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THE TRADITION OF PIANO DESIGN

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The sound of a piano is the result of forms laid down by the designer, implementation by the builder, optimisation by the tuner and regulator and use by the pianist. The potential of the latter three is limited by the material provided for their use, so the production of a "good" sound (which is a subjective concept, governed by personal taste and influenced by the country of origin, type of music and similar factors) must start with the designer.

It would therefore seem reasonable to suppose that the design of the piano string scaling, soundboard and (to a lesser extent) action are carried out with due regard to the influence of parameters,fixed in design, on the final sound. Most significant among these parameters are the variations in string gauge and length accross the range, the position of the strike line as a proportion of string length, the shape and barring of the soundboard, and the bridge position and construction. The designer might therefore be looking to the acoustician for an understanding of the way these factors affect the string vibration, string impedances, coupling to the soundboard via the bridge, downbearing of the strings on the bridge and the resonance and radiation behaviour of the soundboard. At this point the acoustician could start to feel uncomfortable. Certainly, work has been done on these subjects, albeit generally in isolated areas (1-7 and others), but little of it with regard to the designer's need for practical, even empirical, guidelines for his work. But if acousticians have failed to report on their work in a way which might be useful to designers, the reverse situation of designers applying basic acoustics is even worse. There appears to be little feedback from the results of design work applied to further designs; and where it does occur it may be in apparently improving one parameter but at the expense of another whose significance is not understood. For example, string length may be increased by moving the bridge to a less favourable position.

The mechanism (for it is such) of piano design evolved into its present form nearlt a century ago, and has not changed since. It has not, and still does not, fully take into account any of the consequences of the design specifications which acousticians can see to be important. Insofar as they are recognised and considered, the consideration is at best partial and can be misunderstood and so misapplied. A brief sketch of the procedure of piano design is therefore offered, in illustration of its mechanistic nature and of the communication gap which exists.

The procedure of design, in this country at least, is described in several standard, but elderly, books which have not yet been superseded (8-10). The starting point is the overall size of the instrument, as determined by the case size. The next parameter chosen is the length of the shortest string; and here the scope for variability in design ends, all else proceeding from that decision. Wolfenden (8) actually gives this length as 5.4 cm. and indicates no room for argument. Furey (9) suggests 52 mm. but admits the possibility of variation. From here, we follow a series of rules to calculate the dimensions of the other strings, according to principles laid down by Hansing (10). He, to give due credit, would no doubt be appalled at the way his detailed (if quaint-sounding at times to modern ears) description of piano acoustics is misapplied. Suggested figures, such as reduction of the length of strings by a factor of 1/16 per octave from the simple doubling, are used repeatedly and unquestioningly in appropriate and inappropriate circumstances. Thereafter we draw these strings on our plan. For example, we "make a line for the strike position...10in. down from the top edge of the paper" (8), and "for the last note in the treble section raise the strike line 10 mm, and draw a curve back towards the treble till it meets the strike line 4 notes away...measure this string from the point 7 in. from the bottom of the back and 7 in. from the side of the back to the new strike line. Divide by 7. With the quotient obtained, measure from the top of the new strike line. This will be the position of the top bridge".

Certainly what is produced in this way is not absolute, and will be affected by the skill of the soundboard maker in selecting materials and constructing the instrument. But where in all of it is, for example, the simple idea that alterations in string scale alter string impedance and so alter the gradation of tone accross the instrument? There is no consideration of the effect on inharmonicity. In the third dimension of the construction, there is no consideration of the local downbearing of the strings on the local soundboard impedance - naturally enough, since impedance is never mentioned.

This situation results from the historical development of design procedures and the consistent lack of intelligible communication between designers and physicists. It has been lamented occasionally before, but very little acted upon.

The foundations of pianoforte design can be found in the accumulated experience of three centuries of harpsichord making from before 1500 to 1800. The construction was a box or shell giving both strength to resist string tension, and an enclosed soundboard. Low tension stringing gave ease of tuning, a two to one octave ratio and low inharmonicity. The plucking point on the string was varied to give changes in tone colour. The soundboards were flat, and barred into several sections to form soundboards for different string ranks. The thickness was about 3 mm., later tapering from 4mm in the bass to 2 mm. in the treble. In the later pianoforte the taper was reversed and the soundboard changed from a thin flat membrane to a curved spring.

During this period the formula used for string scale by later pianoforte makers was devised by Brooke Taylor, an English mathematician (11). The first pianoforte, by Christofori (1709), was named as being a harpsichord that could play both loud and soft. The pianoforte took seventy years to develop to rival the harpsichord, but after only another twenty years eclipsed it totally.

Acoustical development of the piano continued as it changed tonally from a harpsichord ideal to a new sound quality. The first instance of scientific intervention is noted in 1788 when "natural philosophers" Tiberius Cavallo and Edward Whitaker Gray assisted John Broadwood in establishing the striking point on each string at one ninth of its length, and the need to achieve this of dividing the bass and treble bridges (12). Broadwoods became the first makers to fix the instrument's strike line, and were soon followed by all other makers. Up to 1800 most soundboards were flat, but after this time the crowned or convex soundboard was adopted.

The modern grand pianoforte action was designed by Erard in 1808. and the first upright instruments were introduced by Southwell and Wornam in 1811. It can be claimed that the modern pianoforte was developed from 1825 to the close of the century. This includes the invention of the cast iron frame in 1825 and the introduction of high tensile cast steel wire by Webster and Horsfall in 1834. Soundboard design followed the modern practice of taper from a thicker treble to the bass, and scalloped bars accross the crown. In 1840, Henry Fowler Broadwood secured the advice of William Pole, Professor of Civil Engineering at University College London, to draw up pianoforte scales and design a cast iron frame for a trichord concert grand. By the end of the nineteenth century the design of the instrument was complete with only some action improvements to follow. The conventions of aspects such as tome and touch were also established by this time.

Major treatises on musical acoustics and piano design therefore came after the evolution of the instrument. Helmholtz had some correspondance with Theodore Steinway in 1871 on the development of his company's instruments; Rayleigh's "Theory of Sound" was not produced until 1877. Technical design treatises began in 1888 with Hansing (10), followed by Wolfenden (8) in 1916.

Evidence that the old empirical approach continues is given by Pfeiffer in 1965 (13), where he urges piano makers to "do away with pure guesswork and trial and error and acquire a basic knowledge of mathematics".

This is a sad echo of a former time when Dr. Pole stated in 1840 that "the engineering of the construction is not so well studied as it ought to be and the application of acoustical science...is yet more behind hand".

Might there not be an essential truth in these two statements, a century apart, that both the ailing piano industry and acousticians might heed? Communication of scientific research and its application in practical manufacturing is essential to an efficient and effective modern industry.

REFERENCES

1. P.H. BILHUBER and C.A. JOHNSON 1940 J. Acoustical Society of America 11(3), 311-320. The influence of the soundboard on piano tone quality.
2. C.V. RAMAN 1920 Proc. Royal Society A 97, 99-110. On Kaufmann's theory of the impact of the pianoforte hammer.
3. K.A. EXLEY 1969 J. Sound and Vibration 9, 420-437. Some physical factors determining tonal quality in the pianoforte.
4. K.K. DEB 1972 J. Sound and Vibration 20, 1-7. Dynamics of the pianoforte string and hammer.
5. K. WOGRAM 1981 Das Musikinstrument 694-702, 872-879. Vibrational characteristics of the soundboard.
6. H. FLETCHER 1964 J. Acoustical Society of America 36, 203-209. Normal vibration frequencies of a stiff piano string.
7. T.CHASE HUNDLEY, H. BENIOFF and D.W. MARTIN 1978 J. Acoustical Society of America 64, 1303-1309. Factors contributing to the multiple rate of piano tone decay.
8. S.WOLFENDEN 1916. Unwin. A Treatise on the art of pianoforte construction.
9. J. FUREY 1929. Musical Opinion. The Building of the Piano.
10. S. HANSING 1888 (English edition 1904) The pianoforte and its acoustic properties.
11. K. FENNER 1959. Das Musikinstrument. Bestimmung Der Saiten spannung Des Pianos.
12. D. WAINWRIGHT 1982 Quiller. Broadwood. By Appointment.
13. W. PFEIFFER 1965 Das Musikinstrument. The Piano Key and Wippen.