6 AND 4 COURSES XVIII CENTURY MANDOLIN SETUP: A FEW CONSIDERATIONS

by Mimmo Peruffo

Introduction

When faced with the problem of what kind of strings were used on the 18th century Mandolins of six and four courses, the first thing that stands out is the great heterogeneity of these set up. What is really hard to understand is particularly on the 4 course Neapolitan Mandolin: here we find together gut strings; single and twisted metal wires; wound strings on gut/silk. To complete the already heterogeneous picture, for the 4th course there are also two choices between unison and octave.

Here is the first question: why was it used a gut 1st and not a metal wire like the other courses, when it was then in use in the 1st half of the nineteenth century?
This question is logic: 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.

The strings and their characteristics

Musical strings follow the rules that are summarized in the string equations of Tylor-Mersenne or even called 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 thing 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 certain gauge, the string has clearly lost most of its performances. 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 manufacturers of plucked, bowed and keyboard instruments had to deal with. (1)

The 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 Module, also produces an unwanted sharper frequency when pushed on the frets; this phenomenon is particularly noticeable on short vibrating length instruments ('pitch distortion').

The best solutions, in order to keep the Inharmonicity confined and the string sounding still 'good', is to limit the diameter increase by mean of some solutions (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) Increasing of the vibrating string length

However, there are other implementable actions:

3) Increase the elasticity of the string (does not affect the diameter reduction)

4) Increase the density of the string (affects the diameter reduction)

Point 1 is an exclusive decision of the player: according to the ancients the right string tension (better to call it 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 control by the performer.

Point 2 depends only by the luthier. This solution was adopted from the far past for the Arps, but latter also for the keyboards, theorboes/archlutes etc, were the vibrating string length increase, step by step, towards the bottom strings making them, step by step, thinner (proceeding in this way, the Inharmonicity is under control)

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

At the end of the day, the point where a luthier can act is only No. 2, where vibrating length and diameter are inversely proportional (we consider that the performer has already done its job on the choice of the right feel of tension)
In the sixteen, seventieth and (maybe) the first half of the eighteenth century, the problem of string Inharmonicity was a well-known thing for 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 first note and the hypothetic standard pitch: in practice we are speaking of the well knows rule of those times to tune the first string to the most acute possible just before the breakage.

In order to optimize the sound performance of a musical instrument it was therefore followed by the luthiers the rule of using the maximum vibrating length possible for that given treble note *indicated by the customer* (in other words, in which Country and its related pitch standard the instrument must be then employed) : only in that way all the strings could 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 1st string: there is a limit that we call **Superior limit**
At the same time, it is not possible to increase the amount of bass strings (i.e. increasing of the open range) because there is another boundary called **Inferior limit**.
In other words, the full open range of a musical instrument is enclosed within these two borders.

The so-called Inferior limit however, using pure gut strings, begins to heavily manifest when the frequency range between the 1st string and the last reach, more or less, two octaves. Only the six course Mandolin, on the two models, comes to this range. Generally speaking, the problem was, however, partially solved after the 2nd mid 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 the bass wound strings in the 2nd half of the 17th century. In 2nd half of the 18th century, the wound strings were probably totally in use.

The Superior 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 meter is of 260 Hz (actually, after several tests, I have found that the whole range is of 250-280 Hz), which is a slightly low C.
The value of such a limit frequency, known as 'Breaking Frequency', is completely independent - as strange as it may seem - from the diameter and this can easily be verified both by mathematics (applying the general formula of the 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 between the vibrating length (in m) and the Breaking Frequency (in Hz) is a constant defined as '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 mm2 (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/mm2. In other terms, a string of 1.18 mm gauge, 1,3 of density, 1.0 mt scale at 34 Kg of breaking tension will reach the 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 mm2, 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 in opposition to what has been just explained; *it is the frequency of the 1st string the first parameter to be fixed when designing a musical instrument* such as the Mandolin, Lute, etc etc.
By dividing the Breaking Index for the desired 1st string's 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 meters).

In the case of a six courses Mandolin whose first string is a G: 698.5 Hz (18th-century French chorus of 392 Hz) (3) it obtains: 260/698.5 = .37 m

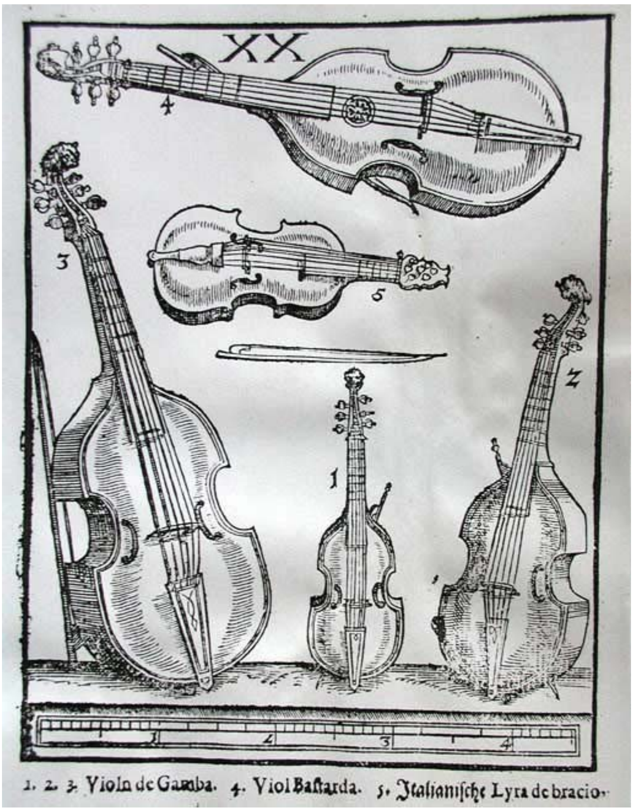
This is therefore the vibrating limit length where we know that the string will break reaching the G (here we are referring to the ancient French pitch standard of 392 Hz).

The choice of vibrating 'working' length should therefore consider *a prudential shortening* of this limit length.
But how much? The more is shortened, more the strings are thicker 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 Music, 1619) made possible to calculate their Working Index and put them in correlation to the gut breaking index. This allowed to understand the security margin adopted in those times (4) (5)

However, in the various calculations was (unfortunately) Ephraim Segerman taken as reference the average breaking load value -or Breaking Point- of a modern gut string *found in literature*: 32Kg mm2 (which is equivalent to a breaking index of 240 Hz/m) that is, actually, too low then the reality.

So, this value ca be placed on '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).



Drawing from 'Syntagma Music' Michael Praetorius 1619

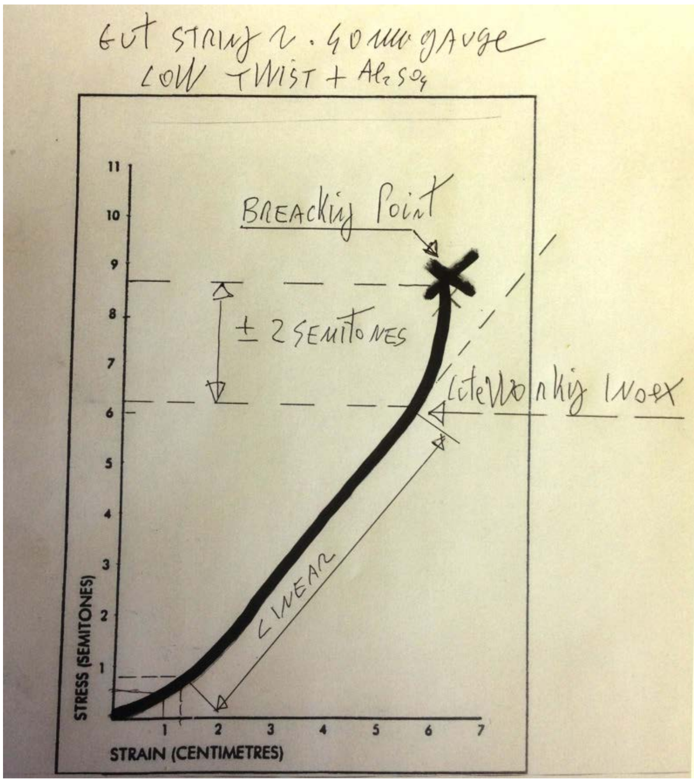
However, comparing the breaking index of 240 Hz/m with all the other Working Index, he found that the choice of the vibrating working length of the Lute family and some Gambas (Viola Bastarda for example) was about 2-3 semitones below the Breaking Index (and hence also of the theoretical vibrating length that we calculated before).

Considering our example, therefore, the length shortening of 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 included into the measures that are actually found in the six courses Mandolins of the time.

However, there is a 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).

Examining the final Stress/Strain diagram, the initial proportional variation that comes out follows the law of Hook and emerge evidently (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 small peg's turns imposed to the string:



The string therefore maintains its linearity till about 2-3 semitones from the Breaking Point; beyond this value, it enters the critical phase. This does not follow the phenomenon of the typical yeld 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 start to bent up to reach the 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 proportionality, just before it changes, and this is exactly two to three semitones from the final exitus, as shows in the graphic.

Such 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 / construction of musical instruments.

For Example, Marin Mersenne was avare 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 chaque 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 chaque 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 forces eſgales, car les dernieres ſont quaſi touſiours plus grandes que les premieres. 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 poulces 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 tenduë 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.

Here there is what Bartoli wrote by the end of XVII 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, quanto 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 ſtrapparſi, è l'eſtremo dello ſtiramento, adunque non ſi viene ad eſſo, mentre la corda, coll'allungarſi puo non iſtrapparſi. Che poi ſi habbia a ſtrappare quando non ſi puo piu allungare, mel perſuade il diſcorrer così. Poniamo, che la graueza 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*.

On the other hand, it is well-known to everybody the rule of those times of tuning the lute and even some bowed instruments at the highest note and stop immediately before the breakage of the first string: this is the ultimate proof of what we have already showed graphically.

The Lute example

The vibrating lengths that were chosen for some of the old, surviving Lutes of the past sum up valuable information.

The main problem is that in order to make an evaluation you have to use not modified instruments and instruments, whose standard pitches can be determined with a relative certainty. This is the case of some unmodified renaissance venetian lutes, German d minor baroque lutes, French baroque guitars.

Starting from an highly supposed standard pitch (thanks to their origins) and from what emerged in the study of their vibrating string lengths, the research on the various 5 course French guitars (at the 17th French pitch standard close to 390 Hz) as well the german 13 course d minor Lutes tuned at the Kamerton of 410-420 Hz (see Baron 1727: Kammerton f note for the 1^{st})) and finally including even some surviving renaissance venetian lutes whose scale is of 56-58 cms probably related related to venetian standard pitch of *mezzo punto* = 460 Kz more or less, has allowed to detect a range of Working Index within 225 and 235 Hz/m with an average of 230 Hz/mt: this can be considered the Lute Working Index of the past times (theorboes generally speaking works with a bit more safety; Some Magno Graill or Buechenberg large theorbo has the vibrating string lengths around 95 cms; at the Roman pitch standard of 390 Hz/m, the related working Index range is of 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 present a safety margin of two or three semitones from the Breaking Point (how we have seen in our Stress/Strain graphic), it is even therefore possible to estimate the average Breaking Point -in Kg- of the Lute 1st strings of those centuries. This can be obtained by increasing the working index that we have deducted 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 16, 17 and 18th century would be between 33.7-35.1 Kg/mm2 (that correspond to 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.
How we can see, he range of all these values is perfectly in line with that of the current treble Lute gut strings of .36-.46 mm gauge (34-38 Kg / mm2).

Going back to the six-courses Mandolin with a 1st string = G, a prudential shortening of two semitones on the average value of the Breaking Index of 260 Hz/m determines a vibrating length of 32.9 cms; it will be 31.1 cms if we are considering three semitones down of a safety margin: these are the typical vibrating lengths found in the surviving instruments.

The range of Working Index (the product between the frequency of the first-string x vibrating length in meters) is as follows:

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

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 & 5 course Guitars only if the safety margin is two semitones whose pitch standard is of 415 Hz.

In the case of the 4 course Neapolitan Mandolin with a vibrating length of 33 cm (the one typical of the Violin) the following is obtained:

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

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

The conclusion is that both these Working Index are included within the Breaking Index of the gut treble, the 6-courses mandolin in particular works exactly like a Lute while the 4-courses Neapolitan has a lower tension condition on the first string, just like for Violin. The plausible explanation is as follows: while in the 6-courses mandolin the frequency excursion between the

first and the last string is two octaves (24 semitones), in the 4 courses this excursion is reduced to 18 semitones. Consequently, in the second case, it is not strictly necessary for the strings working at the highest possible acoustic performance) i.e. close to the Breaking Point like happens on those instruments that has an open range of two full octaves like the Lute, in order to preserve the acoustic performance of the bottom strings.
However, the starting point is still unsolved: why was not used a metal treble whose sound would be much brighter and more readily available, would have had less wear and tear and even a higher breaking load than the gut? (7)

The breaking load stress of a XVIII century Iron for the Harpsichord can reach up to 100 Kg / mm2. For the old Brass this value is lower but always much higher than the average breaking load stress of the 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 gr / cm3 for iron, 8.5 gr / cm3 for Brass; 1.3g / cm3 only for gut.

From simple calculations, taking into account both the ancient pieces of wire for keyboard instruments discussed on some essays of those times, we can list a series of Breaking Index:

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/mm2 for example (which is one of the higher values found among the absolute values of old strings for keyboards pieces), however, has a breaking index of just 178 Hz/m.

This clearly explains why the Battente guitar, fitted with robust metal strings, instead, have a vibrant length limited to only 55-58 cm, while those with the least strong gut strings can reach 68-73 cm (with the same reference chorus). (9)

There has been found a lot of metal strings breaking load stress of the past (10)
Here are some breaking indices found in old metal strings of Spinetta or Harpsichord:

'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; media 125 Hz/m. (14)
'Old' brass: 101-155 Hz/m; media 128 Hz/m. (15)
'Old' brass: 148-153 Hz/m; media 150 Hz/m. (16)

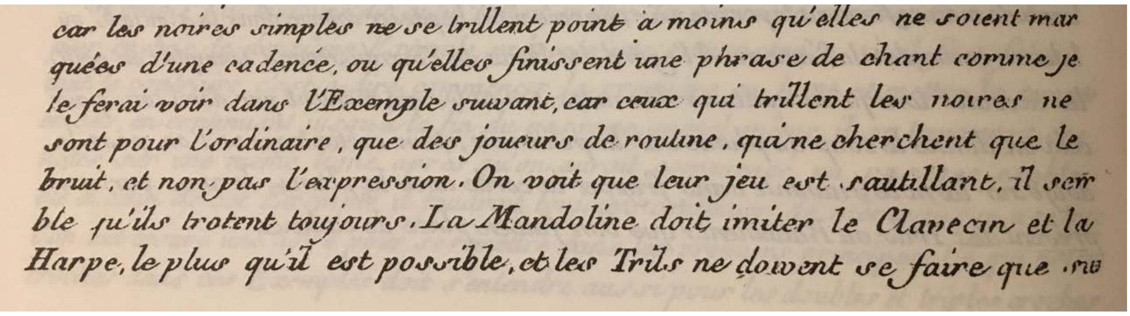
It can be easily noticed that the difference between Mersenne data and the average measured values is not particularly relevant.
The reason why the Mandolins used the gut for the highest string is therefore clear: they did not have pure metals and/or metal alloys that could reach a breaking index similar to gut (260-280 Hz/m). Considering the Iron (the metal with the highest breaking index) this would correspond to a breaking load of 145-160 Kg / mm2.
The evidence of the use of gut trebles on the Mandolin is a clear demonstration that strong metal strings were not available, in the course of the XVIII century and even for the first decades of the XIX. A metallic wire with these values would have been employed immediately, as it actually happened between the 16th and 17th centuries and after the 1830. (17)
The Mandolin was therefore inevitably forced to use gut string for the 1st course due to lack of alternatives.

Historical sources

There are few historical sources of XVIII century containing information regarding the string setups of 4 or 6 courses Mandolin; 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 deducted:

Fouchetti
What Fouchetti wrote about the 4-courses Neapolitan mandolin setup, generally speaking, is considered unreliable, if not quite imaginative. 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.
In fact we find, mix together in a just four courses set, gut string, brass wires, twisted brass wires, wound gut/silk strings.

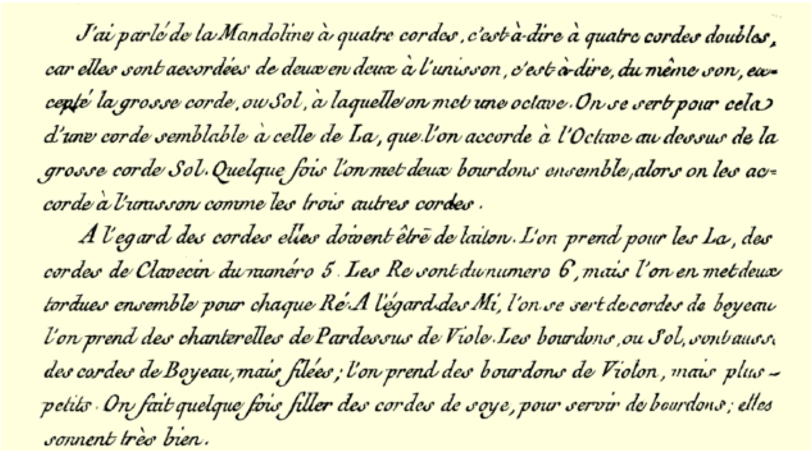
Indeed, this degree of heterogeneity is absolutely amazing. By looking more closely and by making some calculations, we realize that this set include in itself almost the utmost perfection possible for that time both from the mechanical point of view and from the acoustic point of view with very few other possibilities of choice, if we consider what was available in those times, to make strings.
Let's see why (keeping in mind that the most wanted feature for this instrument was the brightness and the promptness of emission, 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, qui 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

Vibrating lengths: the used sizes confirms with clear evidence, especially on the 6 course Mandolins, that we are considering an instrument that, like the Lute, had the maximum vibrating length in order to ensure the best acoustic performance.
Here is the set for the Neapolitan 4 courses Mandolin (Fouchetti says nothing about the 6 courses one):

1. use 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 octave pair you can use a 5-gauge yellow brass like those of the second course. Sometimes the fourth course are installed 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 an 1st 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 1st of three. There are numerous researches (22) (23) (24) that associate three whole lamb-guts with a gauge of .68 to .73 mm.
For simple proportions, the Mandolin/Pardesssus 1st 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 breaking. 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 higher specific weight of iron, is brighter: this fit quite well with the criteria of those time were Mandolin should imitate the sound of the harpsicord.
According to the Cryseul gauges scale, (25) the gauge 5 corresponds to a diameter of about 0.30 mm. (26)
The yellow brass has a specific weight around 8.5 gr/cm3 (red brass: around 8.7 gr/cm3).

Third string
Fouchetti says to take two yellow brass harpsichord of gauge 6 and twisted together. The purpose is clear: the strings twisted together become more elastic, so they minimizing the 'pitch distortion' effect on the frets which with a simple single wire would be absolutely evident even for small pressure variations and / or lateral displacements on the string. With a single metal wire, it would also have a considerable difficulty in tuning and keeping it stable over time because even an imperceptible rotation of the tune peg would produce significant variations. By twisting two wires together, the problems listed above are solved; the use of the brass still guarantees the best acoustic performance in terms of tonal brightness and emission power even though it is still a little lower and 'round' than those of 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 twisting degree and the yellow brass behaviours, as Fouchetti says nothing about it.

We can find a solution by realizing 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.
We thus found that two .30 mm brass strings twisted together with a low twisting produced a final 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 D note of 262 Hz (Parisian pitch standard of 392 Hz) is around 3.4 Kg.

Fourth string
For the fourth string it was used a Violin G wound string, but a bit thin than the ordinary (in those times they were done using a average second violin strings as core: we have employed a thin second one) Considering a gut core wound string, it is evident that you lose the characteristic brightness manifested by the three most acute 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. In this course was also made the arrangement in unison but Fouchetti tells us that it seldom used.
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 the six-courses guitar of the nineteenth century. By use of silk core the sound became even a bit 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 made a wound Violin G strings in those times?
Some sources of those times wrote that a second string of the 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 of a string like this, in order to ensure the balanced setup (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 ordinary, but how much? We should calculate its equivalent gut having the Mandolin scale, the supposed pitch standard and the gauges of all the other strings (and so, by calculation, the related working tensions)

Here is in practice: having as vibrating 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 pitch standard of 392 Hz.

1: 5.44 Kg (average tension value between .56-.59 mm diameter = .575 mm)

2: 5.3 Kg (gauge 5 = .34 mm)

3: 3.4 Kg (two gauge 6 low twist = .30 mm)

4: octave: 4.46 Kg (.34 mm)
4: wound bass: the tension should be the same of the paired octave string: 4.46 Kg

Remarks
1) at 'Parisian' 392 Hz pitch standard, the working index of the yellow brass wire for the octave of the 4th string is about 115 Hz/m (122 Hz/m at 415 Hz): a yellow Brass wire can therefore be safely used.

2) The setting presents a scaled tension profile which probably leads to a situation of equal tactile feel if it wasn't for the third chorus abnormal tension which is quite low. In reality, it is possible to balance the situation if we consider a thinner gauge for the first string realized however always from two guts.
3) Then, in order to have the same working tension of 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 that tends to be in the range of the generally definable light tensions.

Conclusion
The setup described by Fouchetti presents almost perfect coherence on the 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 emission and brightness.
It should be noted, however, that there were not many alternatives: the first string had to be gut, while the fourth had to be a wound gut/silk core string. Most likely, in the second and third courses, iron wires for Harpsichord could be used but this would be at the expense of the brightness (however, it is not expected that wires of this material providing the same working tension of gauge 5 and 6 Yellow brass would 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 wire Brass, but here too, there would have been a loss of brightness, a factor which is emphasized by Fouchetti, who points out, as already said, that the Mandolin must imitate the harpsichord and harp.

Corrette

By examining the method of Corrette, the first evident thing is that he does not seem to make any novelty as described by Fouchetti for the 4 course mandolin tuned in fifths.
In fact, there are substantial differences and, in our opinion, several errors:

1 course called F: it must be a five courses guitar first string

2 course called G: must be a harpsichord gauge 5
3 course called H and R: R must be a demi file: H says nothing.
4 octave, course called K and I: I is a full yarn, nothing regards the K

1) The first gut string is not a treble of Pardessus as for Fouchetti but a 1st string for the 5 course Guitar: what diameter could it be?
So, let's focus on solving this problem: we need to know if there are direct references to the number of strips and Guitar strings or at least an indirect reference to another musical instrument.
It is noted that at the moment we have unfortunately 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 five-string course guitar with five single drone (bordone) added in its length (extended neck)

- First and second string (first course): "*Questi deve essere compani due cantini di chitara*". ("This must be a couple of two guitar 1st string)
- Third and fourth strings (second course): "*Queste deve essere compane due sotanelle di chitara*". (These must be two guitar 2nd)
- Fifth and sixth string (third course): "*Queste deve essere compane doi cantini da violino grossi*". (These must be a couple of thick violin 1st string.)

Etc etc. (28)

To solve this problem then we need to know which was the Violin average diameter of those times and what could be called a 'thick' treble.
Count Riccati (who was, in addition to a great physicist, a discreet violinist amateur friend of Tartini) around 1740/50 made some interesting measurements on the strings of his Violin: from his calculations we get the size of the treble installed on his Violin: about .70 mm (29)
This estimation is indirectly confirmed by the data provided by the French traveler and astronomer De Lalande -1760 ca. - (30), about the pieces of gut used to make mandolin, violin and double bass string from the famous Abruzzi string - operating in Naples - Domenico Antonio Angelucci and that these proportions have 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 Mi and La gauge made from the same number of guts as George Hart suggests. (32) Considering the standardization in the manufacturing

process of Violin strings it is then possible to assume that a "thick" three-row guts could be around .73-.74 mm.
Since the third course of this guitar used a violin gut (at the time realized with three guts called "wires") using simple proportions - maintaining a constant tension - the second course had to consist of two-wire (such as treble of the Mandolin and 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 wires used; but then we have to deal with the tactile feel of tension that must be homogeneous: two gut wires therefore produce a diameter between .57 and .59 mm

Since with three gut string were obtained an average diameter around 0.70 mm (here we refer expressly to a 'big' treble, for example .73 mm, which is consider 'thick' by George Hart), considering a set up with the same feel of the Guitar (which, however, leads to a tension of Kg of a scaled profile, conditioning the choice of its gauges), this is what we obtained:

1st course: ~ .44-46 mm (made by a single whole gut).

2nd course: ~ .57-59 mm (made by two piece of gut).

3rd course: ~ .73 mm (tick violin treble: made of three guts). Etc etc.

a) Corrette :

"*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 himself confirms what was written in the Stradivarian repertoire.
Now that we have a more precise idea of a 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 1st 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 *a even feel of tension* between the strings, the 1st then, according to what the author wrote, has to be of about .44 to .46 mm gauge.

b) Second string: the harpsichord's gauge 5 is used. Corrette though does not specify the type of metal; however, the analogy with Fouchetti is consistent this is why we think that he's talking about yellow brass.

c) Third string: Corrette oddly seems to consider each as single string despite on the pentagram you can see that they are unison. Of one, called H, nothing is said of the other, called R, it is written that it is a *demifilé* without adding any extra consideration: unfortunately, from this statement it is not possible to get anything concrete; we do not know if the strings were both *demifilé* and there are not any indications on how to make it.

d) Fourth string: Corrette says nothing about the octave named K. The bass string called C description is limited to the fact that is a wound string. However, we do not know which core to use (silk or gut).

Any way thanks to Fouchetti we know that both the materials were suitable therefore we might guess that, again, it's a Violin G.

Considerations

The indications given by Corrette about the 4 course Mandolin are, according to the writer, totally unreliable.

- First course (.44-.46 mm approximately): it would have a working tension of only 3.0-3.2 Kg per string.

-Second course (presumably yellow brass gauge 5, but nothing is specified): it rises to at least 5.3 Kg per string. The gap with the first course is remarkable.
To have a working tension comparable to the second course, the first should use the second-string guitar strings (2 gut = first Mandolin = first Pardessus according to De Lalande) aligning with the Fouchetti.

-Third and fourth chorus: nothing useful can be obtained. If it were not for Fouchetti (which gives a useful comparison) the data provided by Correct would be completely meaningless

Six courses Mandolin

With the problems already encountered on the 4-string mandolin tuned in fifths, we still inevitably expect issues. In fact, different indications are unfortunately incorrect: some reasoning is needed. Only at the end of this review work the mandolin's six courses become really doable.

a) First and Second course: Corrette write that the courses called L and M must be Guitar trebles: what does it mean? That he used the guitar treble also for the second course of the Mandolin? Corrette here is very inaccurate. Certainly, they cannot be trebles installed on the second course: there would be a total misalignment in the working tension. We therefore feel that Corrette refers to the first and second course of the Guitar.

b) The third course called N: Corrette says to use Harpsichord Gauge 5 but omits to specify the type of metal: however, we think it is the usual Yellow Brass for Harpsichord.

c) Fourth course called S: Correct says that this is a demi file string but does not add anything else (silk or gut core? Corrette says nothing in matter)

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

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

Considerations
Based on the data provided by Corrette, no one today (but also in his time!) is able to draw the entire strings set up; however, it is possible to introduce some reasoning that eventually might solve the enigma:

Let's start from the only certain data available: the third A note's course, which correspond to the harpsichord gauge 5. We believe it is of yellow brass (.34 mm).
Using a typical six-courses mandolin average vibrating length, .315 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 installing in these two courses the first and second string of the Guitar (of which we have a more accurate idea thanks to Stradivari's Violin) 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, there is certainly a non-balanced tension trend yet still functional.
Things are much simpler with the sixth order: as it is a G we can think that can be a fourth violin string as Fouchetti model, whose octave is equal to the gut second (third of the guitar): considering this hypothesis as valid the tension of bass and its paired octave is about 3.9 kg. The paired octave may be the same yellow brass gauges 5 already used for the 3rd course: a gut string would be about .90 mm.
Obtaining 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, based on Corrette thinking you should use a demi file 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 be like this in order 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 demi. (35) (36)


Violin open wound/demifilè 3rd (France, mid-18th century)

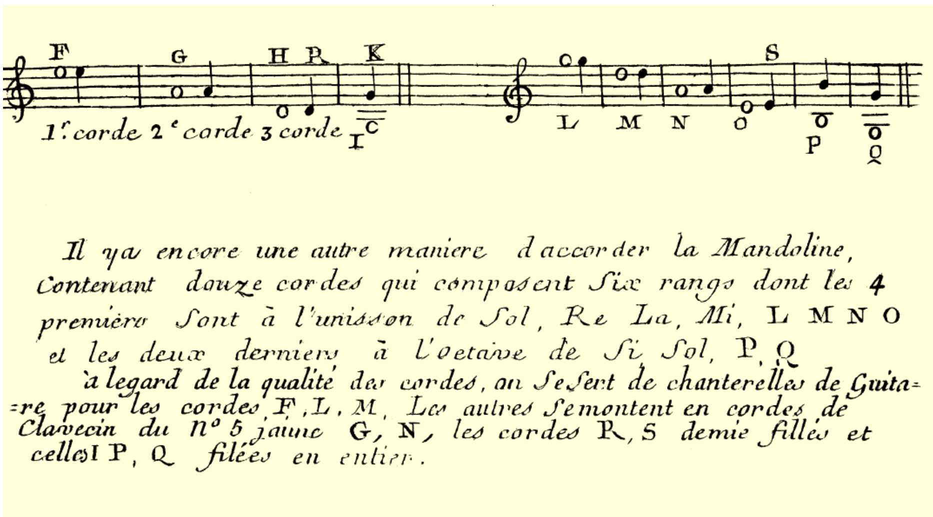
Its octave should have a diameter between .55 and .57 mm: the first string for 4 courses Mandolin/2nd Guitar course.

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) as 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 third guitar string (i.e, a 1st Violin string).
The problem is its realization, especially if you use a gut- core. During 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 had not available the suitable 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 and used to avoid the thinner metallic wires shortage problem: in fact, you can find proof in the Metallic 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 in the Mandolin and then also in the 4 &5 courses of the 5 course guitars and in the XIX-early XX c. guitars.

With the use of silk cores, compared to the gut cores, the relationship between the core and the metal can be unbalanced in favor of the metal, making it possible to have a full-wound string and 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 six-course Mandolin will then be used respectively for the fourth and fifth string of the six-single string guitar, the one that in 10-15 years will appear on the music scene.



Il ya encore une autre maniere daccorder la Mandoline, Contenant douze cordes qui composent Six rangs dont les 4 premiers Sont à l'unisson de Sol, Re La, Mi, L M N O et les deux derniers à l'octave de Si Sol, P, Q
à legard de la qualité des cordes, on Se Sert de chanterelles de Guita=re pour les cordes F, L, M, Les autres Se montent en cordes de Clavecin du n° 5 jaune G, N, les cordes R, S demie fillés et celles I P, Q filées en entier.

Concluding, even for this kind of Mandolin Corrette does not allow us to come to certain and plausible conclusion. However, we made a number of arguments that lead to the following set up proposal, based on the few information from Corrette (the only strong point is the indication that the third course uses the gauge 5, from which we can deduct the value of the tension: at this point, the highest course must have a growing tension while the bass ones a degrading tension according to a similar Fouchetti Mandolin profile) and with the support of Fouchetti:

1G: first the Five-courses Guitar = .44-.46 mm in diameter; Average tension: 4.1 Kg per string

2D: Second of the Five courses 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

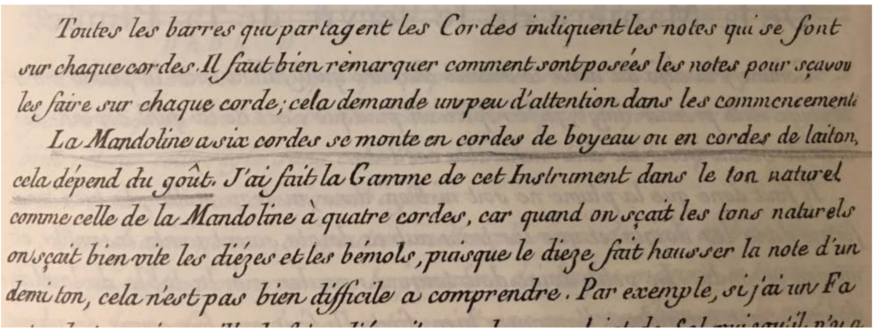
4E: demi file string (third violin according to French use) = 1.10-1.14 mm equivalent gut; Average tension: 4.0 to 4.5 Kg

5B octave: third of the five-courses guitar = .70-.73 mm in diameter; Average tension: 4.2 Kg

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

6G octave: same gauge 5 in yellow brass for harpsichord = .34 mm diameter; Average tension: 3.9 Kg (or a gut string of .88-.91 mm: practically the fourth course of the guitar).

The uncertainty of 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: q2



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 diézes 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 courses Mandolin: the Fouchetti set

- 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 emerging problem is how to tie it up to the fretboard. Being a very hard harpsichord Brass wire the problem is its fragility when bented. In our case, we solved the problem by making a very long loop so that, when put in tension, it will lock itself by eliminating any string breaking problem at the pegs due to the presence of bend points or over-sharp bumps.

Third course: we used .30 mm yellow commercial hard harpsichord brass wire. It is not possible to twist together directly the two wires, being the brass very hard, it tends to break during twisting, until it comes to different twisted degrees along the string. The solution to this problem was to soften just a bit (not totally) the two wires 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 to be bent and still retaining a residual degree of hardness that counteract the yield 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 tone output until you find an acoustic balance between the second and the fourth course.

-Fourth course: following the historical instructions we obtained a Violins wound G whose equivalent gut is of 1.80 mm (slightly lighter second Violin string covered with Silver wire): for the octave it is used a second yellow brass wire same of those of the 2nd course.

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

Six courses Mandolin according to our Corrette interpretation (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 3rd demifile strings are used: equivalent 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 a average XIX century guitar 4th 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 five courses Guitar of .73 mm (see the Stradivari's information: thick Violin 1st)

- Sixth course: the bass consists of a average XIX century guitar 5th A string wound with a silvered copper wire on silk whose equivalent gut is about 1.80 mm. The octave string is a .88 mm gut gauge equivalent to a 4th string for 5 courses guitar.

What about this setup:
There is no mechanical problem; acoustic and dynamic balance are good also in relation to the fifth course. We tested a yellow Brass wire as octaves for the 6th course resulting in a tonal disequilibrium with the other higher courses.
According to the writer, an experimental set of this type is totally satisfactory.

Critical points revolve around the use of Brass wire in the third course, due to the tonal difference with the others gut's 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 therefore is the one that uses gut strings for the first thre 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 remains open the experimentation of a silk-type string on silk core, which however so far was not 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 the first one on 4-double strings Mandolins are technically and acoustically consistent: they shape a set whose tension value is within a range of acceptability and homogeneity between the various strings. The strings of the four courses are close to, from the technological and acoustic vision point, almost perfection considering what was available at that time.
Unfortunately, Fouchetti says nothing about the 6-courses 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 critically re-elaboration of the provided data like we have done here.
So, if you see how much he wrote in comparison with Fouchetti (in some ways there are interesting overlapping), it is necessary to always taking in account what could or could not be done at the time (in short the technical limits and materials to making strings available) , then it is possible to formulate a concrete proposal even for the Six courses Mandolin.
For the 4 courses Mandolin, therefore, only the Fouchetti data is validated only partially by the Corrette one (the gauge 5 for the second course, for example).

For the six-courses Mandolin, as we have seen, we can only refer to Corrette: we believe that our elaboration is interesting not only from the acoustic point of view but also. As already said before, from the point of view of the times available materials.

However, we have a last consideration: Corrette does not clarify whether the six course Mandolin should be played with the plectrum or by fingers like the Lute. We point out that from the values of tension we calculated you could have considerable difficulty playing a six-course Mandolin directly with the fingers. As example, the tension range currently accepted in 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: longer the scale, thinner the strings (i.e. small strings on smaller Lutes): 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 inferior tension, say around 2.0 Kg. This would involve, however, in a gut string for the 1st course of .31-.33 mm gauge only: this is not possible. In fact, the thinnest, unpolished gauge that comes out from a single lamb gut of a few months of life - 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 six course Mandolin with glued bridge may have been played exclusively by mean of 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 difficult to deal only with the fingertip.

On the other hand, it is historically known that among the eighteenth-century mandolinists there are also many Theorbo and Archlutes players, who used the nails of their right hand, such as Filippo da Casa. Hard to cut them off for the chance to play the Mandolin while they are, at the same time, playing also the Theorbo.

I pass the question to all the similar Mandolin players: nevertheless this are the calculations and the result 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*". In -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 phisics*". 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.

More:

-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: "*Abut 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. This is the first Segerman known regarding Mandolin 18 Century sets.

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.
Vedere anche: 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

In this website you can find interesting comparisons between Cryseul gauges scale and tits 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. LABOULAYE: *Dictionnaire des arts et manufactures*, 3rd edition, vol. I, 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*" Paris 1763, p. 22, Capitolo XVI.

35) SEBASTIEN DE BROSSARD: [*Fragments d'une méthode de violon*], manuscript, ca. 1712, Paris, Bibliothèque Nationale, Rés. Vm8 c.i, fol. 12r (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.

On this dictionary is clearly written that with the current metallurgic technology only gold, silver, brass and iron wires included between 1/100 inch: 0,50-0,25 mm gauge can be done. This book is a translation of the Sébastien de Brossard 1703 dictionary.

39) Marco Tiella; information directly gave by the writer, the thinnest diameter found by him in some spinets were around gauge 0.15 mm

40) The clothes of those times could represent an inexplored field of study about metal wire technology: round section metal wires were used for a good part to make complex medival and renaissance clothes decoration. From first examinations of round and flat wire sections turned out that the thinnest gold gauges (the more malleable metal) of those times clothes were around 1/100 till 1/120 inch maximum. This means .12 mm after the starching; an intact wire can reach easily .14-.15 mm gauge.