THE TRIPLE-FRETTED CLAVICHORD IN THE BENTON FLETCHER COLLECTION

Observations and recommendations

Peter Bavington, May 2015

Contents

Peter Bavington, Clavichord Maker
291 Sprowston Mews, Forest Gate
LONDON E7 9AE
E-mail: *peter@peter-bavington.co.uk*

Introduction

1. This clavichord was examined by Ben Marks, Christopher Nobbs and me on 28 October 2014. The aims were to identify ways in which its musical performance could be improved, so that it could be used more often by visiting players, and if possible to see if any further light could be shed on its origins and original state.

Origins

2. The clavichord is not signed or dated. Mimi Waitzman's catalogue identifies it as 'German, late 17th or early 18th century'.[1] This is in line with the criteria proposed by John Henry Van Der Meer in 1975,[2] and I see no grounds for disagreement.

3. As for the place of manufacture, Maria Boxall has suggested that triple fretting of the type found in this instrument is only present in clavichords made in South Germany, by which is meant essentially the region now included in the modern *Länder* of Baden-Württemberg and Bavaria.[3] She found no evidence of triple fretting in other centres of clavichord making such as North Germany, Saxony or Bohemia. If this is accepted, the instrument could be described as 'South German, late 17th or early 18th century'.

4. A feature which might give a clue to the clavichord's origin is the distinctive style of carving on the keylevers (see Fig. 1). I know of only one other clavichord with similar key-carving (see Fig. 2): it is preserved in the Germanisches National-museum, Nuremberg (No. MINe 58) and, like the present instrument, it is an anonymous triple-fretted instrument with the compass *C/E*–c^3.[4] It has been extensively restored and many parts are non-original. It is unsigned; unfortunately nothing is known of its history beyond the fact that it came to the museum from the Neupert collection after the Second World War, and until 1942 was in the Helmholtz collection. It is always possible that more information about it will become available in future. The style of carving is so similar to that on the Fenton House clavichord, and so distinctive, that I think it is possible that it was done by the same hand.

---

1. Mimi S. Waitzman, *The Benton Fletcher Collection at Fenton House: Early Keyboard Instruments*, London, The National Trust, 2003, pp. 86–88.
2. John Henry Van Der Meer, 'The Dating of German Clavichords' in *The Organ Year Book*, Vol. VI (1975), pp. 100–113.
3. Maria Boxall, 'The Origins and Evolution of Diatonic Fretting in Clavichords' in *Galpin Society Journal* LIV (May 2001), pp. 174–178.
4. See Martin Kares, *Verzeichnis der Europäischen Musikinstrumente im Germanischen Nationalmuseum Nürnberg, Band 3: Klavichorde*, Wilhelmshaven, Florian Noetzel Verlag, 1999, pp. 27–29.

Fig. 1: Key-carving on Benton Fletcher anonymous triple-fretted clavichord
(Author's photo)

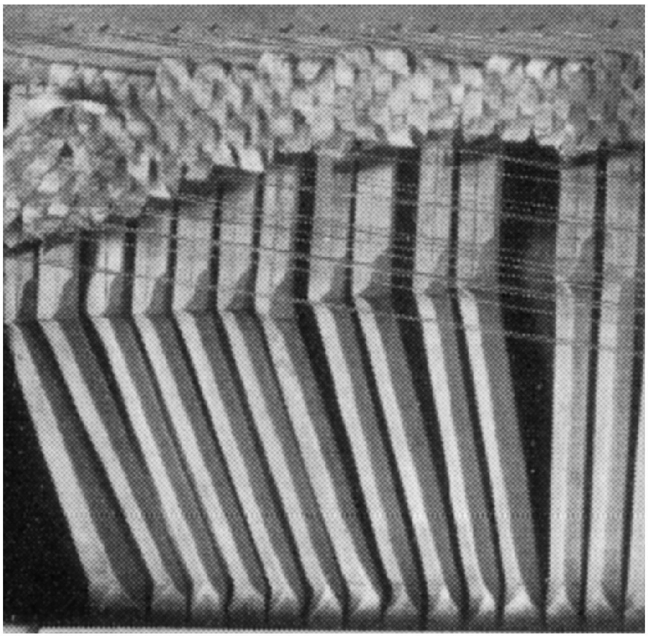

Fig. 2: Key-carving on MINe 58
(from Martin Kares' catalogue: see note 4)

Previous restorations

5. The following restorations are recorded in the Benton Fletcher archives:

> 1948: by Alec Hodsdon of Lavenham.
>
> Various times during the period 1950–70: by Arnold Dolmetsch Ltd, under the supervision of Leslie Ward.
>
> 1978: by Paul Neville under the supervision of Richard Clayson and Andrew Garrett.[5]

There may well have been earlier unrecorded restorations before the transfer of the Benton Fletcher instruments to the National Trust in 1937.

6. There are apparently no written records of work carried out before 1978. Of the 1978 restoration, there is a summary in note form, from which it is clear that this was a major intervention including almost complete disassembly of the case and removal of the bottom boards and soundboard.

7. It is clear that some of the previous work, for example the addition of lead weights to the keylevers (probably by Arnold Dolmetsch Ltd), has changed the character of the clavichord and the way it responds to playing, so that what we now have is essentially a modern revival-style clavichord in an antique case. These past interventions have been so extensive that it would be difficult, and indeed foolhardy, to attempt to restore the instrument to what we might think was its original state. The aim of any change to the present set-up should therefore simply be to improve its present playability, if possible. Historical evidence, for example of the likely design pitch level, may nonetheless be taken into account when it is clearly still relevant.

5. The date is given as 1979 in Mimi Waitzman's catalogue; however, the restoration was completed in 1978 (Andrew Garrett, private communication, March 2015). The summary report of the work done is dated 5 January 1979.

Pitch and stringing

8. The present stringing (materials and gauges) derives from the 1978 restoration by Clayson and Garrett: it is in solid brass wire throughout. No list of string gauges is available. The diameter of the strings on the top note (c^3) and on the lowest note (*C*) were measured and found to be 0.3 and 0.5 mm respectively.

9. The sounding lengths of the strings were checked and found to be in accordance with the list in Mimi Waitzman's catalogue.[6]

10. The instrument is at present kept at $a^1 = 415$ Hz. At this pitch, the string tensions range from 3.4 kgf at the top note to only 1.9 kgf at the bottom. Except for the high treble, in my opinion these tensions are close to, or even below, the lower limit of the working range for brass wire. Consequently, the sound is dull and lacking in volume. This is most serious for the notes of the bass octave below tenor *c*.

11. What might have been the intended pitch when the instrument was made? According to Bruce Haynes,[7] throughout the seventeenth and eighteenth centuries two pitch standards were in use in German-speaking countries, separated by a whole tone or a minor third. There is evidence to show that the higher of these two pitches, which was the pitch of most organs at the time, was approximately equivalent to a semitone above modern pitch, i.e. about $a^1 = 466$ Hz, with some local variation.[8]

12. It seems reasonable to assume that the clavichord was intended to be tuned at one or other of these two contemporary pitch standards. If this is correct, I suggest that the higher pitch is far more likely than the lower. At about $a^1 = 466$ Hz, all the strings would still be at least two whole-tones below their breaking point, but the notes below *c* (except, perhaps, the three notes of the short octave – see para 17) would be within their working range, and would sound louder and clearer than at present: the bass and treble would be better balanced with each other, and the instrument as a whole would sound and feel more robust.

13. Raising the pitch from $a^1 = 415$ to $a^1 = 466$ Hz would involve an increase in the total string tension (assuming no change in the string gauges) of about 12¼%. In my opinion, the structure of the instrument, following the almost complete re-building by Clayson and Garrett in 1978, is well able to stand this.

14. However, some tuning pins are at present leaning over towards the bridge, as a result of the leverage exerted by the pull of the strings. It would be advisable to correct this in any case, but it would be even more important to do so if the pitch is to be raised as I am suggesting. It might be sufficient to push the tuning pins further down into their holes, but it might be necessary to repair the holes themselves if they have become dangerously ovalised.

15. Any decision to raise the pitch should be considered in conjunction with a review of the present stringing. The tensions of the top and bottom notes as at present strung (see para 8) are anomalous: the tension of the top note is almost twice that of the bottom note, when for acoustic reasons one would expect the tension in the bass to be higher, or at least no lower, than that in the treble.

---

6. *Op. cit.* (note 1), p. 88. These sounding lengths were measured with the tangents striking at their present positions.
7. Bruce Haynes, *A History of Performing Pitch: the story of "A"*, Lanham MA and Oxford, Scarecrow Press, 2002; see particularly pp. 371–376.
8. The two pitches were called by different names at different times and places, but the relationship between them, and their absolute level, did not change much.

16. Accordingly any raising of the pitch should probably be accompanied by changes to the present stringing. In Table 1 I have suggested a complete list of string gauges and materials for the clavichord at the higher pitch. It may be that in some parts of the compass these suggestions coincide with the present stringing, in which case I would not necessarily suggest changing the wires for those notes unless they are in some way damaged or defective.

17. In the case of the three notes of the short octave, *C*, *D*, and *E,* the scaling would still be below the working range of solid brass wire even with the rise in pitch to $a^1 = 466$ Hz. For these notes, I have suggested the use of twined strings. These are made of a double length of wire folded back on itself and twined tightly to produce a rope-like composite string. There is evidence for the use of such strings on clavichords from the time of Mersenne onwards.[9]

Table 1: Proposed string list for $a^1 = 466$ stringing
Gauges and materials are based on Malcolm Rose wire

Note	Material	Gauge (mm)	Tension (kgf)
C	red brass (twined)	.4	3.5
F	red brass	.48	3.8
D	red brass (twined)	.4	4.0
G	red brass	.48	4.4
E	red brass (twined)	.4	4.6
A	red brass	.44	4.1
B♭–B	yellow brass	.44	4.4
c–c#	"	.4	4.0
d–e♭–e	"	.4	4.3
f–f#–g	"	.36	3.9
g#–a–b♭	"	.36	4.1
$b–c^1–c\#^1$	"	.34	3.8
$d^1–e\flat^1–e^1$	"	.33	3.8
$f^1–f\#^1–g^1$	"	.32	3.8
$g\#^1–a^1–b\flat^1$	"	.3	3.5
$b^1–c^2–c\#^2$	"	.3	3.7
$d^2–e\flat^2–e^2$	"	.29	3.7
$f^2–f\#^2–g^2$	"	.29	3.9
$g\#^2–a^2–b\flat^2$	"	.27	3.6
$b^2–c^3$	"	.27	3.6

9. See Marin Mersenne, *Harmonie Universelle*, Paris, Sebastien Cramoisy, 1636 or 1637, *Traité des Instrumens, Liure Troisiesme*, pp. 114–116. The twined strings are mentioned in Mersenne's description of a clavichord or *manichordion*, where they are said to be *redoublées & retorces*. For more information on twined strings, see http://www.peter-bavington.co.uk/twined.htm (accessed April 2015).

Temperament and tuning: (a) the original temperament

18. In theory, fretted clavichords incorporate information about the system of tuning intended by the maker, since the sizes of certain intervals in the scale are defined by the points at which the tangents strike the strings.

19. On the present instrument, although some tangents have been moved further forward in their levers, I could find no trace of any of them having been moved to new positions to the left or right. Since the fretting is mostly in groups of three, the sizes of both the semitones and the whole-tones in the fretted groups should be determinable, which in theory should give a reliable guide to the intended temperament. However, it is not easy in practice to interpret this evidence.

20. The present positions of the tangent strike points are probably not original. Many tangents have been bent out of vertical, some quite considerably, which alters the sounding lengths and hence the sizes of the fretted semitones and tones. Some of this bending of tangents may be original, but it seems likely that adjustments have been made at some time in the instrument's history,[10] and the resulting tangent positions may not be the same as those fixed by the original maker.[11]

21. Three types of temperament are *prima facie* possible candidates for being the original system:

(1) Some form of mean-tone tuning. In mean-tone, there is a marked difference between the smaller or 'chromatic' semitones (e.g. C–C♯; B♭–B♮) and the larger or 'diatonic' ones (e.g. C♯–D; B–C); all whole-tones, however, are the same size (note that the interval G♯–B♭ is not a true whole-tone, but a diminished third). All mean-tone temperaments include discordant 'wolf' intervals, and each accidental key can have only one meaning. For example, the key between D and E can produce either D♯ or E♭ but it cannot be used interchangeably for both. The effect of this is to limit the keys in which music can be played.

(2) An irregular circulating temperament. There are many systems of this type, devised in order to overcome the key limitations of mean-tone. There are usually several sizes of whole-tone and semitone, but the distinction between 'chromatic' and 'diatonic' semitones may be blurred.

(3) Equal temperament, in which all semitones are equal in size, and consequently all whole-tones also.

Table 2 gives the sizes in cents of tones and semitones in two kinds of mean-tone, a typical irregular temperament (Werckmeister III), and equal temperament.

22. The original maker would have needed some way of establishing the sounding lengths of each note in a fretted group so as to produce the desired sizes of tones and semitones. It has been known since ancient times that the size of a musical interval produced by different lengths of the same string depends on the *ratio* between the lengths. Unfortunately, in the case of many practical temperaments, the ratios required to produce accurately the prescribed tones and semitones are irrational; however, simple whole-number ratios can in many cases give a close approximation. Some of these approximations are given in the right-hand columns of Table 2.

10. Andrew Garrett (private communication, March 2015) reports that in 1978 tangent adjustment was limited to making sure the tangents struck the correct strings: no attempt was made to change the point along the strings where the tangents struck, hence the temperament remained essentially as it was before. However, the tangents may have been bent during previous restorations by Alec Hodsdon and by Arnold Dolmetsch Ltd (see paras 36–37).

11. The implications of the present tangent positions are considered in paras 35–36 below.

Table 2: Sizes of intervals in various temperaments, with whole-number ratios which provide approximate equivalents

Comparison of the sizes in cents (columns 3 and 5) indicates how close the approximations are

	True ratio*	Size in cents	Approxi-mation	Size in cents
Quarter-comma mean-tone:				
small or 'chromatic' semitone	1.045	76	23:22	76
large or 'diatonic' semitone	1.070	117	15:14	119
whole-tone	1.118	193	19:17	192
diminished third (G#–B♭)	1.145	234	8:7	231
Sixth-comma mean-tone:				
small semitone	1.051	86	21:20	84
large semitone	1.065	109	16:15	111
whole-tone	1.120	196	–	–
diminished third	1.135	219	–	–
Werckmeister III:				
s/tones C–C# and F–F#	1.053	90	19:18	93
s/tones E♭–E♮; G–G#; G#–A; B♭–B♮	1.057	96	19:18	93
s/tones C#–D; D–E♭	1.061	102	18:17	98
s/tones E–F; F#–G; A–B♭; B–C	1.064	107	–	–
Equal temperament:				
semitone	1.060	100	18:17	98
whole-tone	1.123	200	–	–

* The numbers in this column represent the length of the longer string divided by the length of the shorter string.

23. Three conclusions can be drawn from an examination of the figures in Table 2:

(1) Simple whole-number ratios can be used to give a fair approximation of all the intervals required for a triple-fretted clavichord in quarter-comma mean-tone. Sixth-comma mean-tone would be slightly more troublesome, but good approximations are available for the semitones, and the tones could be set out by applying these repeatedly.

(2) For Werckmeister, the whole-number ratios which might be used would not be close enough to the true ratios to distinguish clearly between the slightly varying sizes of the semitones, and to distinguish between these and the semitones of equal temperament. The same is true for most other irregular circulating temperaments, though there is not space to demonstrate this here.

(3) A good approximation is available for the semitones of equal temperament.

24. On this instrument, lines are drawn forward from the rack slots on the top surface of the keylevers: evidently, these lines (sometimes called diapason lines) were drawn before the levers were cut apart, and marked the centre of the rear part of each keylever. However, in most cases the tangents are *not* placed on these lines

and never have been: they are generally nearer to one or other edge of the lever, in a few cases very close to the edge.[12]

25. It seems likely, therefore, that there were four stages in the construction of the keylevers and tangents:

(1) A system of ratios was used to determine the spacing of the rack slots (such a procedure was described by Claas Douwes in 1699[13]).

(2) With the rack in place, the keyplank was put into the instrument and the 'diapason lines' were marked forward from each rack slot. The keys could then be cut apart.

(3) With the keylevers now separated and placed in the instrument, and with the strings in place, a different system of ratios was used, this time to position each tangent in its keylever along the string.

(4) Final adjustments were presumably made by listening to the pitches of each fretted group and bending the tangents to one side or the other to produce the desired intervals.

26. The system used to lay out the rack and keylevers (stage 1 above) clearly resulted in distances between the levers that were *smaller* than those required by any feasible temperament. The required distances were then achieved by positioning the tangents away from the diapason lines, and perhaps by further bending them. This may have been intentional, since it enables the maker to avoid excessive keylever-cranking, which might be thought to reduce the strength and stiffness of the keylevers.

27. It is sometimes assumed that makers arranged the tangent positions so as to produce the intended tuning with the tangents set vertically in their levers. An attempt was therefore made to estimate the sounding lengths that would result with all the tangents vertical in their present positions, and the sizes of semitones and whole-tones this would produce. Table 3 (columns 1 to 3) shows the results for the triple-fretted courses from *d* to $b\flat^2$.

28. As will be seen, with vertical tangents the sizes of the intervals, particularly the whole-tones, are still nearly all too narrow for any possible historical temperament. Nonetheless, it is worth noting that in the first five three-note groups from *d* to e^1 the 'chromatic' semitones are consistently smaller than the 'diatonic' ones, which could be an indication of a mean-tone system. The higher groups are more irregular; however, the higher in pitch and the shorter the sounding length, the less reliable will be any conclusion drawn from the fretting ratios, because a very small displacement of the tangent (or a small error in the measurement) will produce a misleadingly large difference in pitch.

29. The only way to achieve a workable tuning must have been to adjust the sounding lengths by leaning or bending the tangents to one side or the other, and we must assume that this was part of the original plan. In the right-hand columns of Table 3, a scheme is shown which would produce an accurate quarter-comma mean-tone tuning with minimal bending of the tangents from their vertical positions. To achieve this, the central tangent of each group of three is kept close to vertical, and the tangents on either side are slanted away from each other.

---

12. The tangents have been secured in their levers with glue; this is probably a fairly recent modification, but it does not affect their positions in the levers.

13. Claas Douwes, *Groendig Ondersoek van de Toonen der Musijk*, Franeker, Adriaan Heins, 1699; reprinted Franeker, 1722; re-set and reprinted, Amsterdam, 1773. Facsimile edition with introduction and notes by Peter Williams, Amsterdam, Frits Knuf, 1970. There is a discussion of the clavichord layout procedure in John Barnes, 'Reconstruction of Douwes' Clavichord', B. Brauchli, S. Brauchli, A. Galazzo (eds.), *De Clavicordio*, Turin, Istituto per i Beni Musicali in Piemonte, 1994, pp. 75–79.

Table 3: Interval sizes with tangents vertical, and adjusted for mean-tone

For convenience, only the notes in fretted groups from *d* to $b\flat^2$ are shown. Interval sizes are rounded to the nearest 1¢. Because of rounding, the whole-tone size in column 7 may not in every case equal the sum of the two semitones in column 6.

Note	Estimated s/length vertical mm	Semitone size cents	Adjustment mm	S/length after change mm	Semitone size cents	Whole-tone size cents
d	637		+4	641		
$e\flat$	599	106	0	599	117	
e	581	53	–8	573	76	194
f	560		+1	561		
f#	537	72	0	537	76	
g	507	99	–5	502	117	192
g#	487		+6	493		
a	461	95	0	461	116	
$b\flat$	435	100	–4	431	116	233
b	417		+3.5	420.5		
c^1	393	102	0	393	117	
$c\#^1$	379	63	–3	376	76	194
d^1	361		+4	365		
$e\flat^1$	341	99	0	341	117	
e^1	329	62	–3	326	78	196
f^1	315		-1.5	313.5		
$f\#^1$	300	84	0	300	76	
g^1	286	83	–5.5	280.5	116	192
$g\#^1$	271		3	274		
a^1	256	98	0	256	117	
$b\flat^1$	245	76	–5.5	239.5	116	233
b^1	235		+2.5	237.5		
c^2	222	98	0	222	117	
$c\#^2$	215	55	–2	213	72	188
d^2	200					
$e\flat^2$	189	98				
e^2	180	84				
f^2	174					
$f\#^2$	166	81				
g^2	157	96				
$g\#^2$	153					
a^2	147	69				
$b\flat^2$	137	122				

+ sign indicates bending the tangent to the left, thus increasing the sounding length; – sign indicates bending the tangent to the right, shortening it. Adjustments are shown only for the notes *d*–$c\#^2$, as conclusions drawn from the higher fretted groups are unreliable, for reasons explained in the text (para. 28). The amount of tangent bending could be reduced in some cases by bending the centre tangent slightly out of vertical.

30. In each triple-fretted octave, there are four groups of three; three of these define a whole-tone (B–C#; D–E, and F–G in each octave). Since the whole-tone of quarter-comma mean-tone is the smallest of any likely tuning, almost any other possible temperament would require the outer tangents of each of these groups to be bent further apart, leaning further from the vertical.

31. The fourth fretted group in each octave (G♯–B♭) defines a diminished third, which in quarter-comma mean-tone is greater in size than a whole-tone, and would require more tangent-bending than other temperaments; but this is more than compensated for by the reduction of tangent bending in the other groups, and by the fact that the three lowest triple-fretted groups, which would require the tangents to be best furthest from the vertical, all define a whole-tone, and it is not till we reach the fourth group that we encounter the diminished third *g#–b♭*.

32. Quarter-comma mean-tone therefore is the system that requires the least tangent bending; its use is widely documented all over Europe during the period that the instrument was made, and I conclude that it was most probably the original tuning of this clavichord.

33. In mean-tone temperaments, each accidental key can have only one meaning: for example, it can produce either D♯ or E♭ but it cannot be used interchangeably for both. It is this which limits the number of usable keys (see para. 21). In the most common arrangement, the accidentals chosen are C♯, E♭, F♯, G♯ and B♭ and I think this applies in the case of this instrument (for the suggestion that the key between G and A was intended for A♭, see the Appendix).

34. The notes between *B♭* and *C#* are fretted in pairs; for simplicity, these notes have been omitted from Table 3. The spacing of the *B* and *B♭* keylevers is much too close to permit any kind of semitone to be achieved with vertical tangents; the tangents must be bent considerably away from each other to produce even the chromatic semitone of quarter-comma mean-tone. The *c–c#* tangents, however, can be adjusted to produce a quarter-comma mean-tone chromatic semitone with only moderate tangent bending.

Temperament and tuning: (b) the present temperament

35. Table 4 gives details of the sounding lengths with the present tangent positions, and the implied sizes of the tones and semitones. Examination shows:

(1) Despite the tangent bending, the lowest semitone *B♭–B* remains much too narrow for any feasible system; on the other hand, the topmost semitone b^2–c^3 is much too wide. In attempting to discover the intended system (or to devise a practical one) these semitones will be disregarded; likewise the notes above d^2, for reasons given in para. 28.

(2) The semitones *c–c#* and c^2–$c\#^2$ are close in size to the corresponding interval in quarter-comma mean-tone. The intermediate c^1–$c\#^1$, on the other hand, at 90 cents is too wide for quarter-comma mean-tone.

(3) Of the remaining 14 semitones, 12 correspond, either exactly or fairly closely, to the corresponding intervals in equal temperament.

(4) Of the eight fretted whole-tones between notes *d* and $c\#^2$, one is clearly too narrow for any feasible system; three might correspond to quarter-comma mean-tone; and four might correspond to equal temperament. The whole-tone between F and G seems consistently a little smaller than the others.

Table 4: Interval sizes with tangents as they currently are

Only the fretted courses are shown. See note to Table 3 regarding rounding.

Note	Sounding length mm	Semitone size ¢	Comment	Whole-tone size ¢	Comment
B♭	729				
B	701	68	too narrow		
c	685				
c#	656	74	QCMT?		
d	640				
e♭	605	97	ET ?		
e	572	97	ET ?	194	QCMT
f	563				
f#	533	95	?		
g	504	96	?	192	QCMT
g#	489				
a	460	106	ET?		
b♭	434	101	ET ?	206	ET?
b	421				
c^1	394	115			
$c\#^1$	374	90		205	ET?
d^1	363				
$e\flat^1$	342	103	ET		
e^1	323	99	ET	202	ET
f^1	313				
$f\#^1$	297	91			
g^1	280	102	ET ?	193	QCMT
$g\#^1$	273				
a^1	257	104	ET?		
$b\flat^1$	243	97	ET?	201	ET
b^1	237				
c^2	222	113			
$c\#^2$	213	72	QCMT?	185	too narrow
d^2	204				
$e\flat^2$	193	96	ET ?		
e^2	182	101	ET ?	197	ET ?
f^2	174				
$f\#^2$	166	81			
g^2	157	96		178	
$g\#^2$	152				
a^2	144	94			
$b\flat^2$	135	112		205	?
b^2	128				
c^3	119	126	too wide		

QCMT = quarter-comma mean-tone
ET = equal temperament

36. The present tangent positions are probably not those fixed by the original maker; if so, however, they date from an intervention at some date before the 1978 restoration. It seems to me most likely that they are the result of someone tuning the instrument by ear and attempting to put it into equal temperament (without totally succeeding).

37. For a long period (*c.* 1952–1973) the instruments at Fenton House were regularly tuned and maintained by Cecile Ward née Dolmetsch. I believe it is true that she tuned exclusively in equal temperament, working by ear.[14] The present tangent positions could have been set by her; they could equally well have been the result of a previous restoration such as that by Alec Hodsdon in 1948 or Leslie Ward in 1950.

38. The question which immediately arises is whether the tangent positions should be adjusted again to reproduce something like the original temperament, or perhaps just to remove the anomalies arising from the fact that the implied intervals are not always the same in each octave, so that it is not possible to put all the octaves perfectly in tune (for example, if the octave f–f^1 is precisely in tune, the octave $f\#$–$f\#^1$ will be 4 cents too narrow – enough to be noticeable).

39. In my opinion, there are strong reasons for *not* making any such further adjustment:

(1) While it is possible to bend brass sheet back and forth many times without endangering its integrity, each bend produces complex dislocations within the crystal structure of the metal. The consequence of these is that it becomes harder and eventually, if bending and re-bending continues, it becomes brittle and breaks.[15] There is no way of knowing how close the tangents are to this point: bending them to new positions might be perfectly safe, but there is no way of guaranteeing this.[16]

(2) Even if it were possible to bend the tangents safely, it would be undesirable because doing so would impose another layer of interpretation on the instrument. We cannot be *sure* that we know the original temperament, and making a further adjustment may make it more difficult for future researchers to unravel the mystery.

Temperament and tuning: (c) a practical tuning procedure

40. In practice, it has been possible to devise a circulating temperament, very close in effect to equal temperament, which approximately matches the present tangent positions. Details of this temperament are given in Fig. 3 and Table 5. No particular validity or authenticity is claimed for it: the purpose of devising it is simply to show that it is possible to tune the instrument in a way that allows for practical performance without changing the present tangent positions. Players will need to make slight adjustments, by varying pressure on the keys, to bring some intervals into tune when necessary.

---

14. Christopher Nobbs, private communication, April 2015.

15. For a discussion of this process in metals, see J. E. Gordon, *The New Science of Strong Materials*, second edition, London (Penguin Books), 1976, p. 98.

16. It would be possible to greatly reduce the risk of fracture by taking out the tangents and individually annealing them before replacing and bending them, but this itself is fraught with risks and technical difficulties and I do not recommend it.

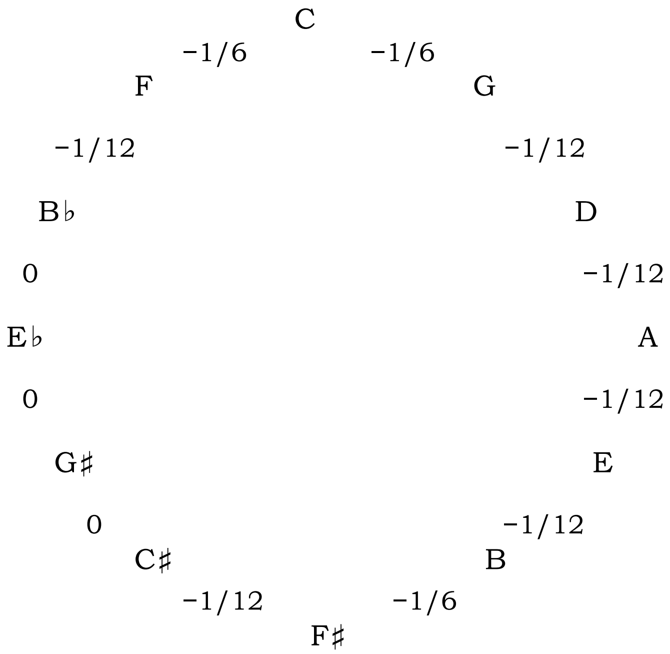

Fig. 3: A circulating temperament which approximately fits the present tangent positions

Deviations of the fifths from pure are shown as fractions of a Pythagorean comma. Six fifths are 1/12 comma narrow, as in equal temperament; three fifths are 1/6 comma narrow; and three fifths are pure.

Table 5: Interval sizes in cents, with present tangent positions and with the proposed temperament

Interval sizes are rounded to the nearest 1¢. The top three fretted groups are excluded from this analysis, for reasons given in para 28

Interval	Present tangent positions		Proposed temperament
	Fretted groups 3–6 (d–$c\#^{1}$)	Fretted groups 7–10 (d^{1}–$c\#^{2}$)	
D–E♭	97	103	101
E♭–E	97	99	98
D–E	194	202	199
F–F♯	95	91	94
F♯–G	96	102	101
F–G	192	193	196
G♯–A	106	104	99
A–B♭	101	97	103
G♯–B♭	206	201	203
B–C	115	113	103
C–C♯	90	72	96
B–C♯	205	185	199

41. A practical system for tuning the clavichord by ear could be as follows:

(1) Tune a^1 to the desired pitch and a one octave below.

(2) Tune d^1/e^1 (which are on the same course) so that the fourth a–d^1 and the fifth a–e^1 are equally tempered (they will be similar to the fourths and fifths of equal temperament, i.e. almost pure).

(3) Tune f so that the third f–a beats about 5 times per second, and the fourth f–$b\flat$ is very slightly wider than pure.

(4) Tune c^1 so that the fifth f–c^1 and the fourth g–c^1 are equally tempered (they will be slightly further from purity than the other fourths/fifths).

With these four steps, all the notes between f and e^1 are tuned. The temperament will be approximately that described in para. 40 and Fig. 3.

42. To tune the three fretted courses below f, I suggest:

(1) Tune e an octave below e^1.

(2) Tune c an octave below c^1.

(3) Tune B an octave below b.

(4) Check that the notes $c\#$, $e\flat$ and $e\natural$ make acceptable octaves with the notes one octave above, and if necessary make slight adjustments. It will not be possible to tune so that all these octaves are precisely pure.

The note $B\flat$ will unavoidably be sharp; however, in contexts in which it is likely to be used, this will probably not spoil the musical effect.

43. The unfretted notes below $B\flat$ can, of course, be tuned by octaves in the usual way.

44. The course that includes the note a^1 has already been tuned. To tune the remaining upper courses above e^1, I suggest tuning the octaves f–f^1, c^1–c^2, d^1–d^2, f^1–f^2, a^1–a^2 and finally c^2–c^3: in other words, the F–F, A–A, C–C and D–D octaves. Some of the other octaves will not be perfectly in tune, and players will need to make slight adjustments, as envisaged in para. 40, to play them in tune.

Summary of observations, conclusions and recommendations

45. The clavichord was probably made in Southern Germany in the late seventeenth or early eighteenth century (paras 2–3).

46. There are similarities with a clavichord in the Germanisches Nationalmuseum, Nuremberg (No. MINe 58) which may indicate a common origin (para. 4).

47. The original pitch was probably around $a^1 = 466$ Hz (paras 8–12) and the original temperament was probably quarter-comma mean-tone with the usual pattern of accidentals in each octave (C♯; E♭; F♯; G♯ and B♭) (paras 28–32).

48. Consideration should be given to raising the present pitch to the suggested original pitch of $a^1 = 466$ Hz. At the same time, the present stringing should be reviewed. Twined strings should be considered for the three notes of the short octave (*C*, *D* and *E*). A suggested revised stringing is provided in Table 1 (paras 12–17).

49. Those tuning pins that are leaning towards the left should be fixed more firmly in the wrestplank, so that they stand vertical (para. 14).

50. No attempt should be made to change the present tangent strike positions, even though they are probably not original (paras 38–39).

51. A practical method for tuning the clavichord is suggested (paras 41–44), the effect of which will be close to equal temperament.

Acknowledgments

52. I am grateful to the National Trust and to Ben Marks for arranging access to the instrument; to Ben Marks and to Christopher Nobbs for their skilled help when examining it; and to Christopher Nobbs and Andrew Garrett for information and advice.

Appendix: G sharp or A flat?

There is in the Fenton House archive a letter about this clavichord from the late John Barnes to Mimi Waitzman, in which he confirms the hypothesis that the original temperament was a form of mean-tone, but observes that the note between G and A was A♭, not G♯ (which is more usual). He points out that Raymond Russell, in the 1969 edition of his catalogue of the Fenton House instruments,[17] also refers to A♭ on this clavichord, though when discussing the other instruments in the collection he refers to the note concerned as G♯.

Curiously, my own observations do not really confirm this. If the note concerned were A♭, one would expect to find a noticeably narrower gap between the A♭ and A♮ tangents or keylevers than between A and B♭. Observation of the keylevers does not show this difference (see Fig. 4 below); the *g#* lever, for example, is indeed very slightly closer to the *a* lever than the *b♭* lever, but the difference is very small when compared with the arrangement of *f–f#–g*, where the *f#* lever is much closer to *f* than to *g*. Moreover, a glance at Table 3 shows that with vertical tangents the intervals would, in fact, be roughly equal. It would require considerable bending of the A♭ and A tangents to bring them close enough to produce a true mean-tone semitone.

John Barnes was an experienced and meticulous organologist, and I am very reluctant to suggest that he, and Raymond Russell before him, could have been in error over this point. The only explanation I can think of is this: although the letter is dated 17 July 1997, it is based on 'old clavichord papers', and it is clear that the observations concerned were made many years before, certainly well before the 1978 restoration. Perhaps at that time the tangents were in a different position; however, the keylevers can hardly have been significantly different from what they are now.

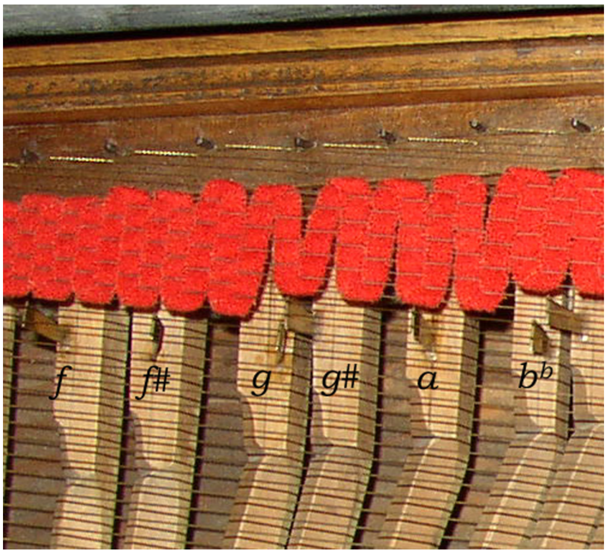

Fig. 4: Rear parts of six keylevers.
Compare spacing of *f–f#–g* with *g#–a–b♭*

17. Not available to me.