STEPHEN PAULELLO

MUSIC WIRES

To make music wire means respecting the standard specifications such as tolerances of diameters, perfection of the cylinder, evenness of the drawing, corrosion resistance, resistance and suppleness in bending and crushing etc... To make music wire of higher quality means going further: looking for an excellent spectral balance, improving the coefficient of internal damping and accelerating the process of stabilization. Thanks to the care taken in the wire drawing, to the speed thereof, to the choice of the number of dies, to the adopted coefficient of reduction, to the quality of the polishing, the Stephen Paulello strings present all these requirements as well as a beautiful appearance, a remarkable sustain and an exceptional evenness in their mechanical performances.

The quality and tone of strings formerly gave rise to numerous debates between musicians, manufacturers and technicians. For decades however and due to lack of choice, piano wires have no longer been a topic of particular research in the world of piano makers and restorers.

Stephen Paulello now proposes five sorts of steel wires, in two finishes (regular polished or nickel plated) and thus reopens the debate. He demonstrates the necessity of having a choice in the manufacture or the repair of "modern" instruments and for the restoration of pianos of the past.

What are the characteristics of these various wires?

THE FIVE TYPES OF WIRE:

Ultra resistant:

- **TYPE XM**: highly impact-resistant.

Intended for pianos intensively played, of which the strings are over-stressed in the trebles or bass (to be verified with the Typogram*).
The breaking load is higher than the current standard one. It extends from 2600 to 3000 Newton by mm² according to the diameter.

POLISHED:	500g rolls: from 0,775 to 1,050 mm (13 to 18½) 2 Kg rolls: from 0,775 to 1,450 mm (13 to 24½)
NICKEL PLATED:	500g rolls: from 0,775 to 0,950 mm (13 to 16½) 2 Kg rolls: from 0,775 to 1,450 mm (13 to 24½)

Modern:

- **TYPE M**: Fine, bright treble and excellent spectral balance.

Primarily intended for pianos **from 1880 to the present day** (to be verified with the Typogram*).
The breaking load corresponds to current standard. It extends from 2200 to 2550 Newton by mm² according to the diameter.

POLISHED:	500 g and 2 kg rolls: from 0,725 to 1,600 mm (12 to 26)
NICKEL PLATED:	500g rolls: from 0,775 to 1,400 mm (13 to 24) 2Kg rolls: from 0,775 to 1,600 mm (13 to 26)

* The Typogram is an Excel program which can be downloaded free of charge on the website.

Post romantic:

- **TYPE 0** (zero): A rich and complex tone.

Primarily intended for post-romantic instruments, or in hybrid scaling for instruments that are under-stressed in the medium. You can string with type 0 in the medium combined with type M, possibly type XM, in the treble (to be verified with the Typogram*).
The breaking load extends from 1700 to 2200 Newton by mm² according to the diameter.

POLISHED:	500g and 2 kg rolls: from 0,725 to 1,600 mm (12 to 26)
NICKEL PLATED:	500g rolls: from 0,775 to 1,225 mm (13 to 22) 2Kg rolls: from 0,775 to 1,600 mm (13 to 26)

Romantic:

- **TYPE 1**: a cello tone.

Primarily intended for romantic instruments, or in hybrid scaling for instruments which are under-stressed at the "break": You can string with type 1 combined with type 0 and type M (to be verified with the Typogram*).
The breaking load extends from 1200 to 1900 Newton by mm² according to the diameter.

POLISHED:	500g rolls: from 0,575 to 1,600 mm (9 to 26) 2Kg rolls: from 0,975 to 1,250 mm (17 to 22½)
NICKEL PLATED:	500g rolls: from 1,000 to 1,350 mm (17 to 23½) 2Kg rolls: from 1,025 to 1,225 mm (18 to 22)

- **TYPE 2**: reserved for the romantic pianoforte

Primarily intended for pianoforte**:** check the relevance of the choice of type 2 thanks to the Typogram. The year of make is not a sufficient criterion.
The breaking load extends from 1000 to 1400 Newton by mm² according to the diameter.

POLISHED:	500g rolls: from 0,400 to 1,400 mm (5 to 24)

NICKEL PLATED FINISH

A protection of the steel against oxidization is necessary. That is why **types XM, M, 0 and 1** are available in nickel plated version.
An oxidized string is more difficult and sometimes impossible to tune. Its sound quality is altered, becoming acid and short. Nickel plating delays corrosion and lengthens the life of the strings. An increase in the seductive quality of the sound is also an immediately perceptible result of nickel plating.

This treatment is fundamentally different from the tin plating usually practiced. The technology applied is much longer and more complicated, which explains why these strings have not been available on the market before. The nickel coat is about 2 µ thick. It is much harder than tin so that it does not dampen the sound vibration. It is tightly bound to the steel by electrolysis which means that the nickel cannot flake off when twisting loops or during the strain of the steel while chipping or tuning.

* The Typogram is an Excel sheet which can be downloaded free of charge on the website.

How to choose?

- **According to the make, date and place of manufacture of the piano? These data are of documentary interest but far from sufficient as a guide for optimal string replacement.**

- **According to the density of the metal? This criterion is not of major importance.**
  This indication seems relevant because it enters into the calculation formula of a string's tensile strength. The density is expressed in grams / cm^3 and varies, according to the alloy, between the minimum values of 7,65 g/cm^3 for iron and maximum of 7,95 g/cm^3 for some steels. However, considering that between these extremes we obtain a discrepancy of tensile strength of only 4%, this information can be considered irrelevant.

- **According to the modulus of elasticity (or Young's modulus "E")? This is an interesting parameter.**
  The modulus of elasticity plays a very small part in the calculation of tensile strength. On the other hand, it is a major element of the calculation of the rate of inharmonicity of a vibrating string. Numerous measurements of inharmonicity made on antique stringings in excellent condition showed that the elastic properties of the various different wires examined were very similar.

- **Thanks to the stress rate? This is THE determining criterion.**

  This criterion concerns the tone and the mechanical behaviour of the string.

  The tone: it is unanimously accepted that, in order to vibrate to its full potential (that is to say with a minimum of internal amortization as well as a good spectral balance), a string should be stressed at around **50 to 75 %** of its ***practical breaking load (PBL)***, depending on the register (This notion is explained below). An under-stress (**less than 45%**) as well as an over-stress (**more than 85%**) gives bad sound results.

  The mechanical behaviour:
  It is necessary to understand the following three notions:
  - ***The nominal breaking load*** (NBL): This value corresponds to the maximal tensile strength to which a steel wire can be subjected before it breaks. The results, obtained in laboratory conditions, extends from 1000 to 3000 Newton by mm², according to the diameter and the type of steel used.
  - ***The practical breaking load*** (PBL): The phenomenon of fatigue as well as the various bends, loops and twists applied to the wire weaken the performances of the strings once set in a piano. It makes it necessary to underestimate the results of nominal breaking load (NBL) by 15 % safety margin for Type 2, and 25 % for the other types. These values are given for every type and every diameter in a following table.
  - ***The elastic limit***: apart from the ultimate phase called "break", a string put under tension goes through two phases:
    - The ***elastic phase*** during which a stress of small intensity produces a stretch which disappears as soon as the tension is released.
    - The ***plastic phase*** during which a stress of strong intensity produces a stretch which partially remains when the tension stops. We then have to deal with an irreversible deformation, the string does not hold tuning, becomes very inharmonic and ultimately breaks.

  The frontier between the elastic phase and the plastic phase should never be exceeded. This border is named **the elastic limit**. It is situated at approximately 85% of the practical breaking load depending on the types of wire

  Under-stress as well as over-stress should be avoided. One should try to reach the ideal stress rate recommended in the Typogram and detailed hereafter.

How to obtain this ideal stress rate in practice?

Measure the vibrating lengths, the diameters and enter them in the blue columns of the **Typogram**.

The **Typogram** is an Excel sheet which can be downloaded free of charge on our website. It will spare you tedious calculations.

The general guide line is as follows:

in the bass:
A stress rate from 50 to 55 % range is ideal.

For plain wire strings:
Target approximately 50 % for the first plain wire string at the break.
Then approximately 60 % for A_4
approximately 65 % for A_5
approximately 70 % for A_6
75% for A_7

You will notice that most instruments, antique or contemporary, require **hybrid stringing** using a combination of several types of wire.

These prerequisites take a little time. But this precision is rewarded by an excellent result in the sound and by saving time during harmonization.

For some models, the scaling of which has not changed since their conception, pre established **stringing instructions** can be consulted on our website.

TYPICAL EXAMPLE OF IMPROVEMENT AT THE BREAK:

Steinway Model O (1, 80 m): the first plain wire string after the break is a B. (Pitch: 442 Hz)

Note	Type	Speaking length mm	Diameter mm	Tensile strength N	Stress %
B	**Type M**	1110mm	1,025mm	491, 1 N	**34.07**
B	**Type 0**	1110mm	1,025mm	491, 1 N	**39.94**
B	**Type 1**	1110mm	1,025mm	491, 1 N	**50.87**
B	**Type 2**	1110mm	1,025mm	491, 1 N	**60.56**

Type XM is not relevant as plain string at the break
If **Type M** is used, the stress rate is insufficient.
If **Type 0** is used the tensile strength is identical, but 39.94 % of stress is still not enough.
If **Type 1** is used, the tensile strength remains the same, and the stress rate of 50.87 % is now satisfactory.
If **Type 2** is used, the tensile strength is still unchanged, and the stress rate of 60.56 % is also satisfactory.

However, in this case and for all modern instruments **Type 2** will not be recommended. Indeed, the very particular sound color of **Type 2** will not match the tone color of the rest of the stringing.

For an instrument posterior to 1880 the use of the Type 2 in hybrid stringing is not recommended.

➔ **Finally, we shall choose Type1 for this first plain wire note.**

Practical**B**reaking**L**oad = **N**ominal**B**reaking**L**oad **- 25%** (or **-15%** for type 2)

Type XM			Type M			Type 0			Type 1			Type 2		
N°	∅	**PBL**	**N°**	∅	**PBL**	**N°**	∅	**PBL**	**N°**	∅	**PBL**	**N°**	∅	**PBL**
									9	0,575	373,93	**5**	0,4	158,00
									9,5	0,6	402,91	**5,5**	0,425	177,00
			12	0,725	762,28	**12**	0,725	674,66	**10**	0,625	432,58	**6**	0,45	197,00
			12,5	0,75	810,79	**12,5**	0,75	716,69	**10,5**	0,65	462,90	**6,5**	0,475	217,00
13	0,775	1048	**13**	0,775	862,20	**13**	0,775	759,60	**11**	0,675	493,83	**7**	0,5	238,00
13,5	0,8	1088	**13,5**	0,8	914,96	**13,5**	0,8	803,37	**11,5**	0,7	525,31	**8**	0,525	261,00
14	0,825	1154	**14**	0,825	969,23	**14**	0,825	847,95	**12**	0,725	557,31	**8,5**	0,55	283,00
14,5	0,85	1198	**14,5**	0,85	1020,77	**14,5**	0,85	893,31	**12,5**	0,75	589,78	**9**	0,575	307,00
15	0,875	1354	**15**	0,875	1077,19	**15**	0,875	939,41	**13**	0,775	622,68	**9,5**	0,6	331,00
15,5	0,9	1384	**15,5**	0,9	1134,85	**15,5**	0,9	986,23	**13,5**	0,8	655,96	**10**	0,625	356,00
16	0,925	1422	**16**	0,925	1193,99	**16**	0,925	1033,71	**14**	0,825	689,58	**10,5**	0,65	381,00
16,5	0,95	1514	**16,5**	0,95	1256,74	**16,5**	0,95	1081,84	**14,5**	0,85	723,50	**11**	0,675	407,00
17	0,975	1582	**17**	0,975	1315,64	**17**	0,975	1130,57	**15**	0,875	757,66	**11,5**	0,7	433,00
17,5	1	1649	**17,5**	1	1378,08	**17,5**	1	1179,86	**15,5**	0,9	792,03	**12**	0,725	460,00
18	1,025	1717	**18**	1,025	1441,66	**18**	1,025	1229,69	**16**	0,925	826,57	**12,5**	0,75	488,00
18,5	1,05	1786	**18,5**	1,05	1506,67	**18,5**	1,05	1280,02	**16,5**	0,95	861,22	**13**	0,775	516,00
19	1,075	1855	**19**	1,075	1572,80	**19**	1,075	1330,81	**17**	0,975	895,94	**13,5**	0,8	544,00
19,5	1,1	1924	**19,5**	1,1	1646,81	**19,5**	1,1	1382,02	**17,5**	1	930,70	**14**	0,825	573,00
20	1,125	1994	**20**	1,125	1715,06	**20**	1,125	1433,62	**18**	1,025	965,44	**14,5**	0,85	601,00
20,5	1,15	2064	**20,5**	1,15	1792,13	**20,5**	1,15	1485,59	**18,5**	1,05	1000,12	**15**	0,875	631,00
21	1,175	2135	**21**	1,175	1854,63	**21**	1,175	1537,87	**19**	1,075	1034,69	**15,5**	0,9	660,00
21,5	1,2	2205	**21,5**	1,2	1934,39	**21,5**	1,2	1590,43	**19,5**	1,1	1069,12	**16**	0,925	690,00
			22	1,225	2007,43	**22**	1,225	1643,25	**20**	1,125	1103,36	**16,5**	0,95	720,00
			22,5	1,25	2081,46	**22,5**	1,25	1696,28	**20,5**	1,15	1137,36	**17**	0,975	750,00
			23	1,3	2236,37	**23**	1,3	1818,76	**21**	1,175	1171,09	**17,5**	1	780,00
			23,5	1,35	2396,14	**23,5**	1,35	1944,18	**21,5**	1,2	1204,49	**18**	1,025	811,00
			24	1,4	2559,60	**24**	1,4	2072,39	**22**	1,225	1237,52	**18,5**	1,05	841,00
			24,5	1,45	2733,93	**24,5**	1,45	2203,25	**22,5**	1,25	1270,14	**19**	1,075	872,00
			25	1,5	2905,85	**25**	1,5	2336,61	**23**	1,3	1353,87	**19,5**	1,1	902,00
			25,5	1,55	3068,13	**25,5**	1,55	2472,34	**23,5**	1,35	1438,55	**20**	1,125	933,00
			26	1,6	3254,19	**26**	1,6	2610,29	**24**	1,4	1523,99	**20,5**	1,15	963,00
									24,5	1,45	1610,02	**21**	1,175	994,00
									25	1,5	1696,46	**21,5**	1,2	1024,00
									25,5	1,55	1783,14	**22**	1,225	1054,00
									26	1,6	1869,88	**22,5**	1,25	1084,00
												23	1,3	1158,00
												23,5	1,35	1232,00
												24	1,4	1308,00

Average density:
Type XM: 7.85 g/cm^3
Type M: 7.85 g/cm^3
Type 0: 7.81 g/cm^3
Type 1: 7.85 g/cm^3
Type 2: 7.82 g/cm^3

Young modulus: E:
Type XM: 202 Gpa
Type M: 202 Gpa
Type 0: 202 Gpa
Type 1: 202 Gpa
Type 2: 202 Gpa

Made by **Colonna Draht**
exclusively for
Stephen Paulello

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