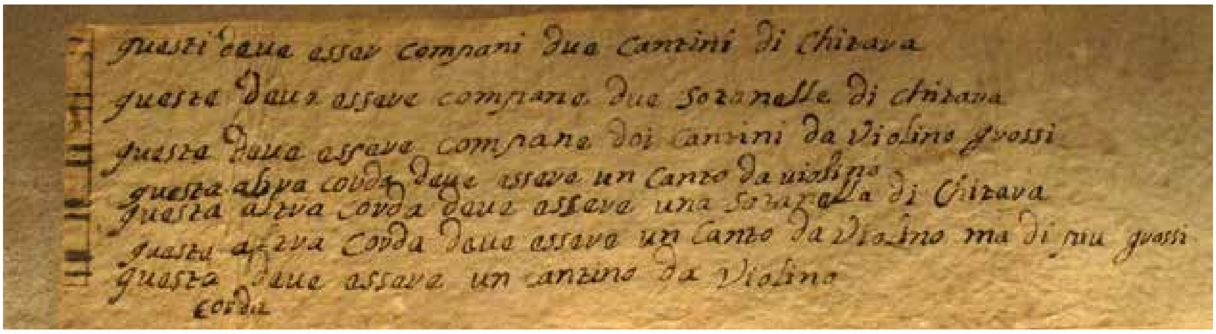
Examining the method of Corrette, the first noticeable thing is that he does not propose any novelties as described by Fouchetti for the 4-course mandolin tuned in fifths. In fact, looking at his diagram printed above, there are substantial differences and, in my opinion, several errors.



First course, called F: this must be a 5-course guitar first string
Second course called G: this must be a harpsichord gauge 5
Third course called H and R: R must be a demi file, nothing is said about H
Fourth couse in octaves, called K and I: I is a wound string, nothing is said about K

The first gut string is not a pardessus treble as Fouchetti says, but a 5-course guitar first string: what diameter could it be? We need to know if there are direct references to the number of strands, or to guitar strings or at least an indirect reference to another musical instrument. Unfortunately to date we have no direct reference; instead, there are several references to a well-studied instrument: the violin.

a) In the Stradivarius Museum there is a drawing on cardboard (drawing no. 375) which shows the description of the necessary strings for the five orders of the *chitarra attiorbata*, which is basically a normal 5-course guitar with 5 single diapasons ('bordone') added on an extended neck.



The instructions are as follows.

• First and second string (first course): 'Questi deve essere compani due cantini di chitara'. (These must be a pair of guitar top strings)
• Third and fourth strings (second course): 'Queste deve essere compane due sotanelle di chitara'. (These must be two guitar second strings)
• Fifth and sixth string (third course): 'Queste deve essere compane doi cantini da violino grossi'. (These must be a couple of thick violin top strings.)

And so on.[28] To solve this problem then we need to know what the average violin string diameter of those times and what could be called a 'thick' treble.

Count Riccati (who was, in addition to being a great physicist, aa amateur violinist friend of Tartini) around 1740/50 made some interesting measurements of the strings of his violin: from his calculations we get the size of the treble on his violin: about .70 mm.[29]

This estimate is indirectly confirmed by the data provided by the French traveller and astronomer De Lalande around 1760,[30] about the gut used to make mandolin, violin and double bass strings of the famous stringmaker of Abruzzo (though working in Naples), Domenico Antonio Angelucci; these proportions remained strictly constant until the end of the following century, in Italy and in France.[31] As for the 'thick' trebles, let's consider as reference the thicker E and A gauges made from the same number of guts as George Hart suggested in 1881.[32] Considering the standardisation in the manufacturing process of violin strings it is then possible to assume that a 'thick' three-strand gut string could be around .73-.74 mm.

Since the third course of this guitar used a violin gut string (made with three guts or 'fili') using simple proportions—maintaining a constant tension—the second course had to consist of two-strands (like the treble of the mandolin and the pardessus, according to De Lalande) and the first of a gut only, just like the treble of the lute.[33] In theoretical calculations, the ratio between the diameters is equal to the square root of the ratio of the number of strands used; but then we have to deal with the tactile feel of tension that must be homogeneous: two gut strands therefore produce a diameter between .57 and .59 mm.

Since with three-gut string we obtained an average diameter around 0.70 mm (here we refer expressly to a 'big' treble, for example .73 mm, which is considered 'thick' by George Hart), considering a set up with the same feel as the guitar (which, however, leads to scaled or graduated tension measured in kg, conditioning the choice of its gauges), this is what we obtain:

First course: .44-46 mm (made from a single whole gut).
Second course: .57-59 mm (made from two pieces of gut).
Third course: .73 mm ('a thick violin treble': made of three strands of gut), etc.

Corrette writes that:

> La guitarre se mont en cinq rangs de cordes, le 1er n'en a qu'un qui se nomme chantarelle, et les quatre autres rangs en ont chacum deux . . . Il faut observer que les deux cordes du 3me rang et la petite corde a l'octave du 5me rang soient égales en grosseur pas si forte que la chantarelle de violon. . . [34]

Corrette thus himself confirms what is written in our document of Stradivarius. Now that we have a more precise idea of 5-course guitar gauges, we can go back to the 4-course mandolin described by Corrette and try to provide the diameters:

a) First string: Corrette talks about the guitar first string. The reference starting point to find out the guitar gut gauges is the third course, which has a gauge equal to a (thick) violin treble: in order to preserve an even feel of tension between the strings, the first then, according to what the author wrote, has to be of about .44 to .46 mm gauge.

b) Second string: a harpsichord gauge 5 wire is used. Corrette, however, does not specify the type of metal; however, the analogy with Fouchetti is consistent and hence we may consider that he is talking about yellow brass.

c) Third string: Corrette oddly seems to consider each as single string even though on his stave diagram we can see that they are in unison. A futher oddity, already noted, is that he provides no explanation for some of the letters on his own diagram: of 'H', nothing is said, while 'R', is a demifilé, but with no further details given; unfortunately, from this statement it is not possible to get anything concrete; we do not know if the strings were both demifilé and there is no further specification.

d) Fourth string: Corrette says nothing about the octave string 'K'. Of the bass string 'C' we are just told that it is a wound string. However, we do not know which core to use—silk or gut. But anyway thanks to Fouchetti we know that both materials were suitable therefore we might guess that, again, it is a violin G string.

Considerations

The information given by Corrette concerning the 4-course mandolin are, in the view of the present writer, totally unreliable.

First course: with a gauge of around .44-.46 mm it would have a working tension of only 3.0-3.2 kg per string.

Second course: presumably a yellow brass gauge 5, but nothing is specified—here the tension rises to at least 5.3 kg per string. The gap between this and the tension on the first course is remarkable. To have a working tension comparable to the second course, the first course should use the guitar second-course strings (two strands of gut = mandolin first course = pardessus first course according to De Lalande) in accoradance with Fouchetti.

Third and fourth courses: nothing useful can be learned from Corrette; if it were not for Fouchetti (which gives a useful comparison) the data provided by Corrette would be completely meaningless.

Six-course mandolin

After the problems already encountered on the 4-string mandolin tuned in fifths, we inevitably expect issues. In fact, other indications in Corrette's diagram are unfortunately incorrect: some reasoning is needed. Only at after reviewing the evidence can we arrive at a workable solution for the 6-course mandolin.

a) First and second courses: Corrette writes that courses 'L' and 'M' must be guitar trebles: what does he mean? That he used the guitar treble for the second course of the mandolin as well as the first? This cannot be right; there cannot be trebles installed on the second course: there would be a total mis-alignment in the working tension. We therefore feel that Corrette is referring to the first and second courses of the guitar.

b) The third course 'N': Corrette says to use a harpsichord gauge 5 wire but omits to specify the type of metal: however, I think it is the usual yellow brass, used for harpsichord.

c) Fourth course 'S': Corrette says that this is a demi filé string but does not add further detail, such as to whether it is a silk or gut core?

d) Fifth course 'P': this is a full wound string but we have no other information: the octave string is not mentioned at all.

e) Sixth course 'Q': This is a full wound string but we have no other information: again the octave string is not mentioned at all

Considerations

Form the data provided by Corrette, no one today (or indeed in his time!) would be able to work out the string set up; however, it is possible to introduce some reasoning that eventually might solve the enigma.

Let us start from the only certain data available: the third course A which is a harpsichord gauge 5, presumably of yellow brass (.34 mm). Using a typical 6-course mandolin average vibrating length, of 31.5 cm, and a presumed Parisian/Roman pitch of 392 Hz, we obtain a working tension of 4.8 kg.

The first and second courses of the instrument must therefore somehow relate to this value: by putting on these two courses the first and second strings of a guitar (of which we have a more accurate idea thanks to Stradivari's violin information) the following working tensions are obtained: 3.9-4.3 kg for the first course and 3.8-3.9 kg for the second. Compared to the tension value of the third course, it is not really in balance, yet will still be functional.

Things are much simpler with the sixth course: as it is a G we can suppose that it may be a violin fourth string as per Fouchetti, with the octave equal to the gut second (the third on the guitar): considering this hypothesis as valid the tension of the bass and its paired octave is about 3.9 kg. The paired octave may be the same yellow brass gauge 5 already used for the third course: a gut string would be about .90 mm in gauge.

Having deduced the working tension of the first, second, third and sixth courses it is logical to think that the working tension of the fourth and fifth must necessarily be between 4.8 kg (third course) and 3.9 kg (fourth course): How can this condition be achieved while fitting in the technological and acoustic correct range?

Fourth course: as we have seen, Corrette says to use a demi filé string. It is necessary here to consider a working tension range slightly lower than that of the third course but in any case, higher than the theoretically associated range in the fourth course. The range has to preserve the linearity of the values calculated so far. If we assume that the range is 4.4-4.7 kg, the following diameters are obtained: 1.10-1.14 mm. These diameters correspond exactly to a third Violin string that was then made in France usually as a demi filé.[35, 36]

Violins with an open wound or demi filè third string (France, mid-18th century)

Its octave should have a diameter between .55 and .57 mm: the first string of a 4-course mandolin or second course of a guitar.

Fifth course: Corrette states that this is a unison and a full wound string. From simple calculations, considering a tension range slightly above that of the fourth course in order to preserve the linearity of the values calculated so far (assuming that the range is 4.1-4.3 Kg) for the note B we obtain an equivalent gut of 1.42-1.47 mm in diameter.

The data should be reliable: its octave, at the same tension, varies between .71 and .73 mm in diameter; the guitar third string (i.e. a violin first string).

The problem is to realise this stringing, especially if you use a gut core. In those times, according to our research, metal wires with a diameter of less than about .13- .15 mm[37, 38, 39, 40] were not produced because they did not have technology to drawing a thinner metal wires.

In other words, the half-wound string described by the writer was not at all a transition string between a gut string and a wound string but a technological way out, in view of the non-availability of thinner metal wires; in fact, we can find proof in the metallicity index characteristic of these particular strings, which is similar to that of full-wound strings, and not less.

If the core is instead of silk, which, according to Fouchetti, was used on the mandolin and then also in the fourth and fifth courses of 5-course guitars and on 19th and early 20th century guitars. With silk cores, rather than gut, the relationship between the core and the metal can be unbalanced in favour of the metal, so that a full-wound string can have a brilliant acoustic output (higher metallicity index).

It is interesting to note that the equivalent gut and the way of making the close wound strings on silk for the fifth and sixth courses of the 6-course mandolin would then be used respectively for the fourth and fifth strings of the 6-single string guitar, which in ten or fifteen years was to appear on the music scene.

To sum up, even for this kind of mandolin Corrette does not allow us to come to certain and plausible conclusions. However, we have made a number of arguments that lead to the following proposed set-up, based on the few information from Corrette (the only really positive piece of information is the indication that the third course uses sgauge 5 wire, from which we can deduct the values of the tensions: at this point, the highest course must have a higher tension while the bass side tensions decline according to a Fouchetti's similar mandolin profile) and with the support of Fouchetti:

1G: the first string of a 5-course guitar = .44-.46 mm in diameter; average tension: 4.1 kg per string.

2D: the second string of a 5-course guitar = .57-.59 mm in diameter; average tension: 3.9 kg per string.

3A: gauge 5 yellow brass for harpsichord = .34 mm diameter; average tension: 4.8 kg per string

4E: demi filé string (third violin according to French use) = 1.10-1.14 mm equivalent gut; average tension: 4.0 to 4.5 kg

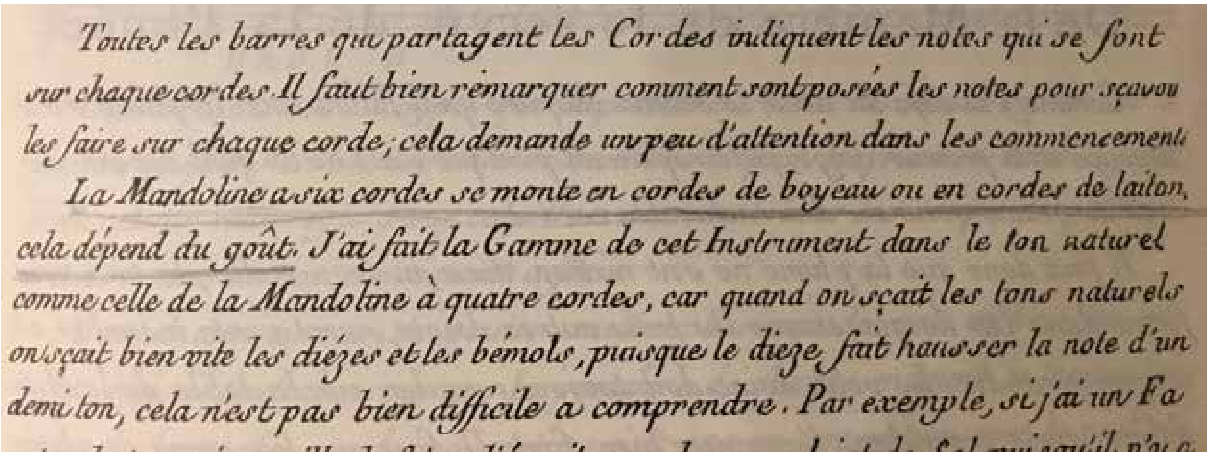
5B octave: third strings of a five-course guitar = .70-.73 mm in diameter; average tension: 4.2 kg

5B: bass: full wound string on a silk core with gut equivalent = 1.42-1.47 mm diameter; average tension: 4.2 Kg

6G octave: another gauge 5 yellow brass harpsichord wire = .34 mm diameter; average tension: 3.9 kg (or a gut string of .88-.91 mm: in practice the same as the fourth course of the guitar).

6G bass: full wound on silk core (it is difficult to think they would have used a gut core or indeed a violin fourth string)= 1.8 mm diameter gut equivalent; average tension 3.9 kg.

The uncertainty over using octave strings in gut or yellow brass gauge 5 is a matter of relative importance: Fouchetti points out that the use of metal wires or gut strings was a matter of personal taste:



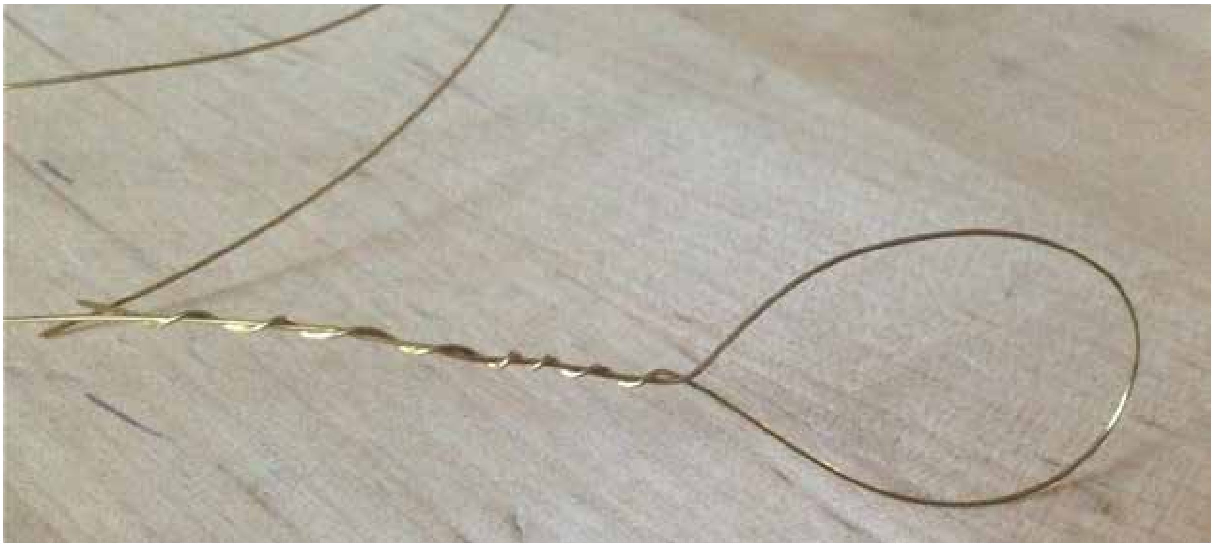
Toutes les barres qui partagent les Cordes indiquent les notes qui se font
sur chaque cordes. Il faut bien rémarquer comment sont posées les notes pour sçavoir
les faire sur chaque corde; cela demande un peu d'attention dans les commencements
La Mandoline a six cordes se monte en cordes de boyeau ou en cordes de laiton,
cela dépend du goût. J'ai fait la Gamme de cet Instrument dans le ton naturel
comme celle de la Mandoline à quatre cordes, car quand on sçait les tons naturels
on sçait bien vite les dièzes et les bémols, puisque le dieze fait hausser la note d'un
demi ton, cela n'est pas bien difficile a comprendre. Par exemple, si j'ai un Fa

Practical evidence

Four-course mandolin: the Fouchetti set-up

First course: .56 mm gut gauge string: no mechanical or acoustic problems were found.

Second course: yellow commercial brass wire for harpsichord diameter .35 mm. The main problem turns out to be how to tie it on. Being a very hard harpsichord brass wire the problem is its fragility when bent. In our case, we solved the problem by making a very long loop so that, when put in tension, it will 'lock' itself, eliminating any string breakage problem at the pegs due to the presence of sharp angles.



Third course: we used .30 mm yellow commercial harpsichord hard brass wire. It is not possible to twist together directly the two wires, the brass being very hard as it tends to break during twisting, resisting the operation, finally coming to different degrees of twist along the string. The solution to this problem was to soften the two wires just a bit (not totally) by heating them to 350 degrees (in this regard we did a number of tests whose final result indicated that the wire has to be heated between 330 and 370 degrees Celsius) for one minute. The wire thus obtains an intermediate degree of hardness, allowing it to be bent and still retaining a residual degree of hardness counteracting the yielding of the wire under tension.

The degree of twisting of the string is a crucial aspect: if it is very high (high twist) the sound is very bright but it also reduces the tensile strength. With less twist (low twist) the sound is less metallic; you have less sustain but you have a higher tensile stress. In other words, depending on the degree of twisting, you can modulate the desired tonal output until you find an acoustic balance between the second and the fourth course.

Fourth course: following the historical instructions we obtained a violin wound G whose equivalent gut is 1.80 mm (a slightly lighter violin second string covered with silver wire): for the octave a second yellow brass wire is used, the same of those of the second course.

Conclusions: The overall acoustic balance of the set was homogeneous and thus also the feel of tension among the strings (at a pitch standard of 392 Hz).

Six-course mandolin according to our interpretation of Corrette interpretation (and playing with a cherry bark pick)

First course: .46 mm gut: no acoustic or mechanical problems found

Second course: .56 mm gut: no acoustic or mechanical problems found

Third course: .35 mm yellow brass wire: the tension feels a little higher than the upper strings; it sounds more brilliant than the second and third course. Working tension: for a better balance the diameter should be reduced to .33-.34 mm. There is no solution for the brilliant acoustic output. Alternative: .88 mm gut string: no mechanical problem; acoustically aligned with the first two top courses and with the fourth course

Fourth course: two violin third demifilé strings are used: equivalent to gut of about 1.15 mm. There were no mechanical problems. The sound was a bit dimmer compared to that of the third course, whenever it is done using yellow brass instead gut.

Fifth course: the bass consists of an average 19th century guitar fourth D string wound with silvered copper wire on silk core whose equivalent gut is about 1.40 mm. The octave string is a gut third string of a 5-course guitar of .73 mm (see the Stradivari information above, re: the thick violin top string)

Sixth course: the bass consists of an average 19th century guitar fifth A string wound with a silvered copper wire on silk whose equivalent gut would be about 1.80 mm. The octave string is a .88 mm gut equivalent to a fourth string of a 5-course guitar.

In the view of the present writer this experimental set-up is completely satisfactory. There are no mechanical problems; acoustic and dynamic balance are good including with regards to the fifth course. We tested a yellow brass wire as an octave for the sixth course but this resulted in a tonal disequilibrium with the other higher courses.

Critical points revolve around the use of brass wire on the third course, due to the tonal difference with the others gut courses. Likewise, the use of a yellow brass wire as an octave of the sixth courses is unlikely to be successful due to the tonal disequilibrium that occurs. The best balancing set-up therefore is the one that uses gut strings for the first three courses and for all the octaves; close wound silk core for the fifth and sixth course and a demifilè wound gut string for the fourth course: however, for this course one could experiment with a silk-type string on silk core, which, however, so far has not been found in the records of the 18th century.

Conclusions

Although some 18th century mandolin methods have survived, when it comes to understanding what kind of strings to use, we have only two available sources: Fouchetti and Corrette.

The data provided by Fouchetti for 4-course double-strung mandolins are technically and acoustically consistent: they give a set-up whose tension value is within a range of acceptability and homogeneity between the various strings. The strings of the four courses are from the technological and acoustic vision point, close to perfection considering what was available at that time. Unfortunately, Fouchetti says nothing about the 6-course mandolin.

The description provided by Corrette, however, is incomplete and sometimes confusing: it is not possible to directly extract anything usable unless you go through a critical re-elaboration of the data provided as we have done here. If we see how much he wrote in comparison with Fouchetti (in some ways there are interesting overlaps), it is always necessary to take in account what could or could not be done at the time (in short the technical limits and materials available), then it is possible to formulate a concrete proposal even for the 6-course mandolin.

For the 4-course mandolin Fouchetti's data is validated only partially by Corrette (in respect of the the gauge 5 wire for the second course, for example).

For the 6-course mandolin, as we have seen, we can refer only to Corrette: I believe that our process of reasoning and evaluation is interesting not only from the acoustic point of view but also from the point of view of the times available materials.

However, we have a last consideration: Corrette does not clarify whether the 6-course mandolin should be played with the plectrum or with fingers, like the lute. One would point out that from the tension values we calculated you could have considerable difficulty playing a 6-course mandolin directly with the fingers. As an example, the tension range currently accepted on the lute today (which is a much larger instrument) is between 2.7 to 3.3 kg.

The rules of the time are clear and repeated several times in historical documents: big lutes have fatter strings, small lutes have thinner strings (i.e. with reduced tensions): a mandolin played with fingers and not with a plectrum with a vibrating length of only 31.5 cm giving a tactile feel of tension similar to the lute should therefore have in proportion a fairly low tension, say around 2.0 Kg. This would involve, however, a gut string for the first course of .31-.33 mm gauge only: this is not physically possible. In fact, the thinnest, unpolished gauge that comes out from a single lamb gut of a few months old—as indicated by ancient sources—is about .40-.46 mm in diameter and produces a higher working tension than those of 2.0 Kg before indicated.

One possible solution (the only that can work out, in my opinion) is that the 6-course mandolin with glued bridge may have been played exclusively with nails. Such a solution would have enabled it to work easily without the plectrum (the nail itself can acts close to a plectrum), with clear and crystal sound and even under considerable working tensions (like in use on the modern classical/flamenco guitars that cannot be used without nails), otherwise objectively it is difficult to play only with the fingertips. It is historically known that among the 18th-century mandolinists there are also many theorbo and archlute players who used the nails of their right hand, such as Filippo da Casa. Hard to cut them off just to play the mandolin while they are, at the same time, playing also the theorbo.

I pass that question on to all the similar mandolin players: nevertheless these are the calculations and the results that emerged.

Vivi felice!

NOTES

1. Djilda Abbott, Ephraim Segerman: 'Strings in the 16th and 17th centuries', *The Galpin Society journal,* XXVII (1974), pp. 48-73.

2. The values obtained in this example are the ones specifically made using the manufacturer technology for trebles, which is used to obtain the maximum tensile strength (and all 'surface abrasion), as we will see better later on. In other words, in their manufacturing process elasticity is not consider (factor that can be overlooked for these thin strings), factor that is on the contrary consider for all the other kind of that are not used on the first spot: for these strings we only want to achieve the maximum elasticity possible. Elasticity and tensile strength are inversely proportional.

3. To make things easier we decide to use a standard frequency value. The French reference pitch according to the existing studies was included between 385 and 400 Hz. See: Alexander J. Ellis in *Studies in the History of Music Pitch: Monographs by Alexander J. Ellis and Arthur Mendel* (Amsterdam: Frits Knuf, 1968; New York: Da Capo Press); Arthur Mendel: 'Pitch in western music since 1500: a re-examination' *Acta musicologica*- L (1978), pp. 1-93; Ephraim Segerman: 'On German Italian and French pitch standards in the 17th and 18th centuries', *FOMRHI quarterly* no. 30, (January 1983), comm.442.

4. Ephraim Segerman: comm 1545 in *FOMRHI Quarterly* 89, (October 1997).

5. Ephraim Segerman: comm 1593 in *FOMRHI Quarterly* 92, (July 1998).

6. Daniello Bartoli: '*Del suono, de' tremori armonici e dell'udito', a spese di Nicolò Angelo Tinassi,* (Roma 1679), p. 263.

7. Metal strings worked near to their breaking point; see: William R. Thomas and J. J. K. Rhodes: 'The string scales of Italian keyboard instruments', *The Galpin Society Journal* XX (1967), p.48; Michael Spencer: 'Harpsicord physics', *The Galpin Society Journal*, XXXIV, (March 1981), pp. 3-7, Ephraim Segerman: 'Bulletin Supplement', *FOMRHI quarterly* no. 39, April 1985, p.11; 1768—Adlung's statement: 'When a harpsicord is strung so that the pitch can be safely raised a semitone, one can be secure . . .'.

8. Marin Mersenne: *Harmonie Universelle* (1636, Livre Troisiesme), Proposition XII e Proposition XIII, see note no.7 p. 58.

9. Ephraim Segerman: 'New Grove DOMI: ES Mo 4: Ca to Ci entries'. *FOMRHI quarterly* no. 43, (April 1986), comm. 698. Also Harvey Hope: 'Ref J. M. S. remarks on the New Grove Chitarra battente', *FOMRHI quarterly* no.43, (April 1986), comm. 709; Peter S. Forrester: 'Citterns and chitarras battente: re. Comm.698, Grove Review'. *FOMRHI quarterly* no. 44, July 1986, comm. 740; Ephraim Segerman: 'Response to Comms 739 and 740', *FOMRHI quarterly* no.44, July 1986, comm. 742; Peter S. Forrester: '17th c. Guitar woodwork'. *FOMRHI quarterly* no. 48, July 1986, comm. 825; James Tyler: *The Early Guitar—A History and Handbook*; Early Music series: 4, (Oxford University Press, London, 1980). Quoted By by Ciro Caliendo: *La Chitarra battente.*

Uomini, storia e costruzione di uno strumento barocco e popolare (Edizioni Aspasia, Aprile 1998), pp. 24–25.

10. Cary Karp: 'Strings, twisted and Mersenne', *FOMRHI quarterly* no. 12, (July 1978), comm.137; Ephraim Segerman & Djilda Abott: 'On twisted metal strings and Mersenne's string data', *FOMRHI quarterly* no.13 (October 1978), comm. 164. See further Cary Karp: 'On Mersenne's twisted data and metal strings', *FOMRHI quarterly* no. 14, (January 1979), comm. 183; Ephraim Segerman: 'Mersenne untwisted-a counter-Carp to comm.183', *FOMRHI quarterly* no.15 (April 1979), comm. 199.

11. Cary Karp: *The pitches of 18th Century strung Keyboard Instruments, with Particular Reference to swedish Material*, SMS-Musikmuseet Technical Report no. 1 (SMS-Musikmuseet, Box 16326, 103 26 Stockholm, Sweden, 1984), 129 pp. See also: 'On wire-comms and wire-comm comments', *FOMRHI quarterly* no. 11 (April 1978), comm. 134; Karp wrote that 'In as much as the lower portion of this range was generated by piano wire . . .'.

12. Remy Gug: 'About old music wire'. *FOMRHI quarterly* no. 10, (January 1978), comm.105. Gug wrote that 'Let us first specify that the concerned strings have been taken from instruments used in the XVIIth and XVIIIth centuries: harpsicords, spinets, clavichords, dulcimers'.

13. Marco Tiella: *Problemi connessi con il restauro degli strumenti musicali*, pp. 22-23.

14. See note no. 10.

15. Ephraim Segerman: 'Neapolitans mandolins, wire strengths and violin stringing in late 18th c. France', *FOMRHI quarterly* no.43, April 1986, comm. 713, the first modern paper on the subject, as far as Segerman himself knew.

16. Gianni Podda: 'Prove di trazione e determinazione della tensione di rottura per corde antiche e moderne', pp. 36-38, *Atti del seminario per la didattica del restauro liutaio* (estate musicale 1981; Premeno).

17. Remy Gug: 'Jobst Meuler or the secret of a Nuremberg wire drawer', *FOMRHI quarterly* no.51, (April 1988), comm. 866, p. 29.

18. Giovanni Fouchetti: *Méthode pour apprendre facilement á jouer de la mandoline á 4 et á 6 cordes* (Paris 1771, reprint: Minkoff, Genève, 1983), p. 5.

19. Michel Corrette: *Nouvelle Méthode pour apprendre à jouer en très peu de temps la Mandoline par Mr. Corrette* (Paris, 1772).

20. Op. cit. 17.

21. Francois de Lalande, *Voyage en Italie […] fait dans les annés 1765 & 1766, 2a edizione,* vol IX, (Desaint, Paris, 1786), pp. 514-9, Chapire XXII 'Du travail des Cordes à boyaux . . .' : '. . . on ne met que deux boyaux ensemble pour les petites cordes de mandolines, trois pour la premiere corde de violon . . .'.

22. Mimmo Peruffo: 'Italian violin strings in the eighteenth and nineteenth centuries: typologies, manufacturing techniques and principles of stringing', *Recercare*, IX, (1997) pp. 155-203. See also

Antoine Germain Labarraque: *L'art du boyaudier* (Imprimerie de Madame Huzard, Paris 1812), pp. 31-2.

23. Patrizio Barbieri: 'Giordano Riccati on the diameters of strings and pipers', *The Galpin Society Journal*, XXXVIII, 1985, pp. 20–34: 'Colle bilancette dell'oro pesai tre porzioni egualmente lunghe piedi 1 _ Veneziani delle tre corde del Violino, che si chiamano il tenore, il canto e il cantino. Tralasciai d'indagare il peso della corda più grave; perchè questa non è come l'altre di sola minugia, ma suole circondarsi con un sottil filo di rame.'.

24. Ephraim Segerman: 'Strings thorough the ages', *The Strad*, part 1, (January 1988), pp. 20–34, pp. 52–5, part 2 ('Highly strung'), March 1988, pp. 195-201, part 3; 'Deep tensions', (April 1988), pp. 295-9.

25 Cryseul, Géoffrion: *Moyen De Diviser Les Touches Des Instruments à Cordes, Le Plus Correctement Possible . . . On y Voit La Manière Dont Les Artistes Doivent Considérer Les Loix Qu'Impose Le Tempérment . . . Et L'on Imagine Un Moyen D'Accorder Les Clavessins* (Paris: Rodez, 1780).

26. http://harps.braybaroque.ie/Taskin_stringing3.htm. On this website you can find interesting comparisons between the Cryseul gauges scale and its relative mm gauges based on numeours scholars' opinions.

27. Don Juan Guerrero: *Methode pour Aprendre a Jouer de la Guitarre* (Paris 1760).

28. Patrizia Frisoli, 'The Museo Stradivariano in Cremona', *The Galpin Society Journal*, XXIV, (July 1971) p. 40.

29. Patrizio Barbieri, op. cit. 21.

30. De Lalande: op. cit. 19.

31. Philippe Savaresse: 'Cordes pour tous les instruments de musique', in Charles P.-L.aboulaye: *Dictionnaire des arts et manufactures*, vol. I, (3rd edn., Lacroix, Paris, 1865).

32. George Hart, *The violin and its music* (Dulau and Schott, London 1881), pp. 46-7. Michel Corrette, *Les Dons d'Apollon*, (Paris, 1763), p. 22, Capitolo XVI.

33. Attanasius Kircher, *Musurgia Universalis sive Ars Magna Consoni et Dissoni in X. Libros Digesta,* (Roma, 1650), Caput II, p. 476: '. . . ita hic Romae gravissimam tesdudinis chordam ex 9 intestinis consiciunt, secundam ex 8, & sic usque ad ultimam, & minimam, quae ex uon intestino constat.'.

34. Michel Corrette, *Les Dons d'Apollon*, ibid.

35. Sebastien de Brossard: [*Fragments d'une méthode de violon*], manuscript, *c.*1712, Paris, Bibliothèque Nationale, Rés. Vm8 c.i, f. 12^{r}, cited in Barbieri: 'Giordano Riccati', p. 34.

36. Jean-Benjamin de Laborde, *Essai sur la musique ancienne et moderne*, (Eugène Onfroy, Paris 1780), livre second, 'Des instruments', pp. 358-9: 'Violon [. . .] Ordinairement la troisième et la quatrième sont filées; quelque fois la troisième ne l'est pas' (Violon [. . .])

37. The thinnest Creyseul gauges scale is no. 12, equal to almost 0.15 mm.

38. James Grassimeau, *A musical Dictionary*, (London 1740). In this dictionary it is clearly written that with the current metallurgical technology only gold, silver, brass and iron wires can be made, including gauges between 1/100 inch: 0,50-0,25 mm. This book is a translation of the Sébastien de Brossard 1703 dictionary.

39. Marco Tiella, personal communication, the thinnest diameter found by him in some spinets were around gauge 0.15 mm

40. The clothes of those times could represent an unexplored field of study in metal wire technology: round section metal wires were widely used to make complex mediaeval and renaissance clothing decoration. From first examinations of round and flat wire sections it turned out that the thinnest gold gauges (the more malleable metal) of those times clothes were around 1/100 to 1/120 inch maximum. This means .12 mm after stretching an intact wire can reach easily .14-.15 mm gauge.