FORTEPIANO DESIGN AND CONSTRUCTION

By

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ABSTRACT

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This thesis explores the fortepiano design of the eighteenth-century Viennese instrument maker Johann Andreas Stein, with reference to other makers as well. The author carefully examined antique instruments and plans of original instruments. The first half of the paper concerns itself with the principles of design and construction of fortepianos built before 1800.

The second section recounts the experience of building an actual fortepiano. The instrument, a Hubbard Harpsichord kit, is evaluated in its faithfulness to the original fortepiano and for its own merits. The author outlines the special efforts and experiments he used to build this instrument. The fortepiano constructed by the author is an integral part of this thesis.

This work is dedicated to

Stephen P. Wilensky

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PREFACE

This thesis consists of two parts, a musical instrument and a paper. The best way of learning how to construct a fortepiano is to build one, hence the practical aspect of this thesis. The paper describes the process and principles of design and construction, and evaluates the instrument built for this project in comparison with the original. The paper fills a need for writing on the design of keyboard instruments and is a complement to the practical craft of instrument making.

The paper is not the definitive work on this subject, nor is it a redundant instruction book. It is broader in scope than simply recounting a single experience in instrument making. It seeks to apply the principles learned from that experience to all fortepianos built from 1750-1800.

The fortepiano built for this project, modelled on an instrument by Johann Andreas Stein (1728-1792), was chosen for several reasons. First, it was available in kit form from a reputable firm, Hubbard Harpsichords, Incorporated. Secondly, it is musically relevant, closely resembling the instruments played by Mozart, Haydn, Beethoven and their contemporaries. Finally, most Viennese fortepianos built before 1800 are similar in overall design. Observations concerning one instrument hold true for many of the others.

The fact that this fortepiano is a kit does not detract from its legitimacy as an instrument and a model. All copies of original antiques are interpretations. A rigorously exact reproduction of methods and materials is not practical or necessary, unless one is specifically studying such things. Modern concerns and perspective influence the work of any present-day copyist.

A kit has some advantages. It is more economical than building an entire copy, requiring less time and money and fewer tools. A kit maker does not have to measure and draw plans, ascertain the original methods and materials, or redesign and interpret the original instrument. However, the kit maker must still address these items indirectly, or else the manufacturer's degree of faithfulness in interpretation of the original design will set the limits of the kit.

I have been a piano tuner and technician for six years now, and have worked for two years in a piano rebuilding shop, where I gained valuable insight into the construction and restoration of modern pianos. In spite of this experience, I had to learn new methods of working with unusual materials as the fortepiano came together. Since it is my intention to build my own copies of historical keyboard instruments in the future, the fortepiano built for this project has served as my apprenticeship to the craft of instrument making.

The original instruments that I examined firsthand form the basis for many of my conclusions about eighteenth-century Viennese fortepianos. The first and most important instrument that I inspected is a fortepiano built by Johann Andreas Stein, dated 1784. The Toledo Museum of Art currently owns this instrument. Philip Belt carefully restored this instrument in 1974. Along with my personal inspection, the restoration report and photographic slides provided valuable information about hidden interior parts.

The Smithsonian Institution in Washington, D.C. possesses a fortepiano built around 1788 by Johann Schmidt, a pupil of Stein (cat. no. 303,536). This instrument, along with photographs and file notes, provides contrast and confirmation of Stein's building methods and designs. I scrutinized a fortepiano dating from circa 1785 by another maker--Carl Hansen of Bamberg (cat. no. 299,852), as well.

The Smithsonian also provided plans, for a fee, of a fortepiano falsely-labelled as a Stein but now attributed to Johan Lodewijk Dulcken of Munich, built circa 1795 (cat. no. 303,537). These plans proved very useful as contrast and confirmation of Stein's work.

The Boston Museum of Fine Arts graciously allowed me full access to another fortepiano which Stein built in 1783 (no. 1977.63). This instrument is thought to be one of Stein's experimental combination instruments, a <u>Saitenharmonika</u>. The extra mechanism is long-since removed, but the fortepiano itself remains the primary interest.

The Metropolitan Museum in New York granted access to their files and inspection of several of their instruments. Two of the most interesting are a fortepiano with a pedalboard attachment attributed to Johann Schmidt (accession no. 89.4.3182)--once again falsely labelled as having been built by J.A. Stein--and a fortepiano by Ferdinand Hoffmann of Vienna, circa 1790 (acc. no. 1984.34).

The Shrine to Music Museum in Vermillion, South Dakota, granted me access to a recently-acquired Tangentenflügel built in 1784 by Späth and Schmal of Regensburg (cat. no. 4145), as well as to another copy of the Hubbard kit and other Viennese instruments.

Instrument plans, presumably accurate, provided additional information about instrument construction and design. The above-mentioned Dulcken plans from the Smithsonian Institution, along with late-arriving plans of pianos by Gottfried Silbermann of 1749 and Anton Walter, circa 1795, from the Germanisches Nationalmuseum in Nuremberg, proved indispensible. Photographic references in various books also clarified certain points.

I also had the good fortune to attend the Michigan Mozartfest symposium in Ann Arbor in November of 1989, where there were fortepiano copies built by present day American builders.

The term fortepiano as used in this paper refers to instruments with Viennese actions. These instruments were not necessarily built in Vienna. Fortepiano usually refers to Viennese instruments of the last half of the eighteenth century, 1749-1800, but it occasionally refers to Viennese-action instruments built from 1800-1845, but with citation to the specific maker. The instrument in use today is called modern piano, grand, or pianoforte. Contemporary English instruments with English-style actions are termed grand pianofortes. Piano is used as a generic term referring to the entire family of piano-type instruments.

The development of the piano family can be divided into four historical periods. The Incunabular Period, circa 1700-1750, covers the experimental era of the early piano, when many instrument designs were incomplete or unsatisfactory. The Classic Period, circa 1750-1800, was an era of stability and success, when piano design had its own sense of finality and completeness. The Transitional or Romantic Period, circa 1800-1860 (or 1880), was the era of expansionist piano design. Ever-louder tone, quicker repetition, wider range and a stronger frame characterized the rush towards the modern instrument. The Modern Period, circa 1880-present, has been the culmination of the prior era's quest. The success achieved at the beginning of this period has led to a decades-long stagnation in design.

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Photo by S.C. Davison

SECTION I

FORTEPIANO DESIGN

A SURVEY OF DESIGN

Musical instrument design begins with the tonal aesthetic. An instrument maker's otherwise diligent efforts will be directionless without a specific tonal ideal as the ultimate goal.

A tonal ideal is not achieved through vague means, nor is tone quality a purely subjective matter--as is often claimed in an effort to accommodate the tastes of others. Agreement as to what constitutes good tone is reachable by those experienced few who create it, whether as performers or instrument makers.

The imperfections in physical materials limit a tonal ideal, but the extent of these limitations is not obvious. While there may be an endless variety of faulty designs, there are only a handful of good ones. This is true of tone quality as well--while there are an infinite number of undesirable tonal results, there are only a few tonal possibilities that are aesthetically acceptable.

The faithful execution of a good design is equally important to the tonal end result. Sloppy work and faulty materials detract not just from structural integrity but also from tone quality. The slightest inattentiveness to detail may have grave effects on the final product.

Good hammer design can impart to fortepiano tone a bell-like quality that is considered the epitome of modern piano tone. However, this bell-like quality is more delicate on a fortepiano by comparison to the same quality on a modern piano. This ringing tone is attainable despite the thin nature of fortepiano timbre. The greatest sin of omission in fortepiano building is the lack of attention that many makers pay to this critical tonal effect.

Our assessment of fortepiano tone quality filters through our familiarity with the modern piano. Fortepiano tone, by comparison with the modern piano, is dynamically limited. It tends towards the soft end of the spectrum, and has a much thinner timbre as well. The bass is distinctly clearer because of this thinness. The fortepiano also has a shorter audible sustain time that makes staccato playing seem natural and unforced.

The fortepiano may have been considered a loud instrument to eighteenth-century musicians, but to modern ears it seems to be a quiet one. The fortepiano does not have the strong presence expected of a modern concert grand, especially when heard on musical recordings or in the modern concert hall. The delicate nature of fortepiano tone is best appreciated in an appropriate acoustical space.

There are three main factors of instrument design that determine fortepiano tone: soundboard construction, string scaling, and hammer construction. Each of the three interacts with the others. The soundboard transmits the energy of the vibrating strings to the air by trading duration for loudness. It accomplishes this through impedance matching. The other important function of the soundboard is to resist downbearing--the crushing downward force exerted by the strings upon the board.

String scaling is the theoretical process of determining specific string length, wire gauge, tension, wire composition, hammer striking point, string spacing and overall layout of the string band. Octave division--doubling and halving--is the foremost determinant of string scaling in the treble, but the physical limitations of string length modify scaling in the tenor and bass. Other considerations figure prominently in scale design, such as inharmonicity, and the strength of tensioned wire as expressed by its breaking point.

Hammer design and construction impart the greatest degree of variation in piano tone quality. A piano ultimately is a tonal success or failure through the crafting of its hammers. Hammer voicing is the manipulation of the hammer mass, the impact material and the contour of the hammer head's striking surface.

The instrument maker achieves the critical finishing details of hammer performance through hammer voicing. The manner in which the impact material deforms and therefore transmits its energy to the string determines how bright or harsh, how sweet or dull will be the tone. The mass of the hammer head helps to determine the hammer's potential for loudness and its quickness in repetition. The contour of the impact surface affects the excitation of harmonic partials in the string.

There are two other important categories of fortepiano design that are not directly related to tone production: case and action construction. The case primarily serves as a means to resist the crushing forces of the strings. Strings contract towards their natural resting point when they are under tension. The history of piano case construction has largely been the attempt to resist ever-increasing string tension. The case secures the edge of the soundboard, and it also serves as a convenient means of presenting the instrument to the performer.

The action is a mechanical intermediary between the performer and the strings. Ideally, it provides a predictable and measured response to the musical intentions of the player. The regulated mechanics of the action, coupled with the tonal performance of the hammers, defines the touch of an instrument.

Examination of the fortepiano's tonal possibilities in combination with the touch of the action mechanism provides insight into composition and performance. The idiomatic characteristics of an instrument play a prominent role in the music written and performed upon it.

Instrument-making traditions cannot be ignored when copying historical instruments. The established keyboard literature precludes much straying from the path of the original instrument makers. The early years of the harpsichord revival clearly demonstrate this rule. Modern makers applied new technology to an old instrument without sufficient regard for the musical consequences.[1]

The technology of past eras, however, is transferable into the technology of the present day by preserving the important characteristics of the old methods. Incidental aspects of obsolete methods can be replaced for practical reasons. The trial-and-error experiences of the original makers offer valuable guidelines that the modern copyist should not ignore.

The piano has radically changed over the last two centuries, but it is difficult to determine where one type of piano ends and a new type begins. Comparison between an eighteenth-century Viennese fortepiano and a twentieth-century grand piano reveal marked differences in volume, range, construction, and touch. However, it is much harder to decide whether a six-octave fortepiano built in 1810 is distinct enough from a five-octave one built in 1789 to consider them as separate instruments.

Design and context help us to differentiate among instruments in the same family. Differences in action design that result in a new touch or function might

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[1] Cf. Frank Hubbard, "Reconstructing the Harpsichord," in The Historical Harpsichord, Volume 1 (Stuyvesant, N.Y.: Pendragon, 1984), 1-16.

constitute a new type of instrument. Thus, the English-action grand pianofortes are considered distinct from the Viennese-action Flügel of the same era. String scale changes that alter melodic and dynamic ranges can change the way we view a keyboard instrument.

Musical context--the literature written for and the artistic use of a particular type of piano--helps to define an instrument. The bravado style of playing associated with Liszt and other Romantic pianists is appropriate to the louder pianos of the nineteenth century, but not to the eighteenth-century fortepiano. The eighteenth-century fortepiano, however, handles some harpsichord literature well. The harpsichord is more-closely related to the early fortepiano, musically and organologically, than it is to the modern grand. These two types of instruments are somewhat interchangeable. Eighteenth-century keyboard literature labelled "for piano or harpsichord" is not merely a sales ploy, but reflects their musical versatility.

Social context, interacting with technology, also affects instrument classification. For example, an instrument as soft in tone as the clavichord is legitimately played only in a private setting. The fortepiano serves well in intimate gatherings and as a vehicle to publicly display an individual performer's talents.

The modern pianoforte holds a long-exalted position because of its utility, versatility and unsurpassable design. The predominance of the modern grand fosters the common presumption that earlier pianos are inadequate. Many writers and performers assert that the music of the Viennese masters can be played as well or better on the modern grand, thus rendering the fortepiano unnecessary.[2] One may extend this argument by claiming that the harpsichord also is unnecessary, because much of the keyboard music of J.S. Bach likewise can be effectively performed on the modern grand. Contrasting piano designs from different periods now cast the modern instrument in a new light. The modern piano is legitimate as an instrument in its own right and for its own musical virtues, not because it borrows much of its literature from earlier eras. The Classic-era fortepiano should be considered as an equal member of the piano family with its own particular merits. It is not an inferior ancestor of the present-day instrument.

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[2] Cf. Cyril Ehrlich, The Piano, revised edition (Oxford: Clarendon, 1990), 1-26.

THE MEANS OF TONE PRODUCTION

String Scaling

String scaling, like almost everything in musical instrument design, is a truce in the battle between theory and practice. Theoretical string scaling occasionally calls for the ridiculous, while practical concerns reduce string theory to the physically possible. In addition, tonal aesthetics refine string scaling. The tonal possibilties truly are not endless. There are very few aesthetically-pleasing choices within the practical realm of scale design, and only a few other undesirable or haphazard alternatives.

The physical materials involved in string scaling by nature are imperfect. Every vibrating string introduces inharmonicity to a scale, due to the wire's inherent stiffness. Tonal aesthetics guide the scale designer towards the best compromise solutions. A good scale design favors harmonic congruency, in other words.

General musical considerations also guide string scaling and pitch. The chromatic scale and the ranges of the human voice and ear form the particulars and the outline of the string band's range. Keyboards center on the most sensitive area of human hearing, which is in turn best attuned to the human voice.

Scale design subdivides into two parts, establishment and duplication. Establishment is the particular arrangement of strings that will form the scaling within the range of one octave, and duplication is the octave doubling or halving of these fixed frequencies across the entire range of the instrument.

The operative principle of octave establishment is the imitation of natural string subdivision. A string of any given fundamental frequency provides the basis for other notes in the scale whose frequencies match (or nearly match) its overtones.

String length modification is another aspect of scale design. A practical problem in octave duplication soon arises with the low-frequency strings. Low bass strings theoretically become too long in proportion to the whole instrument. A keyboard instrument case would need to be outrageously long and lopsided in order to accommodate the theoretical doubling of low-pitched strings (see Figure 1, page 11). Long, slack strings also are uncontrollable, since they swing in relatively large arcs when set in motion.

Similarly, octave duplication only extends so far in the treble. Very short, high-pitched strings are stiffer and more inharmonic, difficult aurally to discern, and harder to accommodate between soundboard and nut. They have limited musical usefulness as well.

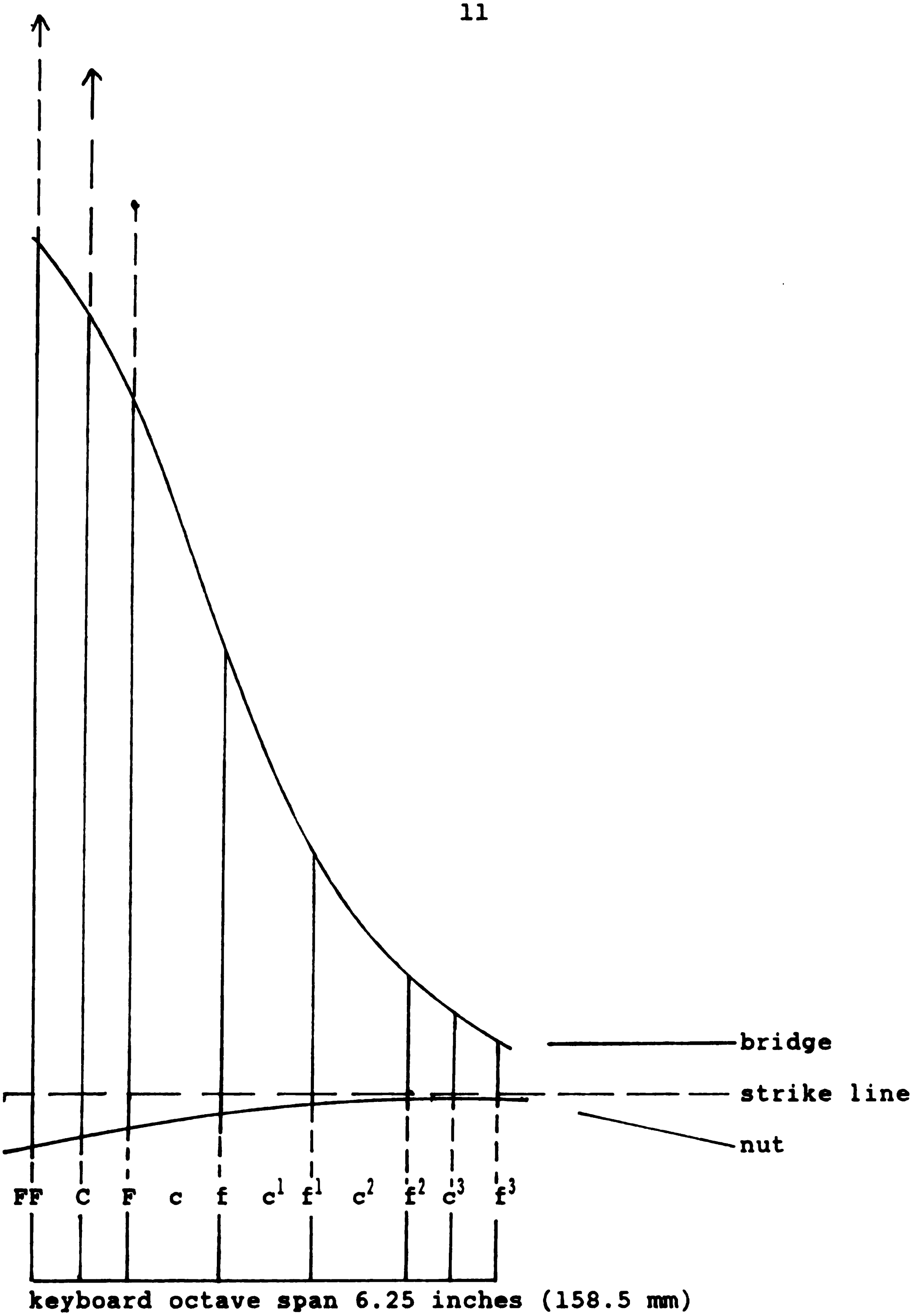

Figure 1. Just Scaling Compared to Compromised Scaling

Difficulties in perception and application often dovetail to define the outer limits of string scales. Musical interest and usefulness fades at the extremes of an instrument's range, but this is not completely true with regards to the high treble of eighteenth-century fortepianos. The high treble--e^2 to g^3--lies well within the standard melodic range. The melodic lines of many contemporary keyboard pieces run right up to the end of and seem hindered by the short keyboard. Nonetheless, achieving loud volume in the high treble of the fortepiano is difficult.

The instrument maker presumably begins to lay out his scale somewhere in the middle of the keyboard. Scales become increasingly distorted toward either end of the keyboard for mechanical and auditory reasons. The ends of the range thus are impractical and improbable starting points. It also is reasonable to exclude any note below c or even c^1 for use as a starting pitch, since many harpsichord and piano scales remain "just,"--i.e. near-faithful doubling and halving of octave pitches--only down to one of these points.

A maker also avoids beginning a scale too high in the treble so as to sidestep the problems of inharmonicity, difficulties in pitch perception, and modified string length. The use of a very short string as a starting point might cause major scaling inaccuracies after it is doubled in length several times. A starting pitch in the middle of the comfortable hearing range, with a string having low inharmonicity and easily perceived overtones, distributes any inaccuracies or compromises to both extremes. Any minor scaling errors that originate in the middle of the keyboard would be obscured at the already distorted ends of the range.

Present-day convention uses the sounding length of c^2 as a shorthand description of an entire scale. However, this convention is not necessarily legitimate when considering an original maker's scaling method. A maker might choose a whole-number measurement for the string length of his starting pitch if he preferred mathematically simple ideas. This pitch does not have to be c^2.

Starting length and pitch for a scale could be a tradition passed from master to apprentice or knowledge acquired by a journeyman. Stein, for example, came from a family of organ builders, and worked with several other instrument makers early in his life. The traditional methods of laying out organ pipe scales might have affected his approach to keyboard scaling.

A maker is likely to choose a scale starting pitch that simplifies his task. It is easy to eliminate any accidental notes as a potential starting pitch, since they function as keyboard compromises and as abstractions of simple musical theory. One might look directly to F among all of the naturals, since it often delineates the ends of the fortepiano keyboard and is a mentally convenient outline of the keyboard octave. C is another likely starting pitch. It is the most closely related note to F, and it is probably more important in scaling theory. Organ pipe scales are laid out in terms of the length of C pipes, and C's also frequently delineate the ends of keyboards. Extensions of range of a fourth or a fifth are the most common type of keyboard expansion. Many keyboards throughout history have alternated ending on F and C, and occasionally on G or A.

String scale subdivision within the octave in part is the convenient, condensed result of other processes. Keyboard octave span partially determines string spacing--the lateral location of a string on the bridge and the nut. The string unisons must follow the alignment of the keys and the hammers, since the natural keys are all of even width at their heads and the hammers are all evenly spaced. The theoretical octave span of the string band, as determined by nut/bridge layout, and the spread of the human hand both arguably influence keyboard octave span in return.

One must also consider the continuously curved bridge in relation to keyboard width, string spacing and string length. The bridge bevel would not form a smooth, continuous line if the maker specified the theoretical length of each chromatic unison when laying out the scale.

It is possible to have a smoothly curving bridge outline on a modern piano and still have string lengths that deviate from this outline. Bridge notching--which squares the bridge bevel to the strings--defines string length on a modern instrument. The harpsichord or fortepiano bridge, however, does not allow such precision for each unison. String length on these instruments depends on a continuous bridge bevel which runs parallel with the general outline of the bridge. Non-theoretical factors influence string length more on early keyboard instruments.

If a maker laid out the length and lateral spacing of several crucial notes a fourth or fifth apart and which encompass all of the bends in the bridge, then he could, in conjunction with the the keyboard octave span, establish the length and location on the bridge of all the other strings. Practical adjustments are made only where extremes of length such as the low bass and high treble intervene. The largest length of the bridge is a smooth, straight line.

Considerations of string composition and thickness foreshorten the bass end of the bridge, giving it an inward curve or a squared miter. Practical adjustments for hammer access and damping cause the bridge to curve almost parallel with the gap in the high treble. The long, continuous line of the bridge makes scale layout easier but represents a compromise in theory. It is also conveniently true that evenly spaced fourths, fifths, and octaves come out acoustically correct--more or less--with a straight-line bridge, given an allowable variation in string tension.

Wire drawing in eighteenth-century Europe was a specialized industry requiring skilled laborers and refined materials. The individual maker, then as now, did not have the resources to make his own metal strings. He depended on a comprehensive distribution network in order to acquire them. Presumably, early fortepiano makers utilized the same sources and therefore the same types of wire as did contemporary harpsichord makers. Neither of the two groups made music wire, and they were both quite dependent on only a few wire-drawing enterprises.

The wire available for stringing eighteenth-century harpsichords is divided into three types: red brass, yellow brass, and plain iron. Eighteenth-century fortepiano makers no doubt pitched their instruments the same as contemporary harpsichords and probably used the same-gauge wire for most every note. The wire used for any particular note on a fortepiano later increased in thickness as the demand grew for a louder instrument with a wider range. This trend, however, did not find full expression until the nineteenth century.

Grant O'Brien proposes that harpsichord makers designed their scales so that the tuned strings were near their breaking pitch.[3] A maker, laying out his scale, would begin the bass end of a run of a certain diameter wire with a lower-tensioned note, and end up with a higher-tensioned string--near its breaking point--at the treble side of the run. A wire of any gauge and composition thus would be pitched close to its most musically desirable tension, i.e., near its breaking point. The maker would change to the next-stronger type of wire when he neared or exceeded the actual breaking pitch of the former type.

The available music wire does not dictate musical style, but musical style operates within the context of the musical potential held by the wire itself. Thin bass strings on eighteenth-century fortepianos, for example, have a tonal clarity that does not carry over to their muddier modern counterparts. Fortepiano literature reflects this fact.

Wire gauging, or thickness, is very important to tone quality. Wire can be drawn into various diameters, whether it is made of iron or a brass/copper alloy. Drawing is a process whereby a metal rod is reduced to thinner and thinner diameters by being forced through a tapered hole. The drawing process aligns and strenghtens the outer fibers on the wire. The wire is then termed case-hardened. The more times a wire is reduced through drawing, the more case-

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[3] Grant O'Brien, "Some Principles of Eighteenth-Century Harpsichord Stringing and Their Application," Organ Yearbook 12 (1981): 160-176.

hardened it becomes. Thus, the smallest-diameter iron wires are proportionally harder than their thicker counterparts.

Wire must be as thin, as tensioned, and as structurally uniform as possible for musical purposes. The thicker a wire is in relation to its length, the stiffer it will be. Stiffness is the main cause of inharmonicity in any string. Strong, thin wire is more musically pleasing.

Hammer-striking-point is as equally important to tone as is string scale layout and composition. The arrangement of harpsichord registers clarifies this point. Very different tonal effects are obtained from the same harpsichord string, depending upon where along its length the string is set in motion.

The position of the bridge and the nut subtly help to determine the hammer-striking-line on a fortepiano. A nut that lies other than perpendicular to the line of the strings effectively alters the hammer-striking-point. It is obvious that fortepiano makers paid special attention to the hammer-striking-point on their instruments, since the nut curves away from the bridge in the bass, but curves right up to the gap in the treble.

The hammer-striking-line on modern pianos is laid out first, and the strings are then laid out to intersect it at their most favorable point of harmonic reinforcement. The traditional outline of the case on earlier instruments constricts the strike line. Most hammer-lines in fortepianos are square to the case front and spine. Walter's hammer-line, by contrast, smoothly angles backwards towards the bass in order to obtain a richer timbre from the brass strings. The angled hammer-line creates a smooth transition from the mid-length strings tp the bass. Universally, the treble strike-line is as near as possible to the nut end of the speaking length of the wires. The positive results to tone reinforcement garnered through proper striking-point are nowhere as obvious as on the shortest treble strings.

The length of each string in a single unison on the Toledo Stein, with its smoothly curving bridge and nut, vary from 2mm in the treble, to 10-15mm in the midrange and 20-70mm in the bass. This variance within a unison is enough to create a subtle difference in tone color at the striking-point, especially in the lower ranges. This length differential might be termed <u>tone-color mismatching</u>. The combined tone of the two struck strings of the unison is tonally richer than either one alone, and is a characteristic which separates early pianos from modern ones.

Soundboard Theory and Design

The soundboard, along with the string scaling and the piano hammers, also contributes to piano tone. It transforms the vibrations of the strings into a useful level of loudness by robbing them of duration. Rib-imparted spring tension simultaneously delays the eventual collapse of the soundboard from structural fatigue in the wood fibers. This intentionally added spring tension counteracts the downward force, or downbearing, of the strings. The bridge, which sits higher than the theoretical straight path of the tensioned strings, deflects the strings upward. This upward deflection creates a downward restoring force in the strings that would crush a soundboard that had no reinforcement.

Piano soundboards have a limited lifespan of ideal performance, despite major efforts to preserve them. A soundboard that loses its ability to counteract the downbearing of the strings sounds muffled and muddy. Over time, the soundboard might deflect downwards or warp and crack. These effects may be due in part to multiple temperature and humidity changes as well as downbearing.

Soundboard thickness must be proportional to string scaling. All fortepiano soundboards before 1800 are quite thin by comparison with the modern piano--about 3mm. They are also quite similar in thickness to harpsichord soundboards. This thinness is surely due to proper impedance matching between the strings and the soundboard. In truth, soundboard impedance is slightly mismatched to the strings, which allows the vibrating string to feed its energy to the board in small amounts over a musically-useful time span.

Soundboards are intentionally varied in thickness in order to facilitate board resonance. Some harpsichord makers theorize that the thickness of the board should vary according to where the various adjunct members, i.e., the rails, bridges and ribs, attach to it. Thicker areas inhibit vibration and thinner areas facilitate vibration, according to this theory. The soundboards on most modern pianos are thinner at the edges in order to enhance vibration right up to the rigid border, where the board meets the frame. This thinness, together with the arched ribs, imparts a natural, upward dome to the board. Fortepiano soundboards incorporate design aspects of both harpsichord and modern piano soundboards.

A properly constructed soundboard has a good balance between resonance and sustain time over the entire range of the instrument. Too much resonance results in a short sustain time and a harsh, loud tone. Too much sustain time mimics a freely vibrating string by having a long duration and insufficient volume.

The adjuncts to the soundboard are essential factors in tone production and board strength. The ribs on Stein's fortepianos serve the contradictory functions of adding rigidity to the soundboard while at the same time not inhibiting the board's acoustic responsiveness. Stein's ribs taper from full-size at the spine to nearly nothing just before the bentside land. They cantilever out from the spine edge of the frame, and they support the board like brackets support the underside of a shelf. The ribs impart most of their rigidity to the board on the "dead" side of the cutoff bar. This arrangement leaves the narrow band of "working" soundboard between the cutoff bar and the hitchpin rail with as little restriction as possible.

The ribs on Stein's pianos taper severely towards the bentside after passing through notches in the cutoff bar. The ends of the ribs overhang but avoid the bevelled top edge of the bentside liner. The ribs are very thin underneath the bridge, which is the point of greatest string downbearing. Therefore, the soundboard relies mainly on the strength of the glued-down bentside edge, the cutoff bar itself and the thicker ends of the ribs, which lie beyond it in the dead area of the board, to counteract the downbearing of the strings (see Figure 2, page 23).

Stein's instruments have six evenly spaced ribs at right angles to the mean line of the bridge. The ribs run diagonally across the soundboard, closer to the front on the spine side. Five of the ribs are similar in profile and vary slightly from each other in thickness and in height--depending on their length and the amount of the board that they span. The sixth rib is a flat, short, and broad strap that thickens and strengthens the board near the tail. This

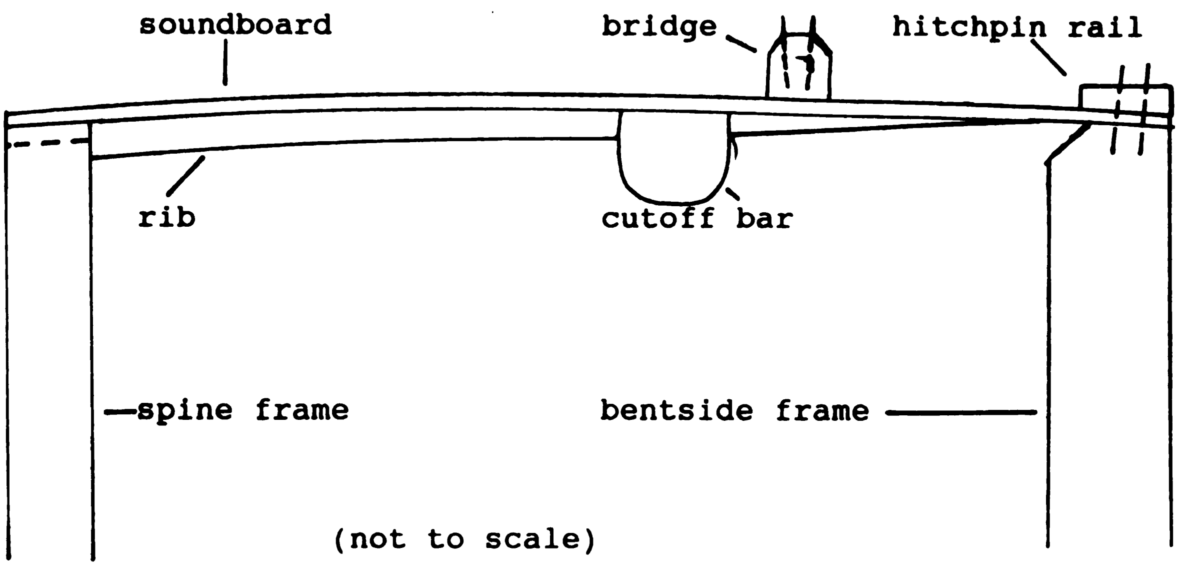

Figure 2. Profile of Stein Rib, Bridge, and Soundboard

strap rib is a structural compromise that fits into a small area. There is not enough space at the narrow soundboard tail to accommodate a typical, thick rib that has an immediate taper at its intersection with the bass bridge.

The fortepiano soundboard overhangs the belly rail a considerable amount in order to align the hammer-striking-line with the backward facing hammers. This design is unusual by comparison with the soundboards in English-action grand pianos. Most of the overhang is nonessential. A wide strip of wood, the apron, is glued to the bottom side of the board, and reinforces the overhang.

However, the overhang in the high treble, e^2-f^3, functions as a working part of the soundboard. The bridge sits somewhat unsupported in this region of the board, and has less soundboard area around it in comparison to the rest of the bridge.

Tone quality suffers from the lack of rigidity at the edge of the soundboard in the high treble. Stein attached three oddly-arranged, experimental ribs to that area of the board in order to counteract this tonal deficiency (see Figure 3, page 25).[4] Walter ran his ribs on a diagonal opposite to that of Stein's ribs, which allowed him to run a long rib from the spine all the way into the narrow beak, or high treble corner, of his soundboards. Thus Walter's ribbing is more consistent than Stein's, while it simultaneously stiffens the vulnerable and weak high treble.

This experimental ribbing coincides with triple-stringing of the last octave or more of treble notes that one finds on most fortepianos. However, neither of these efforts seem to completely resolve the problem of tonal deficiency in the high treble of fortepianos.

There is a detrimental effect on tone quality and volume in a modern piano if the soundboard edge becomes unglued from the belly rail. This is especially true in the

[4] See The Piano, The New Grove Musical Instrument Series (New York: W.W. Norton, 1988), p.17, photo 7c. This photo is of the Nuremberg Stein. The author's personal copy of a photographic slide of the restoration of the Toledo Stein shows a slightly different arrangement of high treble ribs. The Hubbard kit completely omits these ribs.

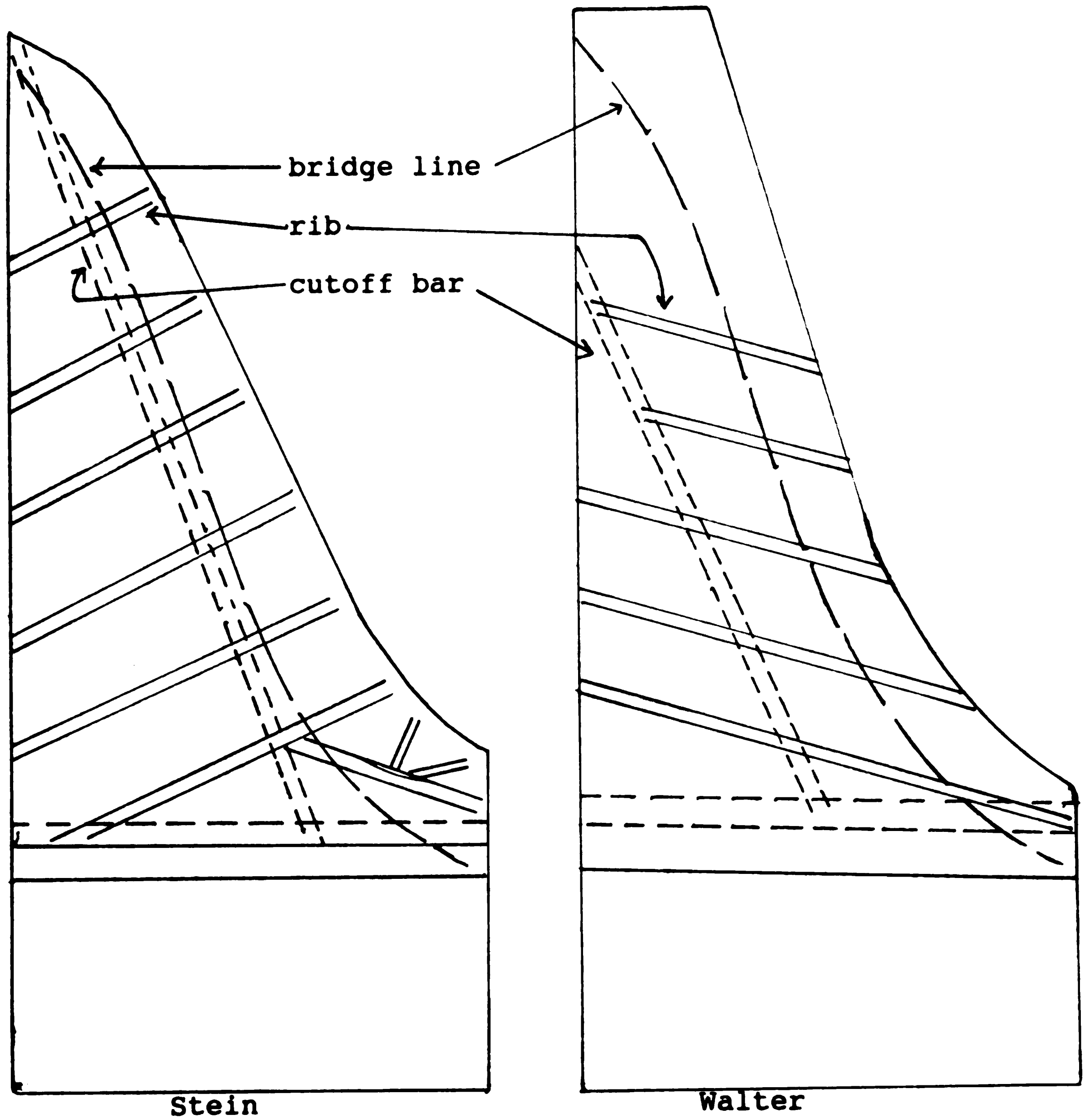

Figure 3. Rib Configuration, Stein vs. Walter

high treble, where there is little soundboard and the bridge lies close to the edge of the board. The free-hanging edge of the fortepiano soundboard in the high treble may dissipate some of the board's vibrational energy, in a manner similar to an unglued soundboard edge in a modern piano. A doubly reinforced edge that imitates the effect of a solid rail, and which extends further forward to give slightly more soundboard area, might resolve the problem of weakness in the high treble.

Stein's rib design boldy breaks with harpsichord tradition since his fortepiano ribs extend directly underneath the bridge. Most harpsichord soundboards are ribbed only in the dead portion of the board--the front left corner. The ribs under the bridge in Stein's instruments help to bear part of the downbearing and to distribute vibrations across the grain of the board, even though they have a severe taper.

Thin, tapered ribs are a tentative attempt at soundboard bracing underneath the bridge. Stein might not have been afraid to extend thicker ribs beneath the bridge if he had thought that the ribs would enhance soundboard resonance. The irregular bracing found on Stein's instruments in the high treble indicates a need for more volume in that area--theoretically obtainable through greater board stiffness. This arrangement seems to contradict the rib tapering under the rest of the bridge.

Thin, tapered ribs may therefore be Stein's compromise solution between enhanced resonance and soundboard support.

A piano built by Gottfried Silbermann, dated 1749, has characteristic harpsichord ribbing (see Figure 4, page 29).[5] All of the ribs end at the cutoff bar, in the near left-hand corner. The Broadwood firm was still barring its soundboards in this manner in 1798.[6] Walter cut a shallow gap in his ribs directly beneath the bridge, theoretically leaving the soundboard more free.[7] Walter's ribbing style keeps the soundboard thin where auxilliary members (the bridge) attach to it. The ribs theoretically would add stiffness to the board directly beneath the bridge and thus inhibit its vibrations. The Smithsonian Schmidt has ribbing that is quite similar to Stein's ribbing, but the ribs are not continuous from one side of the case to the other side.[8] The long ribs do not extend past the cutoff bar. The short ribs, which lie beneath the bridge, are tapered on

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[5] Gottfried Silbermann, Piano, Freiberg, Saxony 1749, plan and elevation number MI 86, drawing by Antoine Leonard (Nuremberg: Germanisches Nationalmuseum, 1984). The action mechanism of this instrument is modelled on Cristofori's.

[6] Edwin M. Good, Giraffes, Black Dragons and Other Pianos (Stanford, California: Stanford University Press, 1982), 88, figure 3.5.

[7] Anton Walter, Hammerflügel, Vienna circa 1795, plan and elevation number MINe 109, drawing by Susanne Wittmayer (Nuremberg: Germanisches Nationalmuseum, 1974).

[8] Johann Schmidt, Viennese fortepiano, catalog number 303,536, photo nos. 56408-B, D, and F (Washington, D.C.: Smithsonian Institution).

both ends. These short ribs also are much thinner than their long counterparts on the dead side of the board. There are ten short ribs, in contrast to only six of the long, thick ribs. This soundboard has warped downwards around the bridge after two hundred years' time, which indicates that there is a structural flaw in Schmidt's design.

The Smithsonian Dulcken has a combination of ribbing styles (see Figure 4, page 29).[9] The dead area of the board, beyond the cutoff bar, has thick ribs that run at a right angle to the spine--a typical harpsichord design. However, the ribs that lie underneath the bridge are thinner and discontinuous. Six thin strap ribs run beneath the bridge in the working area of the soundboard. The strap ribs run perpendicular to the bridge, from the cutoff bar to the bentside.

The above evidence suggests that fortepiano makers were wary of bracing the soundboard directly under the bridge, but that there was a compelling need for some bracing. The discontinuous nature of the ribbing beneath fortepiano bridges also suggests that the beneficial effect of cross-grain transmission of vibrational energy either was not of primary concern or was unknown to early fortepiano makers.

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[9] Johan Lodewijk Dulcken, Fortepiano--Munich circa 1795, plan and elevation, catalog number 303,537, drawing by Thomas Wolf, Sheridan Germann and J. Scott Odell (Washington, D.C.: Smithsonian Institution, 1975).

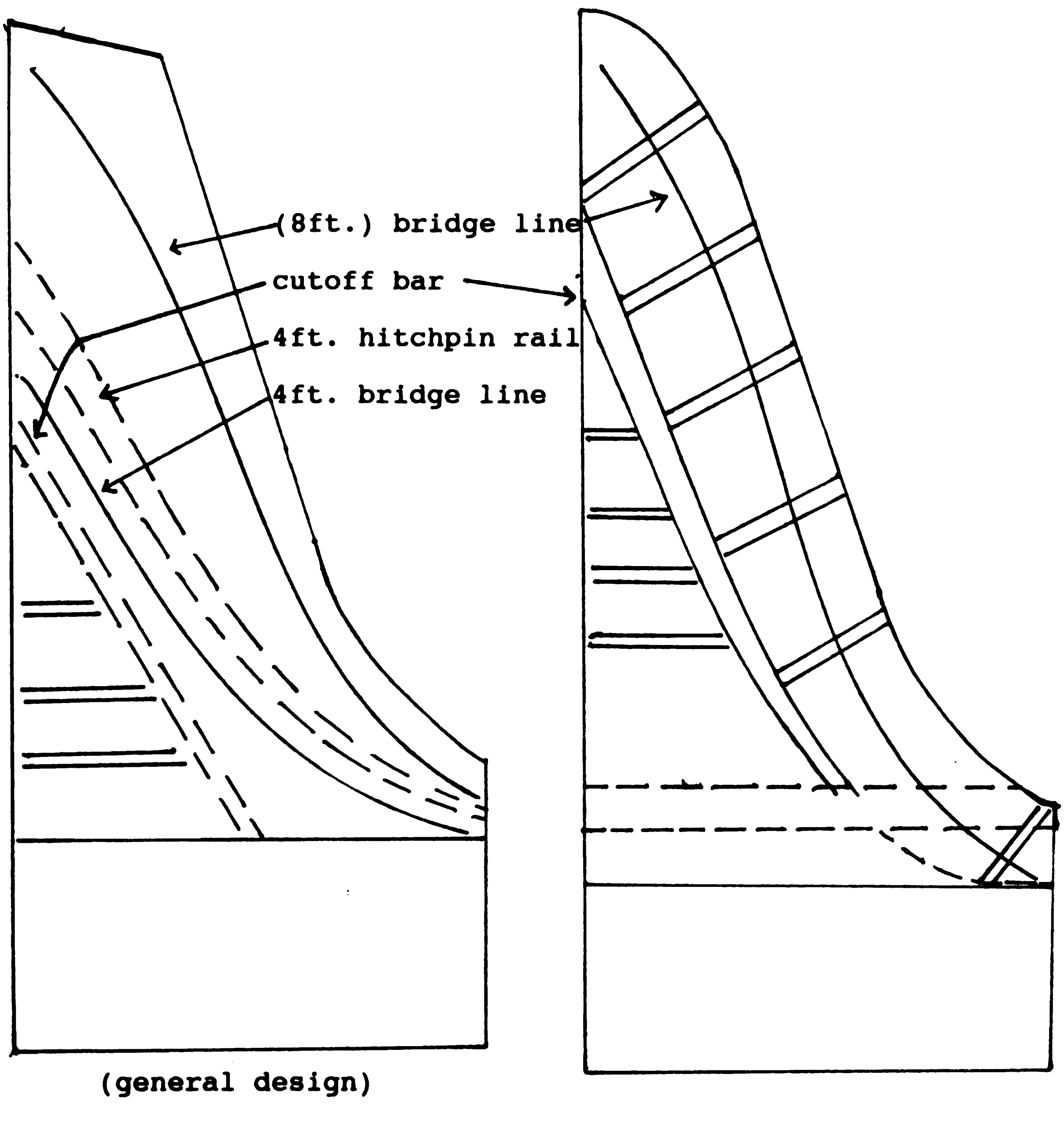

Figure 4. Rib Configuration, Harpsichord vs. Dulcken

Alternately, one can argue that early fortepiano makers were aware of the benefits of cross-grain transmission of vibrations, but that they were concerned only with the working area of the soundboard. Thus, it would be acceptable to have thick, deadening ribs on one side of the cutoff bar but not on the other side.

Stein's ribbing method--more than that of any other early piano maker, is the closest forerunner of modern ribbing methods. Stein's ribs are continuous--they run nearly all the way across the soundboard from side to side; they run cross-grain, which enhances soundboard resonance; and they run on the same diagonal as modern piano ribs, from nearby on the bass side to further away on the treble side.

The cutoff bar is a long, thick softwood strip, usually the same material as the board itself. It limits the area of the soundboard that the strings drive. The actual area free to vibrate is a surprisingly small percentage of the whole board. Instrument makers theoretically can make smaller soundboards, but the supposedly "dead" area of a board may actually contribute something to the total output of the whole instrument.[10]

The cutoff bar on Walter's fortepianos is much farther from the bridge than it is on Stein's instruments. There are wider bands of freely vibrating board, approximately

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[10] Edward L. Kottick, "The Acoustics of the Harpsichord: Response Curves and Modes of Vibration," Galpin Society Journal 38 (April 1985): 55-77.

equal in width, on either side of the bridge. Stein placed his cutoff bar very close to the bridge, similar to a four-foot hitchpin rail on a harpsichord. However, there is no pressing need in a fortepiano to crowd together soundboard accessories from both sides of the board, as is necessary on a harpsichord with both a four-foot and an eight-foot bridge.

The bridge is the highest point the strings travel across, so they form sloping angles on either side of it. Downbearing is caused by the upward deflection of the strings to the height of the bridge as compared with the height of the hitchpin rail and nut. Downbearing also pushes the soundboard downwards as the strings attempt to conform to a straight line between their terminals. The lower tension of early fortepiano strings, however, causes minimal deflection of the board.[11]

The tops of the nut and the hitchpin rail do not always lie at the same height. However, the downbearing angle is formed not only by the difference in height between bridge and nut or hitchpin rail, but also by the distance between each pair. In the Toledo Stein all three rails increase in height towards the bass, but downbearing angles are not

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[11]I conducted an experiment with downbearing that showed little or no soundboard deflection. The results were somewhat inconclusive, due to the difficulty of measuring deflections in thousandths of an inch with crude devices. One may conclude, however, that there is no <u>severe</u> downward deflection of the fortepiano soundboard.

necessarily the same on both sides of the bridge.

Stein's bridge profile is fairly simple--a square block with chamfered edges. The pins are inserted at the upper corners where the bevels meet the top face. The nut on the Toledo Stein is also simple, and is reminiscent of a harpsichord nut. It has a rounded front and a square back, with an upper bevel connecting both. The pins are driven in at the top point. The terminal ends of the strings meet both the metal pins and the wood of the nut or bridge at the same point in both cases. This positioning is not always the case, and is an area of dispute among makers then and now. Some makers insist that there is better transmission of vibrations when the string meets the metal pin before the wood of the bridge. This concept contradicts modern piano theory, where the string simultaneously meets the pin and the bridge top to avoid false-beating.

The bridge couples the strings to the soundboard in a simple progression. First, downbearing creates a positive connection between strings and bridge. Next, the metal pins aid in transferring vibrational energy into the bridge itself. Finally, the hardwood bridge transfers vibrations along its length, through the glue joint, and into multiple runs of soundboard grain--thus exciting the entire board.

The hitchpin rail, like the wrestplank, must secure the ends of the strings. It should be made from a hardwood in order to hold the hitchpins firmly in place. The hitchpin rail is glued on top of the soundboard which in turn is glued to the bentside land. The hitchpins are driven down into the bentside frame in order to benefit directly from the strength of the entire frame. The hitchpins are bent back in line with the length of the strings in order to prevent the loops from slipping off. Each string has its own eye-loop, unlike the modern practice of sharing one hitchpin and string for every two notes.

The nut, which is glued to the wrestplank veneer, is also made from a hardwood. All pieces that have metal pins to hold or direct the strings must be made of some type of hardwood. Lateral string tension would eventually crush softwoods and tear the pins out of their holes.

The bridge and nut pins not only delineate the sounding lengths of the strings, but also align them laterally over the hammers. The back pins on the bridge help to create side bearing as a further way to keep the strings firmly planted. The back pins also direct the waste ends of the wire to the hitchpins.

Soundboard thickness and surface area are proportional to the string gauging on a keyboard instrument. The greater the string tension, the stronger must be the resistance. The lesser the tension, the lighter must be all of the attendant parts. The thin strings and slight downbearing of a pre-1800 fortepiano require a thinner soundboard with less reinforcement than even a six-octave instrument built in

1815.

Hammers and Tone Production

The method and materials employed to excite the strings of a keyboard instrument make a critical contribution to tone quality. Piano hammers decide the ultimate tonal qualities of a piano, even on an instrument of otherwise impeccable design and execution. This influence is due not only to variation in hammer design and construction, but also to the many possible tonal nuances arising from the manner in which a string is set in motion. Not every possible tonal quality is aesthetically acceptable, but musical and social context partly determine acceptability.

Most piano hammers present a round profile to the strings. However, the range of profiles varies from a perfect arc to a pointed tip. Different hammer profiles cause very different tonal results, since the hammer momentarily remains in contact with the string. In general, the smaller the length of the string which the hammer directly contacts, the greater will be the number of overtones which remain undamped. The more pointed the hammer, the brighter will be the sound. The broader the face of the hammer, the duller will be the resulting tone. Hammer size and shape is also proportional to string length and thickness, just as the relationship between the strings and the soundboard is proportional.

The damping effects of a hammer aid in classifying it as broad or pointed. The overtone wave segments on the string shorter than the segment of string that the hammer contacts will be damped by the hammer. The hammer profile helps to determine which harmonics will predominate in the tonal mixture of a given note. The combination of undamped partials created by the striking hammer forms the most variable component of tone quality. String composition and soundboard construction are the other two determinants of tone quality.

The hammer covering must be elastic in order to transfer energy from the hammer to the string. The means of exciting the string must always be more pliable than the string itself. The strings eventually have a detrimental effect on the hammer covering by slowly forcing it to conform to the shape of the more resistant material--the music wire. Hammers must have enough resiliency to retard this process while still performing their appointed task.

Hammer mass and momentum determine the force with which a hammer attacks its string. This force must be proportional to the strength of the string itself. Too large a force will break a string. It follows that the stronger a string is, then the louder it can be made to sound. Fortepiano strings, being much thinner, cannot withstand the force needed to make them as loud as their modern counterparts.

Hammers must be as light as possible in order to be as quick as possible while still maximizing their dynamic potential. They must deliver quick repeated blows to the strings, and they therefore must have low inertia. A hammer head of larger mass may deliver more energy to the string but it will be slower to recover, so the maker must compromise between the two variables.

The hammer surface material that contacts the string has a direct affect on the tonal results. The more forceful the blow is, the deeper is the amount of the impact material involved in the tonal result. A very light impact may involve only the very surface of the hammer covering. Ultimately, tonal effects vary with how the material deforms down to the wooden molding itself.

The wooden molding is not to be tonally disregarded, either. Its shape helps to determine the final profile of the striking surface, since it is the hard foundation of the hammer. Its mass figures largely in the overall weight of the hammer head, so it must be strong yet light. The amount of (indirect) access that the string has to the hard molding figures prominently in the loudest dynamic range of the instrument.

The Boston Stein of 1783 has unusual hammer heads that are completely round, and have a large hole drilled through the center of each molding (see Figure 5, page 37). They rest in a semicicrcular depression on the end of the hammer shank, and a leather strap wrapped around the shank and through the hole in the molding secures them to their mounting. One thin layer of leather is glued onto the rounded upper surface of the treble hammers, and two layers on the bass hammers.[12] A similar design is found on pianos by J.H. Silbermann of 1776,[13] and by Gottfried Silbermann of 1749,[14]--presumably patterned after the Cristofori hammers of 1726.[15] Stein may have obtained the idea for these round hammers from Johann Andreas Silbermann, since he

profile front

Figure 5. Stein Hammer Molding, 1783 (Boston)

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[12] John Koster, "Grand Piano (originally Saitenharmonika?)," Keyboard Instruments at the Museum of Fine Arts, Boston, unpublished manuscript, (Boston, 1989). The bottom layer of leather is glued on to the entire surface of the molding, which is atypical, and ends around c^1. It tapers in thickness from bass to treble, and there is evidence that it extended to the very top. The top layer is of uniform thickness and is applied normally, with only the ends glued down. The total thickness of both goes from 3mm in the bass to .8mm in the treble.

[13] Rosamond Harding, The Pianoforte, 2nd edition (Old Woking, Surrey: Gresham, 1978), 38, fig. 26.

[14] G. Silbermann, plan no. MI-86, Germanisches Nationalmuseum.

[15] Harding, 28, fig. 18.

worked for him in Strasbourg from 1748-49.

This style of hammer cannot be evaluated tonally since the Boston Stein is not in playing condition, but the long-lived concept of round, hollow moldings has interesting implications. Cristofori's round hammer heads were made from a parchment strip rolled into a cylinder, while Gottfried and J.H. Silbermann's round hammer heads are made of paper.[16] Stein made his round hammer moldings out of a hardwood, which indicates he was either searching for an easier method of making them or for a sturdier base for the leather covering that would yet--with the hollow center--maintain a light weight. Stein's solution fulfills both requirements.

Stein and other makers also used other types of hammer heads. A drawing in Pfeiffer shows a Stein hammer, supposedly from 1773, with a later hammer molding style and multiple layers of leather.[17] The hammer moldings of the 1784 Toledo Stein have a rectangular profile, but with rounded tops and shoulders (see Figure 6, page 39). The moldings taper at the bottom to narrow points. The four vertical corners have petite, scalloped cuts for fine voicing. The bottom of the molding has a v-shaped gouge

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[16] John Koster, personal letter of September 25, 1989. See also Koster, "Grand Piano...Saitenharmonika?."

[17] Walter Pfeiffer, The Piano Hammer, trans. by J. Engelhardt (Frankfurt am Main: Verlag Das Musikinstrument, 1978), 87, fig. 67.

that is tenuously glued to the round hammer shank. The moldings graduate in thickness from treble to bass with the treble hammers being the smallest. Their uniform width allows each of them to strike all two or three strings of their respective unison. There is one thick layer of leather on the rounded top.

profile front profile front

(bass) (treble)

Figure 6. Stein Hammer Moldings, 1784 (Toledo)

There are three different styles of hammer leathering from Stein, as well as two types of hammer molding, in the above examples. Other makers show various degrees of agreement and contrast with Stein. An action elevation of hammers built by Stein's children, Nannette and André, shows hammer moldings remarkably similar to the Toledo Stein, with one layer of leather.[18] Johann Schmidt, Stein's "pupil,"

[18] Nannette and André Stein, Fortepiano, Vienna circa 1800, elevation of fortepiano action, instrument accession no. 64.252, drawing by H.L. Smith (New York: Metropolitan Museum of Art, January 1976).

also made hammers with one layer of leather covering, with some similarity to the Toledo Stein.[19]

Other makers also resorted to multiple layers of leather. The Cristofori piano of 1720 has two layers of leather.[20] The elevation drawing of the circa 1795 Anton Walter fortepiano in the Germanisches Nationalmuseum shows a graduated approach to hammer leathering, with three layers in the bass and middle and two in the treble. Makers added still more layers of leather in the early nineteenth century, which later were covered with a strip of felt.

The variation in hammer head design indicates the makers' dissatisfaction with their tonal results. Too many layers of leather immediately dull fortepiano tone to a great degree, making an instrument all but useless. One or two layers of leather, or even bare wood, provide a wider dynamic range, but this arrangement easily leads to an unpleasant harshness. Later and larger instruments with thicker strings were able to accommodate thicker hammer coverings, so multiple layers of leather later became

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[19] Johann Schmidt, Hammerflügel, Salzburg 1790, action elevation M.I.Ne-100, drawing by Friedemann Helwig (Nuremberg: Germanisches Nationalmuseum, 1968). The Hammer covering is vague. Also, Johann Schmidt, Piano, instrument accession no. 89.4.3182 (New York: Metropolitan Museum of Art) photograph no. 218884 ff. The photo shows a taller molding on the hammer, and a three-quarter round head.

[20] Bartolomeo Cristofori, Piano, Florence 1720, elevation of action, instrument accession no. 89.4.1219, drawing by Stewart Pollens (New York: Metropolitan Museum of Art, 1978). View of lowest bass hammer.

standard. Leather did not maintain its prominent position, however, and its utility as a hammer covering is questionable.

Leather is elastic by nature, but in a manner different from compressed wool. Leather responds to tension by losing some of its elasticity. Leather works better, for example, as a drumhead--which can periodically be re-tightened--than as the covering on a fragile hammer molding.

Nor does leather compress in the same manner as tensioned felt. When the string strikes a leather hammer covering it does not benefit from an elastic rebound the way it does with a tensioned felt hammer. Leather has more elasticity across its face than through its thickness--and this does not aid in the transfer of energy. Leather acts like a pad that cuts the harshness of the wooden hammer molding. The fact that Stein used one moderately thick pad of leather on his later hammers seems to confirm that he sought balance between loudness and harshness. This arrangement probably was a reluctant compromise.

The voicing of leathered hammers is affected by the type of hammer covering. The thickness and hardness of the leather largely determines the resultant tone quality. The very thin surface of the leather is also important. Hammer leather always has the buff side facing the strings, in order to cut the harshness of the hide's top grain.

A hammer must be evenly voiced with its immediate neighbors and with the entire keyboard, as well. Voicing leathered hammers for dynamic continuity is accomplished by altering the mass of individual hammer heads. Tone color can vary remarkably from one end of an instrument to another without being aesthetically disturbing, as long as the transition is slight and smooth from one note to the next. The effort that a performer expends to achieve the same dynamic level from one hammer to another must seem like a smooth transition.

An instrument must have dynamic balance over its entire range. The bass accompaniment must not overwhelm treble melodic lines, but should be loud enough to support melodies. The high treble must be able to act as harmonic reinforcement, neither being too weak so as to add nothing, nor too strong to draw attention away from the mid-range of the instrument. Smoothness, regularity, predictability, and balance are the characteristics of fine hammer voicing.

CASE CONSTRUCTION

The Bottom and Frame

The case and the action are independent units. They are separately constructed and later united to form the entire instrument. The case of a keyboard instrument functions not only as a piece of furniture but also as a load-bearing structure. A soundly designed case resists the crushing force of the strings while maintaining its shape. It directs the sound, protects delicate parts, and provides easy access for playing.

The case is composed of three major elements: the framing, the wrestplank, and the bottom; the soundboard and the strings; and the sides, lids and legs. The first set resists string tension, the next deals with with tone production, and the last has ancillary functions.

The bottom protects the soundboard and creates an enclosed space. The bottom is also a mount for the legs and a shelf for the action. Some of its intended functions are indispensable, while others are less useful.

All fortepianos built before 1800 have closed bottoms. Not until the arrival of six-octave pianos did the bottom gradually begin to disappear. At first, makers cut a large square hole--which was covered with a screen, in the center of the bottom.[21] Makers eventually eliminated the screen and the entire bottom except for the keybed. The burden of structural strength was initially thrust upon the wooden frame and later upon the cast-iron plate.

Makers construct instruments with bottoms in one of two ways: either from the bottom up or from the frame down. With the former method, the maker cuts out the bottom and marks the postions of the framing members, which he then lays out upon the bottom. Knee braces, diagonal braces, and cross-frames, which need a lower surface to rest upon, characterize instruments built in this manner. The maker begins with the framing members in the frame-first method of construction, and then attaches the bottom to the complete frame. Stein and his followers built their instruments in this latter style. Stein's fortepianos also have cross-frames and diagonal braces that rest on the bottom and make it an integral part of the structure. His method of framing, however, is much less dependent on the bottom than the methods of other makers.

The bottom boards on many Viennese fortepianos are made of spruce or another softwood, and they are approximately one inch thick. They consist of a few wide planks joined

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[21] This observation is based on a personal inspection of a modern copy of a six-octave fortepiano from 1816 by Nannette Streicher, and also of a Steinway grand from 1876, where the bottom has an open, rectangular hole but still retains wide perimeter planks whose grain runs parallel to each adjacent side.

together. Stein used a cruder grade of lumber for his fortepiano bottoms. Narrow, knotless boards with even grain are more stable, but using them involves more labor.

The thickness of the bottom makes it rather inflexible and thus lends rigidity to the entire case. The bottom attaches to the frame with hide glue, wooden pegs, and dowels. The outside face of the bottom, and on occasion the spine, often have a brownish stain applied to them.

The bottom boards on Stein-type instruments are cut to shape with the grain running parallel to the bentside rather than to the spine, as is customary with harpsichords. There is some speculation that this grain orientation strengthens the cheek-bentside corner.[22] Early keyboard instruments are prone to "cheek disease," where the case bends upwards at the cheek due to overwhelming string tension (see Figure 7, page 46). Others claim that cheek disease is caused by weakness at the keybed/bottom joint, in instruments where the grain of the keybed runs at right angles to the grain of the bottom (which in this instance runs parallel to the spine).[23] This problem plagued instrument makers until the invention of the cast-iron frame.

Twisting of the wrestplank, and shearing of the soundboard and hitchpin rail a few centimeters from the inner rim of the cheek, characterize cheek disease. The

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[22] John Koster, personal letter of September 25, 1989.

[23] Conversation with Larry G. Eckstein, August, 1990.

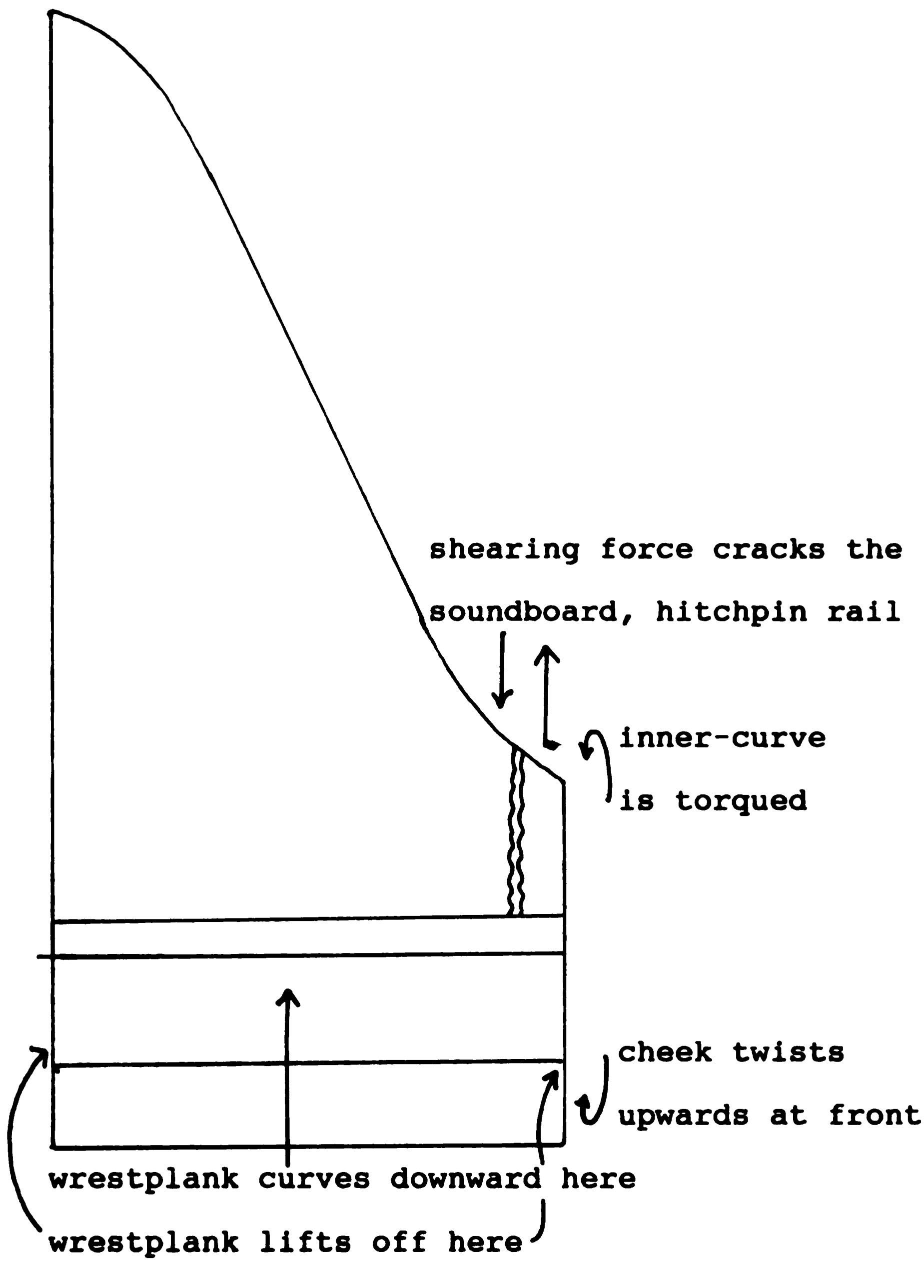

Figure 7. Effects of Cheek Disease

straight grain of the bottom boards would better resist cheek disease if they ran at an angle to this shearing force. However, cheek disease is sometimes found even in fortepianos where the bottom boards do run parallel to the bentside. Some instruments have an additional set of broad planks that run parallel to each side around the perimeter of the bottom. They serve not only as leg mounts but as further strengthening elements. Even so, cheek disease sometimes occurs in these instruments, as well.[24]

The practice of cutting the bottom boards with the grain parallel to the bentside is somewhat baffling. Sawing acute or obtuse angles on both ends of the individual boards is tedious work. Also, this grain orientation contradicts the rectangularity of the overall design, where the right angle formed by the line of the front and the line of the spine form the simple basis of the instrument's layout. The grain of the bottom boards normally runs parallel to the spine in many keyboard instruments. Diagonally-oriented bottom boards diagonally mitigate the effects of cheek disease, but this is not the final answer to structural strength.

Makers dispensed with the bottom even before the complete cast-iron frame made its appearance, thereby

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[24] The fortepianos by Ferdinand Hoffman (Metropolitan Museum of Art: accession no. 1984.34), and Johann Schmidt (Smithsonian Institution: catalog no. 303,536) have cheek disease.

confirming that the frame alone bears most of the string tension. The bottom really has less-important role in structural strength.

The frame serves several purposes. It counteracts the string tension, serves as a landing for the edge of the soundboard, holds the tuning pins and nut on the wrestplank, and is a ground to which the case sides proper are attached.

The frames of harpsichords and early pianos differ greatly from most modern pianos in that they are entirely pieced together. Modern grand pianos have a laminated, continuous rim joined with cross-frames in the center and the front. Successful load bearing is the most critical aspect of a keyboard instrument. A greater number of joints in the framing presents more opportunity for instability. Stein has an efficient framing design with comparatively few pieces.

Stein's fortepiano frame has eight main pieces: the spine, bentside, inner and outer curves, belly rail, cheek, and two cross-frames (see Figure 8, page 49). In addition, there are three diagonal braces and the wrestplank. The frame outlines the form of the case, and is itself delineated by the string band. The belly rail, cross-frames, and wrestplank span the distance between the outer frame members, and the diagonal braces cross from the top of the bentside to inner corners.

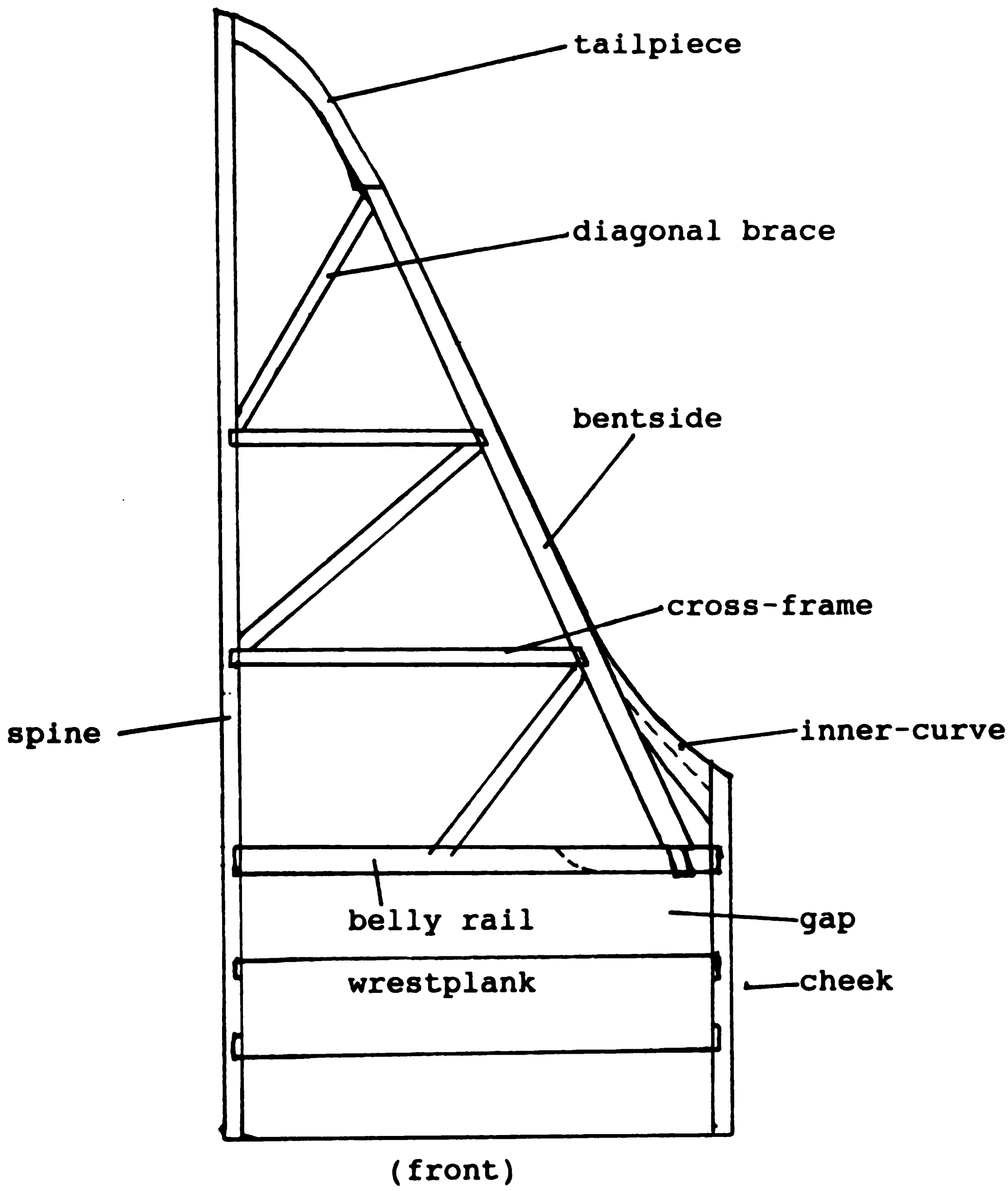

Figure 8. Stein Framing, 1784 (Toledo)

The frame members of Stein-type fortepianos are made of spruce or pine. This deviates from the harpsichord-making tradition, where the case sides are softwood and the liners (or frame) are hardwood. The frame members, while not really liners, are thick enough to compensate for some of the rigidity lost from using a softer wood. The wrestplank is made of hardwood such as oak or maple, in order to maintain tight holes for the wrest pins.

Stein did not employ high-quality lumber in the frame. Photographs of the Nuremberg Stein reveal large knots in the bottom planks. There is visual evidence that knots like these are responsible for the large cracks in the bottom.[25] The Toledo Stein has large knots in the bentside and tail frames.[26]

Fortepiano framing design is somewhat reactionary. A case might consist only of the sides, with little interior framing, if that alone could resist the pull of the strings. Soundboards likewise might not have ribs if they were strong enough to resist downbearing. At first, case reinforcement probably consisted of knees--triangular pieces of wood that fit in the corner between bottom and sides. Knees solve the immediate problem caused by the string tension pulling the

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[25] The Piano, Grove Musical Instrument Series, 17, photo 7a.

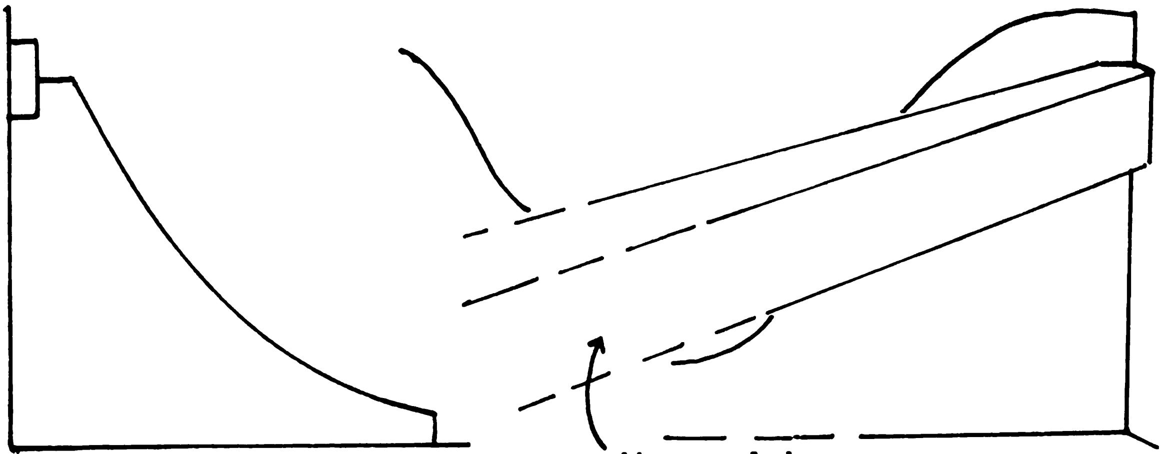
[26] Phillip Belt, "Report on the Restoration of the Toledo Stein," unpublished document (Toledo: 1974). Evidence from photographic slides included with the restoration report.

case sides down and inward by forming a diagonal vector of resistance from the top of the bentside, just below the soundboard lands, to the bottom boards.

Knees brace between sides and bottom, while cross-frames brace between case sides. Upper cross-frames float unsupported just below the soundboard lands, while lower cross-frames rest on the bottom. Lower cross-frames are scooped out in the center, to allow other braces to travel over them. They thus maintain a continuous airspace beneath the soundboard as well. Lower cross-frames function as a combination knee-brace/cross-member since they rise up at their ends to meet the case walls like a knee, and span between sides like a cross-frame. All these different types of interior braces are not necessarily found in every type of keyboard instrument (see figure 9, page 52).

Diagonal braces run from near the tops of the soundboard lands on the case sides to corners formed by the bottom and other frame members. They have difficult compound cuts on their ends to accommodate three mating surfaces. They are sometimes notched into the walls of opposing sides, avoiding the bottom altogether.

Diagonal braces and cross-frames often are perpendicular to one of the case sides, usually the bentside. Sometimes one type of interior brace is perpendicular to the spine and another type is perpendicular to the bentside in the same instrument. Braces rarely are



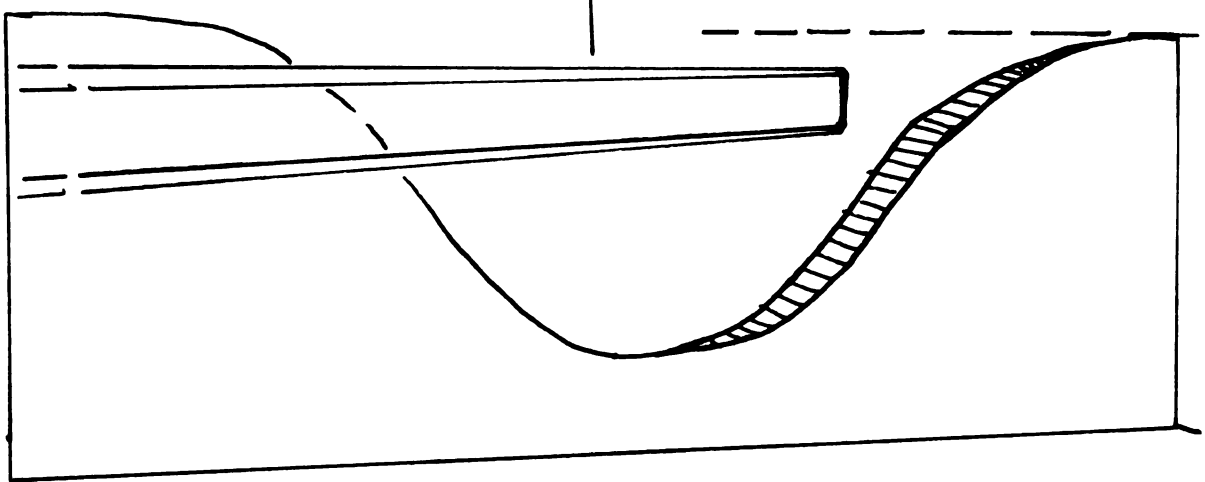


Figure 9. Interior Bracing Forms

perpendicular to the belly rail. The lower cross-frames in Stein's pianos are square to the spine, and are of the combination type. This style is similar to some French harpsichord designs.[27] Stein visited Paris in 1758, early in his career, and trained in the shop of J. A. Silbermann in Strasbourg. His method of cross-framing may come from this tradition.

Cross-frames that run perpendicular to the spine and parallel to the belly rail fit neatly into the conception of a "squared" instrument design. The diagonal struts securely brace in the right-angle corner formed by the spine and the cross-frames. The bentside, in combination with the cross-frames, belly rail and diagonals, forms a series of overlapping triangles. Triangular strut arrangements cannot shift, as can those with four corners, so this is a very clever and solid design.

The diagonal braces in Stein-type instruments occur in various configurations, indicating that makers had not settled on their placement. In the Nuremberg Stein from 1788, the middle diagonal skips the cross-frame and is cornered at the spine/belly rail joint. Also, the front diagonal is square to the belly rail, and rises from the bentside/bottom/front cross-frame corner to the top of the

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[27] Cf. three-quarter plan of a French harpsichord in Frank Hubbard, Three Centuries of Harpsichord Making (Cambridge, Mass.: Harvard University Press, 1967), plate XII.

belly rail near its midpoint.[28] In the 1784 Toledo Stein the two back diagonals are cornered at their respective cross-frames near the spine, and the front one similarly runs from the top of the bentside/cross-frame corner to the bottom of the belly rail at its midpoint. In the Smithsonian Schmidt of circa 1788 there are four diagonals and three cross-frames, with each diagonal brace either originating or ending in at least one corner formed by the cross-frames.[29] Two of the diagonals bolster the belly rail at its lower edge.

It is important to note in all of the above instances that the makers' conception of frame reinforcement is short-sighted, since it does not take into account the gap in the case between the wrest plank, where one end of the strings are fixed, and the hitchpin rail, where the other end of the strings are attached. This is, perhaps, the consummate failure of fortepiano design, one that was ultimately solved by the unified cast-iron frame. Some makers like Walter and Dulcken spanned the gap between wrest plank and belly rail with a wooden or iron brace, with mixed results. Gap spacers are not a sure defense against case warpage, either. More braces were added to counteract greater string tensions

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[28] The Piano, Grove Musical Instrument Series, 17, photo 7b.

[29] Johann Schmidt, Viennese fortepiano, catalog no. 303,536 (Washington, D.C.: Smithsonian Institution), photograph no. 56408-B.

as the piano evolved in the nineteenth century, but the contracting forces of the strings soon outgrew the wooden frame altogether.

It is interesting to examine Stein's bentside design in connection with diagonal bracing. Stein used a straight board to form the greater part of this frame member, and then added separate curved pieces on either end. The long straight board continues directly to the belly rail, where its small tenon secures it in the belly rail mortise. The extension of this board functions as another diagonal brace and is located in the weakest part of the case--the cheek/bentside corner. It also forms another triangular bracing arrangement between the bentside, inner curve, and belly rail (see Figure 8, page 49).

Stein exploited the straight line of the bentside as much as possible. The curved pieces are made out of glued-up blocks. He glued up two boards side by side to make the inner curve and then scalloped the outside board to form the curve. The ends are cut at the appropriate angles to meet the bentside, cheek, and belly rail. For the tailpiece, Stein glued blocks on top of each other, the grain running with the longest mean axis of the piece. He then cut the whole tailpiece to the proper curve. Thus, both of the curved frames are thicker than the bentside or spine in order to accommodate the deviating arcs on each of their ends.[30]

The curved frame members are glued to their mates by butt joints. The tailpiece and spine in the Schmidt fortepiano have a lap joint that offers additional security.[31] Some makers use dovetail joints at the spine/tail seam, and in cases where there is a square tail, the joint often is a simple miter.

The outline of the case sensibly follows the pattern formed by the string band--straight on the bass side and cheek, curved on the back. The front is square to the keys. More precisely, the bentside advantageously follows the outline of the bridge, since the bridge maintains a uniform distance from the bentside. Some bridges on both harpsichords and early pianos are mitered in the bass, i.e., they have a short, straight end part joined at a sharp angle to the main curvilinear part. Instruments of this sort have a square tailpiece mitered between the bentside and spine, in order to keep the waste ends of the bass strings a reasonable length.

Keyboard instruments with a continuously curved bridge usually have a squared tailpiece, also. This contradiction between the outer form of the case and the shape of the bridge indicates that makers declined to make a curved form

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[30] In the Hubbard kit, blocks of wood are glued on both ends of a straight plank, and the whole piece is re-sawn and sanded to form the complete bentside assembly.

[31] Joh. Schmidt (Smithsonian: 303,536), photo 56408-D.

when they could get by with a straight one. Therefore, instruments with double-curve bentsides of the Stein type are rarer, even though there are many kinds of instruments with curved bridges in the bass.

Hass, Vater, Zell, and Gottfried Silbermann all made harpsichords with double-curve bentsides. Silbermann also made pianos in this style. Stein continued the German tradition of double-curve cases, perhaps because he had worked with members of the Silbermann family and with F. J. Späth. Stein's disciples also built instruments with double-curve bentsides, into the early nineteenth century. The fortepiano by Anton Walter in the Mozart Museum--once owned by Mozart--curiously has a partial curve at the tail, which shortly meets the mitered back. This semi-curve is highly unusual (see Figure 3, page 25). Some of Walter's other pianos have only the inner curve near the cheek, and the tail is square.

The spine and cheek frames are simple in comparison with the bentside. They are straight boards of uniform thickness and height. The upper front corners of each piece have a chamfer which creates part of the cheek profile. Triangular blocks are later glued on top of spine and cheek, in front of the wrest plank, in order to raise the height of the cheeks even with the outer case sides.

Spine and cheek frames must also make accommodations for the wrestplank. In the Toledo Stein, there are two mortises in each frame into which the wrestplank tenons fit. A step is cut into the frames in other designs, and the wrestplank butts up against the vertical face behind it. This backstop provides some resistance to the contracting forces of the strings.

The wrestplank is more than a terminus for the strings, it is also an integral part of the framing. It links the spine and bentside via the cheek. The bentside and the wrestplank have the greatest burden of bearing the string tension since the strings attach directly to them. Thus it is interesting to note the wrestplank's weak and vulnerable position, due to the gap through which the hammers reach the strings. The gap extends from the front face of the belly rail to the back face of the wrestplank. The entire middle length of the wrestplank is unbraced and subject to distortion, since the wrestplank is secured only at its ends. The real problem, however, lies with the cheek.[32]

The cheek--as in case side--is the short framing piece that meets the treble ends of the belly rail, the bentside, and the wrestplank. The short cheek board gains no rigidity through length like the bentside and spine frames. This leaves the cheek vulnerable to upward pulling by the string

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[32] "Cheek" is used in two ways. The front ends of the case, on either side of the keys, are referred to as "cheeks;" thus the front end of the spine is also a "cheek." The cheek as a frame member is the short, straight piece on the treble side of the piano that squarely faces the audience. "Cheek disease" refers to the frame member.

tension. Triple-stringing of the last treble octave exacerbates this problem.

The cheek pulls upward in a twisting manner. This twisting also exerts torque on the wrestplank, which gives in at its weakest point--the center of the board. The wrestplank develops an apparent sag in the center, causing the strings to pull away from the nut (see Figure 7,page 46). The sagging wrestplank may impinge on the action below it. This twisting force can even split the wrestplank in half.

Makers applied a wooden or iron brace--spanning the gap from wrestplank to belly rail--in response to this sagging. The brace always sits where the worst deflection occurs, in the center of the wrestplank. This solution addresses the immediate problem without examining the overall condition. Instrument makers might have better solved the problem of cheek disease in wood-framed instruments instead by doubling the thickness of the cheek frame.

The wrestplank can still pull away from its moorings even if cheek disease is minimal or nonexistent. It will first lift off the spine and cheek steps from the front side, since the wrest pins are located closer to that edge. Stein addressed this problem in the Toledo instrument with mortise-and-tenon joints--two tenons on each side of the wrestplank extend into mortises in the case liners. The tenons are flush with the lower edge of the wrestplank, which leaves an inch of frame wood above each mortise that theoretically secures the wrestplank. The wrestplank on this instrument still split, however.

The belly rail is the thickest frame member. It serves as a wall between the action well and the airspace beneath the soundboard. It is also the front landing for the soundboard edge, along with the spine and bentside frames. The belly rail, like most framing on fortepianos, is thicker than its counterpart on harpsichords. Harpsichord belly rails often are split into two disjunct upper and lower beams, while fortepiano designs always employ a single beam.

Fortepiano makers cut rectangular or oval holes in the belly rails of their instruments in the belief that the holes served an acoustic function. These sound holes sit between frame joints in order to accommodate interior bracing. Makers thought that the air in the resonant chamber beneath the soundboard enhanced bass tones but needed an opening to escape, as on a violin or guitar. There is no certainty that these holes indeed have any such effect.

The belly rail is a type of cross-frame, but is far thicker than any interior brace. This thickness might be compensation for strength lost to the sound holes. Makers also may have thought it necessary to have a wider landing to glue down the left front end of the soundboard as compensation for the narrow gap between the soundboard and the top of the belly rail in the treble.

The belly rail is the largest "cross-frame," and it is the last barrier before the gap. Interior braces lodge against it, and tension from up to one-half of the string band can bear upon it.

The Stein frame comes together in a specific order for strength and practicality. According to the restoration report for the Toledo Stein,

> "The tapering of the joints make it evident that Stein's sequence of assembly was first to put the wrest plank, spine and cheek together, then drop the belly rail into position. The bentside liner was then inserted into its mortise in the bellyrail and the tail joint was glued. Then the [cross-]frame members were inserted from the bottom, the treble block glued in and the bottom put on."[33]

The wrest plank must be inserted into either the spine or cheek or both simultaneously, due to its sideways-protruding tenons. The belly rail, with its tapered ends, either slides into place from the top or attaches to one

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[33] Philip R. Belt, "Report on the Restoration of the Toledo Stein," unpublished document (Toledo: 1974).

frame at a time. Logic dictates, in either case, that these four parts are joined first.

The belly rail dado tenons taper toward the bottom, while the belly rail itself has vertical faces. This wedge creates a tight, self-clamping joint.

Since the bentside has a square tenon that fits into a mortise in the belly rail, the maker attaches the belly rail first. There is some question as to whether the tailpiece is glued onto the bentside before the whole is put in place or if it is glued to both the bentside and the spine at the same time. Due to its round shape and odd angles, the tailpiece is difficult to clamp in place. There is a square, blind mortise on the inner face of the spine near the tail of the Toledo instrument that could have supported a clamp to hold the tailpiece in place until the glue dried. The bentside would be a stationary face to which the tailpiece could be glued if the cross-frames were inserted first.

The inner-curve block is glued to the bentside after the bentside is fixed at both the belly rail and the tail. The bentside then cannot change the angle of its mating faces to the inner-curve block.

The two cross-frames are next inserted into their blind dadoes while the frame is flipped upside down. The cross-frames can only be fit this way, since the outer frames are already glued together. The cross-frame tenons in the Schmidt piano also seem to be half dovetails, requiring a vertical sliding fit rather than a straight insertion.[34] It is reasonable to insert the cross-frames before the tail piece, thus stabilizing the bentside first.

Frame assembly is a quick operation. The parts are first carefully cut to size and fitted together dry, then glued one after the other. Hide glue turns sticky below seventy degrees Fahrenheit, so even while working in a hot room the maker applies the glue fast and immediately puts the joint together. The hide glue holds one joint sufficiently closed in order to assemble the next one on the frame, although it does not completely cure for twenty-four hours. The joints are self-clamping in most instances, except for the above-mentioned tail piece and inner curve.

At this point the bottom is glued on. Photographs of the Smithsonian Schmidt show four large dowels driven into the bottom of the assembled frame.[35] The strategically-located dowels align the bottom squarely with the frame. One dowel is at the tail, while a second is in the belly rail at its junction with the spine. Two more dowels are located right next to each other in the belly rail at the cheek-bentside corner. One dowel is sufficient to match the bottom to the frame, and the second one may be intended as further reinforcement of this vulnerable area in order to

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[34] Joh. Schmidt (Smithsonian: 303,536) photos 56408-D and -F.

[35] Joh. Schmidt (Smithsonian: 303,536), photos 56408-B, -D, and -F.

counteract cheek disease.

Square wooden tenon pegs close any gaps between the frame and the bottom. External clamps are rarely necessary. The maker must work quickly, however, to cover such large, disjunct areas with quick-setting hide glue.

The diagonal braces, dependent on the bottom, are now put in place. Blind mortises must be cut out ahead of time. The diagonals are nailed as well as glued in place since they are often unsupported on the ends. The nails serve as permanent clamps.

Stein's framing style, while rooted in the past, also represents a bold break. His frame is much heavier than any found on a harpsichord or on other contemporary fortepianos. Stein's framing seems cumbersome, but this heaviness also has an elegant simplicity. It anticipates later framing methods of Conrad Graf, and ultimately the framing of the modern piano, because it transfers load-bearing to the frame rim and de-emphasizes the bottom. It is the first distinctly modern type of piano framing.

The Case

Either the case sides or the soundboard are next attached to the frame/bottom assembly in a Stein-type instrument. Case side attachment is much more difficult when the soundboard is installed first. The attached bottom and soundboard prevent access to ideal clamping surfaces--the inner faces of the frame. It is not possible to clamp from one side of the case to the other side, since the bentside and spine are not parallel surfaces. A large, mirror-image caul would effectively transform the case into an object with parallel sides and thus allow clamping, but this is a clumsy and awkward solution.

An alternate but very destructive method is to clamp the sides to the frame with nails and battens, which then are removed after the glue is set.[36] This method nullifies one of the primary benefits of having case sides, which is to provide a uniform ground for the veneer. It is far easier to install the case sides first and afterwards to install the soundboard in Stein-type fortepianos.

The case sides have incidental functions in Stein-type fortepianos. The heavy frame members assume the burden that case sides carry in other styles of harpsichord and fortepiano design. The case sides are decorative and protective, but not load-bearing. They provide a uniform ground for the veneer, and surfaces to hang other case parts. The simple miter joints between case sides indicate that these parts do not carry any stress from string tension.

Stein's case-sides proper are made of soft wood, as

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[36] Hubbard Harpsichords, Eighteenth Century Viennese Fortepiano (Waltham, Mass., 1986), 34-6.

with harpsichords and other keyboard instruments. There are three separate boards to cover the three different sides (see Figure 10, page 67). The spine and cheek are straight boards. These boards are simple flat pieces with angled top-front corners that match the bevelled cheeks. The vertical joints of the bentside have miters at the cheek corner and at the tail.

The double-curve bentside presents the same woodworking problem of any curved object, i.e., how to shape it with tools meant to cut straight lines. A thin board simply flexes into the desired shape. Kerfs--slots formed where the saw teeth destroy the wood--sawn into the backside of a thicker board make it act like a thinner one. A thick board can be softened up with warm, moist heat and bent to shape on a form. It then dries roughly to that shape. Lamination, where two or more pieces of thin full-length boards are glued side by side on a form, is another solution.

Walter and Stein chose a combination of two methods: gluing on a flexible bentside that is thinner than the spine or cheek pieces, and then attaching a narrow strip to the inner face above the soundboard. This method makes the top edge of the case a uniform thickness on all three sides and creates a visual illusion of solidity. It also makes the bentside rigid enough to withstand incidental rough handling. Other makers omit the inner laminate,

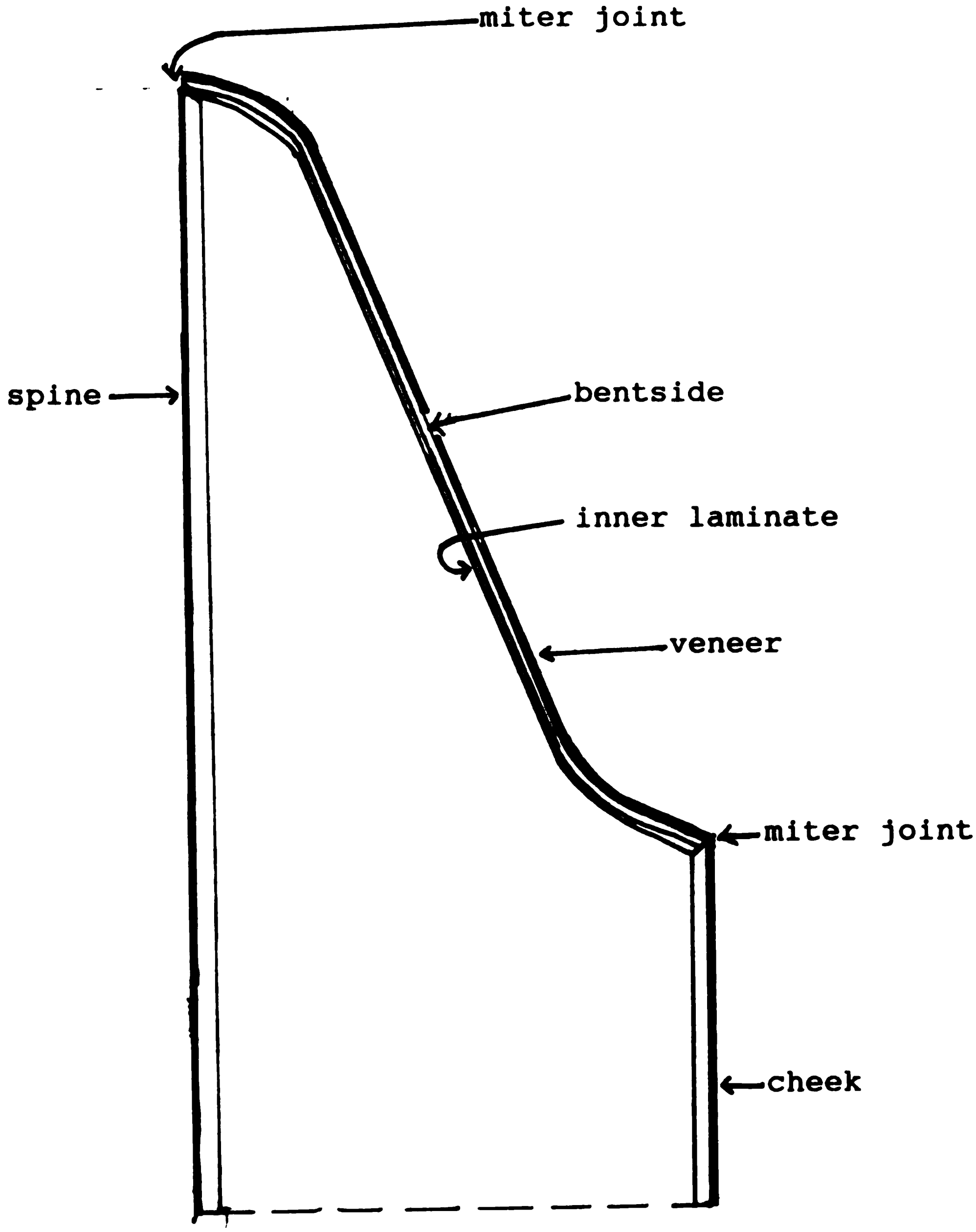

Figure 10. Stein-type Case Sides

leaving the bentside thinner than the spine and cheek.

The case sides are high enough to protect all other parts that sit below its top edges, since the delicate strings and soundboard are prone to damage. The lid must be hinged to the case well above the height of strings and bridge. The dampers and damper cover sit above the height of the strings, as does the music desk, and they determine the minimal height of the case sides.

Simplicity and muted elegance characterize case design in the Viennese Classic period. Natural wood grain, decorative paper, inlay, and marquetry are all used as surface decoration on fortepianos.

Hardwood veneers are used in a sparing manner, since they are rarer and more expensive. Useless and hard-to-work areas of a tree, like crotches and burls, make the most striking veneers. The veneers are sometimes ornamented with moldings and decorative inlays.

Walnut and cherry are the most common veneer woods on eighteenth-century Viennese fortepianos. They provide a basic choice between a dark wood and a warm, reddish tone. Light-colored woods are sometimes used for contrast.

There are several common veneering styles. In one type, arcade-figured crotch veneers or imitation flat-sawn veneers are laterally pieced along the cheek and bentside. Sometimes the veneer panels are simply non-descript.

Another veneering style is a series of solid center panels, one on the cheek and two or three on the bentside. An optional narrow inlay surrounds each edge, and is followed by cross-banding that runs along the top and bottom of the case and between each panel. The panels may be burled, book-matched, or just solid veneer. The inlay often is a highly-contrasting color of wood or even metal that outlines the center panel. The cross-banding creates a shimmering pattern of short lines, since the veneer is cut across the grain.

Not all instruments had fancy veneering. Some fortepianos were veneered in plain sheets the length of the case sides. There are examples by many makers of unadorned cases, which presumably sold for less money.

Veneering is a study in economy. Makers attach the best pieces in the most visually-prominent parts of the case. Makers expend little effort wherever the instrument is not readily viewed--the spine and bottom, the back of the name-board or the damper cover. This laxity sometimes impinges on the illusion of solidity.

The spine normally is not veneered. It sometimes is stained a brown color or merely painted black, which implies that these instruments are not intended to sit in the center of the room.[37]

The keywell presents an intimate setting for the

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[37] C.F.Colt, The Early Piano (London: Stainer and Bell, 1981), 52.

player, and is ideal for ornamentation. The inner faces of the cheeks, and especially the nameboard, frequently have very fancy burled veneers or highly contrasting light wood panels.

Moldings add distinctive character to the case. A few simple moldings make even the austere Classic-era fortepiano cases appear more soft and pleasing. Moldings are cut from long thin strips of wood, and are glued to edges, corners, and case profiles.

Moldings can be very simple, but most of them have complex profiles that require making a special plane iron. The instrument maker hand-shapes these plane irons, which are unique to his shop. There may be general similarities between molding styles of different makers but the idiomatic cut made by a particular plane iron is impossible to duplicate. These molding profiles therefore serve as a reliable method of identifying the maker of any given instrument.[38]

Even though a maker has his own distinct planes he does not necessarily make his case ornamentation all the same from one instrument to another. Slight alterations in moldings make a pronounced difference in the character of a case.

Stein's fortepianos have simple combination moldings,

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[38] Cf. Friedemann Helwig, Atlas der Profile (Frankfurt am Main: Verlag Erwin Bochinsky, 1985).

with a few groupings of complex moldings. The simple combination moldings can be considered one piece. There is a cap molding on the top edge of the case with a small, inward-facing quarter-round bead bordered with two square edges. The outer lower edge of the case has a thick, flat strip of wood that wraps around the cheek and bentside, but usually not the spine. Sometimes this strip is simple and unadorned, and sometimes it has ebonized carvings on it. This strip is thick enough to accommodate additional concave moldings on its upper and lower edge. This is a common molding on Stein's instruments.

The cheek faces--front, bevel, and top--on Stein's instruments are often fluted and ebonized, as is the drawer front. Sometimes these areas are quite plain. The nameboard usually has a combination cap molding. The soundboard and wrestplank have a shallow, unevenly-concave molding which runs along the spine. This molding serves to hide the soundboard/rim joint. The nut, a functional piece, oddly enough has the most complex molding. The molding serves a useful purpose, however, since the strings thereby make contact with the metal pins of the nut before reaching the wood of the nut itself.

The legs are a distinctive part of a keyboard instrument case, and have a great variety and detail of styling. Leg styles change so much that one can identify periods, locale, and even individual makers by them. One leg style, characteristic of Anton Walter's pianos, is square and tapered, with a block head and a brass ferrule at the bottom. The Stein-type leg is a round, narrow, tapered leg with a tight neck topped by a cylindrical head. The body is circled by widely spaced vertical gouges. The foot is turned in imitation of a ferrule. Variations of the round leg style are found among many makers.

Legs are solid if turned on a lathe. They usually are veneered, however, if they have flat, square faces. Both styles are topped with a fat wooden dowel cut with threads. The leg dowels screw into plain leg blocks or into the broad reinforcing planks attached to the bottom. The leg blocks prevent the dowels from breaching the top surface of the bottom.

There is an excess of legs on fortepianos, largely due to the tradition of placing two legs in the front corners. This forward placement leaves the cheek bentside/corner unbalanced and doomed to fall. Thus, a minimum of four legs is necessary to stabilize the instrument, including the leg at the tail. Some makers add a fifth leg midway along the bentside. This decorative leg complicates the task of balancing all of the legs on the ground.

Lids come in three pieces: the lid proper, the flap, and the fallboard. The fallboard is usually glued at the miter joint between the bevel and the drop, but sometimes this joint is hinged. The lid proper stretches from the tail to the front edge of the soundboard. It ends at this point so that the flap may fold back and expose the music desk. The hinges between lid sections are arranged so that the fallboard rests upon the flap while the flap is resting upon the lid proper. The propstick raises the entire lid in this position. Some instruments use the folded-back fallboard as a music desk, not opening the lid further. Some lids are not finished on the bottom side, an indication that the makers either were saving money or that they thought the closed lid is the normal position.

There are two styles of lid: the solid, veneered lid and the raised-panel lid (see Figure 11, page 74). The solid lid has the grain of the veneer running cross-wise, i.e. the grain is vertical when the lid is up. This orientation provides a good format for displaying extravagant figure in the wood. Solid lids, along with the inner rim, are sometimes papered on the inside, akin to Flemish harpsichords.[39]

The raised-panel lid has slotted framing members with one or two cross braces that encircle raised panels. Raised panels are solid sheets of wood with tapered edges that fit loosely into grooves in the frames. The loose fit allows the panels to expand and contract with changes in humidity

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[39] E.g. the Boston Stein had a papered interior lid that was unfortunately destroyed in a fire during restoration. The Walter fortepiano in the possession of the Niederösterreichisches Landesmuseum in Vienna also has a papered lid.

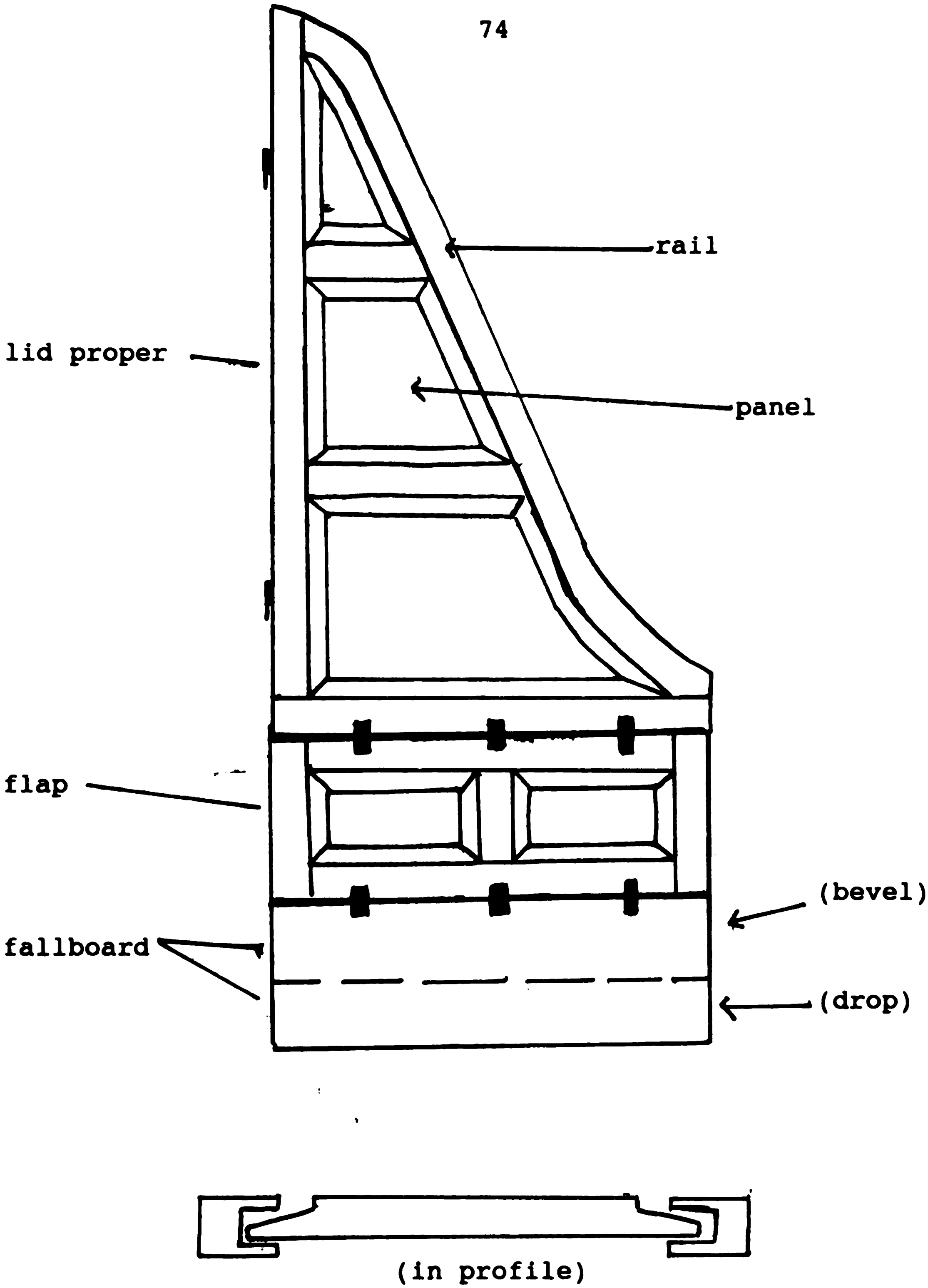

Figure 11. The Raised-Panel Lid

without warping the large lid. This design is very stable, and lends a rich look to the instrument. The flap is also composed of two raised panels, arranged side-by-side. The fallboard bevel and drop boards are too narrow and thus impractical to make in the raised-panel style, so they are either veneered or solid pieces of wood.

Lid edges are decorated with moldings, as are the inner edges of the frames in the raised-panel lid. Sometimes the lid has a simple cap on its edges that overhangs the bottom face, forming a soft accent.

Stein's lids are hinged to the spine with two lid hinges. Flap and fallboard are hinged with smaller strap hinges. All of Stein's hinges are made of iron and are painted black.

Lid locks are located between the fallboard and the front edge of the case. They come in a variety of styles. Two or three brass hooks are often located along the cheek and bentside. They secure the lid while moving or storing the instrument.

Prop sticks are quite plain and functional on early fortepianos. They are hinged to a block that is directly-attached to the lid proper near the corner of the bentside and cheek. The tip of the prop is held close to the lid, during storage, by a rotating brass L-shaped bracket located near the spine side of the lid. The prop stick remains safely attached to the instrument, preventing its misplacement. The lid must open quite far to remove the prop stick or it scrapes across the strings--a clumsy setup.

Damper covers provide decorative protection. Primarily, they do not function like a jack rail in a harpsichord, which stops the upward movement of the jacks, but they do obscure and protect the delicate dampers and damper rack. Stein's damper cover serves as a "modesty screen"--a device that prevents the player from viewing the moving action parts. The front flange of the Stein damper rack also provides a storage ledge for the music desk. The Stein damper cover has modest moldings at its top two corners, and also along the edge of the front flange. It rests on blocks glued to the inner rim, and is secured at either end by two long brass hooks.

Fortepianos without solid damper covers have damper racks with decorative grillwork backed by satin cloth. Walter, F. Hofmann, G. Silbermann, and others use this kind of rack.

Stein's music desk is a plain mortise-and-tenon frame. There are two upper and lower rails connected by four vertical pieces. A molded bottom ledge supports the music. Protruding support dowels rest in brackets at both ends of the desk. The brackets are rectangular pieces glued into the corners behind the cheeks. The bass bracket has an enclosed notch, while the treble bracket notch is open at the top. A number of instruments, among them a Späth/Schmal

Tangentenflügel and a fortepiano by Schmidt, have this style of bracket and a consistent disposition for the bracket notches.

Two small propsticks that rotate on screws in the case sides support the Stein desk. There are three notches on each side on the back of the desk. The Toledo instrument also has a green baize cloth backing. The cloth presumably is also a modesty screen, similar to the damper cover. The delicate music desks of early fortepianos are meant to hold only a few loose sheets or a thin booklet of music.

Walter thoughtfully exploited the decorative potential of his music desk by capping it with a distinctive crown in the center. His desk is narrower, and flanked by the flat ends of the support rack. These end-tables are a convenient location for candlesticks.

Makers might sign their instruments in a number of possible places, but sometimes they did not sign them at all. J.A. Stein affixed a paper cartouche in the left front corner of his soundboards. There are a number of shameless forgeries of this emblem, an indication of Stein's reputation.[40] Stein affixed his signature to the inside face of the bottom boards in the Toledo instrument, guaranteeing this instrument's authenticity. Other Viennese

[40]E.g., J. L. Dulcken, Fortepiano, plan and elevation (Smithsonian: 303,537), cartouche illustrated on plan; and Johann Schmidt, Fortepiano with pedalboard, Metropolitan Museum of Art, accession no. 89.4.3182, observation from personal inspection of instrument.

makers attached inked and glazed porcelain ovals, encased in glass with a brass frame, to the center of the nameboard.

Stein-type instruments have small amounts of ebonized ornamentation. The hitchpin rail, bridge, soundboard molding and nut are blackened on most early fortepianos. The fluted cheek faces and the drawer front sometimes are ebonized as well. This discreet amount of ebonization predates the empire furniture style that became popular after 1801.

The ebony natural keys are part of the contrasting black ornamentation of the case. The sharps are stained dark, but capped with a white bone or ivory covering. Viennese makers reversed the keyboard materials and colors as early as 1802.

Gold-colored mounts for candles or candle holders are affixed to the inside cheek faces, the cheek tops, or the cheek bevels. The music rack end-tables can support candlesticks.

Soundboard Installation

There are several methods of soundboard installation, and it is not clear which one Stein used. Soundboard installation follows case side attachment but precedes case veneering in Stein-type instruments, if we follow the proposed order of procedure.

When the soundboard is glued to the frame before the attachment of the case sides it is merely trimmed flush with the outer edges of the frame. This method complicates the procedure for attaching the case sides (see above). A soundboard that is installed after the case sides are attached follows a slightly different procedure. The complete soundboard assembly is dry-fitted to the frame before the case sides are attached. It is clamped to the frame and then trimmed flush, as if it were glued in place. The soundboard is then removed, the case sides are attached, and afterwards the soundboard should fit snugly in place. The bentside inner rim and the hitchpin rail are then attached. This method combines the advantages of the other two. It allows a tight fitting soundboard assembly and it permits use of the inner frame faces when clamping on the case sides.

An alternative installation method is to fit the soundboard after the case sides are attached. This is more difficult to accomplish on a fortepiano with a closed bottom than on a modern piano with an open bottom. The soundboard is laid on the top edge of the case, the case outline is traced on the bottom, and the board is trimmed back to the line. A scribed line marked in from this edge accounts for the width of the case sides. The excess width is trimmed to the scribed line, and then the board should slide into place. This method does not provide as clean a fit as the other two methods. This method is probably the only one that can be used on instruments with liners instead of frames, like Walter's instruments and the Smithsonian Dulcken. Liners hang on the inside walls of the case sides--and are thus dependent on them--while frames independently rest on the bottom.

Every edge of the soundboard is covered up after installation. The hitchpin rail runs the length of the bentside, and a block for the prop stick covers the cheek edge. A corner molding hides the seam between the spine and the soundboard. This molding might cover a ragged seam, and thus might indicate what method the original makers used to install a soundboard.

The soundboard blank is a thin sheet of spruce boards, edge-joined and cut oversize to the outline of the case. The front edge is square to the spine edge, and overhangs the front of the belly rail. In grand pianos with the English-style action, the front edge of the soundboard is flush with the front of the belly rail. The hammers face in reverse on a Viennese action, and in the high treble they must strike near the nut ends of the strings instead of near the bridge end of the strings. The short treble strings require that the bridge thus be set closer to the player, actually crossing over the belly rail and onto the overhang. The belly rail is undercut in the treble area in order not to touch--and thus deaden--the soundboard.

The overhang of the thin soundboard is vulnerable to splitting or breaking. It is therefore reinforced on the underside by an apron, and on the top edge by a narrow batten. The apron is a thin piece of wood on the dead side of the cutoff bar. It is as wide as the overhang on the bass side but it tapers in width in the treble to avoid the working area of the soundboard beneath the bridge. The top batten is extra reinforcement for the front edge of the board. The underside of the board is marked for the apron with the soundboard blank aligned parallel with the back edge of the wrestplank. The soundboard, now aligned to the frame by the apron, is ready to be marked for the ribs.

The Stein frame lands must be prepared for rib inserts before the case sides are attached. Dadoes for the ribs and cutoff bar are let into the bellyrail and spine lands. The ribs and the cutoff bar run into the frame, thus preventing a thin weak area around the edge of the soundboard.

The ribs taper off completely before reaching the bentside land in the Toledo Stein, but seem to travel up to or even touch the frame in the Nuremberg Stein.[41] The ribs severely taper on the bridge side of the cutoff bar in both cases, and do not present such a sharp contrast in rigidity

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[41] The Piano, New Grove Musical Instrument Series, 17, photos 7b and -c. The photo of the frame is too fuzzy to determine if there are dadoes in the Bentside land, but photo 7c displays a change in coloration of both the rib ends and soundboard edge where they had been glued down to the land. Wood exposed to air increasingly discolors with age.

at their bentside ends as compared with their much thicker ends at the spine (see Figure 2, page 23). This lessens the risk of soundboard splitting at the glue joint with the frame.

Stein's cutoff bar is let into the belly rail, but photos of the Nuremberg instrument imply that the frame is also notched at the tail to receive the cutoff bar, unlike the Toledo instrument. Photos of the Schmidt instrument also clearly show that the cutoff bar is notched into the spine land at the tail.

The ribs and cutoff bar are laid in their dadoes, with small marking pins protruding upward. The soundboard blank is pressed upon the sharp pins, marking the location of all underside pieces. The precisely located parts are glued to the soundboard, and then the whole assembly should cleanly fit onto the frame.

It is harder to locate the Stein ribs and cutoff bar, since they do not reach all the way across the frame. Stein presumably left the ends of the ribs overlength in order to mark their position, and afterwards shaved them down.

Bridge placement must be very accurate, since it partly determines the string lengths. The bridge should only be attached after the soundboard is precisely located on the frame so that there is no question as to its final position. The bridge is glued on before the soundboard is installed, with firm support underneath the fragile board. Go-bars and a go-bar deck are useful for all soundboard gluing operations.

The hitchpin rail is glued on top of the installed soundboard. The outer edge of the hitchpin rail must be flush with the frame and/or with the inner face of the case side, depending on which method of construction is used. The propstick support block next is attached, but the spine molding is only glued on after the inner rim has been veneered.

The order of assembly of the bentside inner laminate, the inner rim veneer and the hitchpin rail provide additional clues as to the soundboard installation procedure of early fortepiano builders. Elevation drawings of various makers indicate that the bentside inner laminate is glued on before the soundboard is installed, but that the veneer is glued on afterwards.[42] The inner rim veneer thus overlaps the soundboard edge, causing potential damage if the board is removed. Soundboard installation in modern grand pianos allows future removal with no damage to the case or the veneer. Replacement apparently is not a prime consideration in the assembly sequence of Viennese soundboards.

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[42] In the elevation drawing for the Smithsonian Dulcken (cat. no. 303,537), the bentside veneer is shown to be attached before the soundboard and hitchpin rail, but the inner rim of the spine is shown veneered after the soundboard is installed! The instructions for the Hubbard kit are the most cumbersome regarding potential replacement of the soundboard, where both the inner laminate and the veneer are glued on above the hitchpin rail and the soundboard.

The wrestplank is usually veneered on the top side with the same type of wood that is used for the soundboard. The Toledo Stein has the grain of the veneer running the length of the wrestplank rather than matching the orientation of the soundboard grain. An instrument with a narrow gap can create the illusion that soundboard and wrestplank are all one piece if the grain and joinery match in both pieces. Such an illusion is impossible when the wrestplank veneer runs perpendicular to the soundboard grain, as on the Toledo Stein.

The bottom of the origianl oak wrestplank in the Toledo Stein would also have been veneered if the top were veneered for stability. The wrestplank, with its uneven layers of lamination, will tend to absorb humidity unevenly and thus warp. This arrangement therefore implies that the top surface was veneered only as a decorative element.

The veneer in the Toledo Stein overhangs the ends of the wrestplank and probably was glued on after the frame was assembled. The wrestplank veneer must be attached before the wrestplank is drilled for the wrestpins and before the nut is put in place.

The nut, together with the bridge, delineates the lengths of the strings and must be carefully located. The bridge and nut pins must align the strings above the evenly spaced hammers. The wrestpin holes, as well as the hitchpin holes, are drilled in relationship to the nut and bridge pins in order to provide adequate side bearing for the strings.

The top edges of the Stein frame function as a landing for the soundboard. The board must be firmly attached to the frame around all of its edges. The landing in most other harpsichord and fortepiano designs is the top of a wooden liner that hangs on the inside case walls. The case provides functional support for the liner, unlike the Stein case. It is misleading to label the heavy frame members of a Stein-type instrument as <u>liners</u> since they are so different in thickness, height and function. The relationships between frame and case are reversed in Stein's instruments: the frame now forms a support for the case sides, and the soundboard is now directly attached to the firmest part of the instrument, just as it is in the modern piano.

The edge of the soundboard must be securely attached to the outer frame members, but the center framing must clear the bottom of the soundboard. These requirements account for the scooped-out cross-frames and lighter framing beneath the board, while the heavier framing members are on the perimeter. This dichotomy in Stein's framing does not hold on Graf's later instruments, or on modern pianos. Graf's radially-arranged central beams are thick and heavy, but much lower than the soundboard. The center beams are as structurally important--and as heavy--as the outer frame members. Stein's framing style, however, is the only one among fortepiano makers in the eighteenth century to foreshadow the future direction of piano design.

ACTION DESIGN

The action is a mechanical intermediary between the performer and the strings. The action provides reliability, regularity, ease, and precision that are not otherwise available. A keyboard player has versatile command over many notes, simultaneously and in close succession, through the individual key levers.

The touch of an action is very important. Ideally, a well-conceived and regulated action should feel as though there is nothing standing between the performer's intent and the musical result. There is a near-magical effect when an action is correct: the instrument is easy to play whatever the demands, and one senses a limitless reserve of musicality to draw from it.

The feel of a poorly regulated or designed action can be grossly obvious or subtly expressed as a sense of labored frustration. The pianist is not necessarily aware of the real source of his or her discomfort and dissatisfaction.

In the simplest explanation, an action is activated on one end and performs work on the other end. The crudest lever can fulfill this basic requirement. Musical considerations intervene, however, to refine the mechanism in a number of ways. Moreover, actions are designed to create a mechanical advantage for the performer by translating a small movement of the finger into a large movement of the hammer. An action requires a certain level of complexity in order to be musically worthwhile.

Complicated action mechanisms are more likely to malfunction. It is important that the action be easily serviced, and thus it should be a self-contained unit.

There were a multiplicity of experimental action designs before the arrival of the modern piano action. These various designs can be classified into a few types.[43] In the broadest sense, action mechanisms fall into upright and grand categories, and the latter into English and Viennese. Viennese actions have their hammers attached to the key levers instead of to an independent wooden rail.

Even though various instrument makers devised different piano actions, it is wrong to assume that each maker was influenced by or even aware of all of the other types. There were no clear precedents established in piano design until the latter half of the eighteenth century. Many designs are too crude or clumsy to be considered anything but dead ends. Some are economic expediencies. The lasting, useful inventions devised throughout the evolutionary history of the piano are few in number.

It is not clear if Johann Andreas Stein invented the advanced form of the Viennese action, or prellmechanik, but he was one of the first to use it. Stein's early

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[43] Cf. Pfeiffer, The Piano Hammer, 19.

application of this design influenced those around him and those who followed him--including his two children. Some of his contemporaries used modified versions of his design (see Figure 12, page 90).

Advanced action designs like the prellmechanik have several common attributes. Instead of having merely a prelleiste, or "bump rail," the developed prellmechanik has individual escapement levers, or prellen.[44] A piano hammer delivered to a string will block up against that string, unless it is released from its impetus. A blocking hammer produces a short, dull buzz if the player does not quickly release the key. An action with blocking hammers has limited musical application, and therefore makers strove early on to eliminate this problem.

A piano hammer has enough momentum to restrike the elastic string one or more times when it rebounds from it on a moderate or hard blow. Burbling hammers take control away from the pianist and transfer it capriciously to the action. This effect is annoying and unpredictable. An advanced action design eliminates this problem.

Pianists want control over all tone-producing aspects of their instrument. Not only is it important to control when a note sounds, it is also important to control when a note is silent. Pianos thus have the means to control

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[44] Also called hoppers or auslöser. Prelle (sing.) and prellen (pl.) will be used interchangeably with the American "escapement lever."

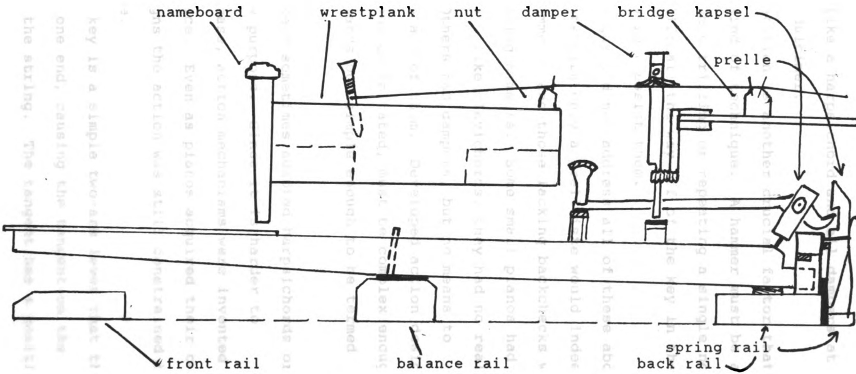

Figure 12. Viennese *Prellmechanik* by Stein, 1784 (Toledo)

individual dampers like a harpsichord and all dampers at once like a refined dulcimer.

Rapid note repetition is another crucial factor that involves a special kind of technique. A hammer must be able to respond quickly when trilling or repeating a single note. The fingers do not lift all the way off of the key in these cases, nor can arm weight assist them.

Early piano designs did not address all of these above concerns. Instruments with only a prelleiste would indeed have had blocking hammers, and those lacking backchecks were prone to double-striking hammers. Some small pianos had such feeble tone that, like clavichords, they had no real need for dampers. Others had dampers, but no means to simultaneously raise all of them. Developed action designs, in order to endure and be imitated, must be complex enough to fulfill basic demands but simple enough to be termed elegant.

Early piano makers sometimes adapted harpsichords or clavichords to a new purpose. Since it is harder to redesign an entire case, action mechanisms were invented to fit in the given space. Even as pianos acquired their own characteristic designs the action was still constrained by the surrounding case.

The clavichord key is a simple two-arm lever that the finger depresses on one end, causing the tangent on the other end to strike the string. The tangent has a positive and immediate relationship to the key lever. The harpsichord jack has much the same relationship to the end of its key lever. It also moves in a simple vertical path at a right angle to the key lever.

The piano hammer must move somewhat independently of the key lever, in order to avoid blocking. Mechanisms with only a prelleiste do not resolve the problem of hammer blocking, but they are an improvement over those crude devices with an immovable hammer fixed to the key lever.

A relationship must be established between the semi-independent hammer lever and the key lever. One lever moving roughly parallel below another will not have much influence, unless the extreme end of one somehow pushes up on the extremity of the other. This results in nothing more than an unnecessarily complicated version of a one-lever mechanism. The initiating lever must move in an opposing manner to the resultant lever, or there must be a third, intermediate lever interposed between them. All lever interaction must occur within a confined space.

The hammer lever in English actions moves in roughly parallel motion to the key lever, but there is an intermediate lever to transfer motion in a teeter-totter manner between the two levers. The hammer lever must be staggered above the key lever, due to space limitations.

The intermediate lever in the Viennese action is ingeniously dispensed with by turning the hammer lever around. Here, the end of the key lever acts upon the opposite end on the hammer lever. The hammer need not be directly attached to the key lever. In fact, the Anglo-German action, a hybrid form, has reversed hammer levers on separate rails. The Viennese action is simple and elegant, since it has one less action rail but performs the same amount of work.

Action designs are constrained in height by the distance between the bottom and the wrestplank. The height of the action partially determines the depth of the case, just as the parts protruding above the soundboard help determine the height of the case sides. The keybed could be lower than the rest of the bottom but no fortepiano maker has ever done this. The fortepiano keybed is always at the same level as the rest of the bottom, for simplicity and strength.

In theory, the bottom on the entire case could be lowered, thus providing more space for the action. This redesign involves all framing and bracing, however, and changes the character and appearance of the case. The wrestplank must maintain its height relationship to the soundboard, so it can only be altered on the bottom side in order to accommodate changes in action design. Case redesign is a radical step. It is easier to redesign an action.

The depth of the action is governed by the distance from the front of the case to the belly rail. In English-action pianos the belly rail serves as the front terminus for the soundboard and the hammers lie mostly under the wrestplank. In the Viennese prellmechanik the belly rail is pushed back, allowing the action to operate underneath the soundboard. The key levers are approximately the same length in both types, so the lost depth in the English action must be made up by adding material to the front of the wrestplank. The nameboard limits the length of exposed key lever, and it backs up to the wrestplank. Both parts form a protective cover around the action.

The theoretical distance a hammer travels from its rest position to the string is determined in part by the amount of time it takes to execute the stroke. Longer hammer strokes impede swift playing, therefore the hammer must be located reasonably close to the string. Hammer stroke accounts for the greater distance between the hammer and key lever in the English action. The entire Viennese prellmechanik must be raised closer to the strings in order to maintain a reasonable hammer blow distance, since the hammer is directly attached to the key. A sled, or drawer, slides beneath the action and elevates it. The drawer is incorporated into the keyframe on Walter's instruments, and the whole unit drops down and slides out.

Most fortepianos have straight keyboards where the keys are all of equal length and run parallel to each other. The key levers in Walter's instruments grow progressively longer towards the bass end in order to accommodate the angled hammer-striking-line.

The amount of work the finger must perform determines the length of the key lever. The key lever, acting in concert with the other levers in the action, moves the hammer a certain distance. The hammer head is relatively farther away from the pivot point of the key lever than is the finger. The hammer travels farther for every measured distance that the finger moves the key lever. The hammer thereby gains more momentum on its way to the string--and imparts more energy to the string as well--than if it only moves the same distance as the finger.

Because the key lever transfers some of the leverage differential to other levers, it does not travel as far. The key lever can then return sooner to its rest position, ready to be depressed again. This setup aids repetition and fast playing, and justifies a multi-lever system.

The key dip in Stein's fortepianos is approximately five millimeters, or one-quarter inch. Modern pianos have three-eighths inch key dip. This shallow dip implies that the finger must do all of its work with only a slight stroke.

A felted rail at the back of the action regulates the key dip. This rail in Stein's instruments is also divided by vertical wood braces that serve as guide slots for the key lever tails. These square arcades serve a dual role in regulating key travel.

The key levers must be guided in two places in order to travel straight. The balance pin always serves as one of the points of control, since it is the point of least movement. Balance pins establish a constant pivot point and control front to back movement of the keys. The hole in the bottom of the key lever is loose enough to provide free pivoting but no play fore and aft. The balance pin hole has a wide mortise at the top of the key that tapers towards the pivot hole. This arrangement allows for the wider arc of movement at the top of the key lever in relation to the balance pin.

Balance mortises are only slightly wider than the pin itself, and have no felt or leather bushings on their side walls. These lightweight levers move only in a straight up and down motion and not with a complex lateral component, unlike keyboards with splayed keys. There is no knocking or rubbing against the mortise walls and no need for bushings.

The tail is the other guided part of the lever on many early instruments--whether in slots, with a tongue-in-groove, or with pins. Modern instruments employ a guide pin at the front of the key. Walter's key levers are pinned in an unusual spot, on a rail midway between the balance rail and the key fronts.

Key levers rest upon the keyframe--a set of interlocking rails. The rails regulate the movement of the action as well as support the keys. The long rails run parallel to each other if the keys are all of the same length. The back rail is set at an angle to follow the key levers if they grow longer in the bass. The balance rail usually runs parallel to the front of the keys, but follows the back rail if the levers are extremely disproportionate in length from bass to treble. The front rail, where present, always runs parallel to the front of the case. The long rails are joined together with short side rails, and one or two center rails.

The balance rail is pinned with thin iron pins. The top surface is set higher than the back rail so that the levers will rest on the back rail. The back rail establishes the starting height of the tails, and it is felted to prevent noise. The front rail, if not pinned like Walter's keyframe, merely reinforces the keyframe and serves as a backstop to the drawer front on Stein's instruments. The front rail is stained dark in order to be less visible below the fronts of the keys. The keyframe also provides a foundation for the rest of the action, with the prellen and their springs attached at the rear.

The endblocks, vertical pieces glued on either side of the keyframe, keep the entire action in place. They fit against the cheeks with close tolerances, preventing sideways movement. They each have a raised block on the top rear that prevents drawing the action forward and breaking off the hammer heads while it is in playing position. Stein's nameboard fits into slots in the top faces of the endblocks, further restricting movement.

The hammer shank is conveniently attached to the key lever by the kapsel. The kapsel, a slotted wood block, is inserted into the back of the key lever on a metal wire. The wire is thick enough to remain in place but thin enough to bend for regulation. The Stein-type wooden kapsel is drilled through the sides with two large, aligned holes. These holes are bushed with an unusually thick white wool cloth. A metal pin, inserted and held firm in the wood of the hammer shank, rotates in the center of each bushing. The bushings eliminate noise and provide the proper amount of friction that allows the hammer shank to rotate without wobbling. They are much thicker than those used on modern pianos. The thicker cloth might be spongier, slowing down the returning hammer and thus functioning as a backcheck.

The back corner of the key lever is bevelled in order to drive the kapsel wire in at an angle. The s-shaped hammer shank can then rotate to its maximum extent, unimpeded by the solid kapsel base.

The invention of another style of kapsel, made of brass, is credited to J.J. Seidel, another Viennese fortepiano maker.[45] This type of kapsel is similar to

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[45] The Piano, New Grove Musical Instrument Series, 18.

Stein's wooden one in that it has two upright posts, but the center pin rests in two dimples instead of bushed holes. The brass kapsel is more friction-free, and soon won out against Stein's wooden kapsel.

The hammer shank is also a two-arm lever. The hammer rests on the end of the long arm, and the short arm is fashioned into a <u>beak</u>. The beak fits into a notch in the prelle, or escapement lever, and raises the hammer to just below the string before slipping away.

The hammer head rests low near the key to allow the hammer sufficient travel distance. The s-curve shape of the shank lowers the beak, which otherwise would be left riding high in the air. This design allows for shorter prellen and enables both the prellen and beaks to comfortably clear the bottom of the wrestplank.

The inner faces of the kapsel's upright prongs are filed into opposing arcs, so that the hammer shank cannot bind on the sharp corners. The kapsel thereby retains its close clearance at the center pin, which helps to prevent sideways travel of the hammer without posing the danger of restriction. The hammer shank's shoulders are also rounded at the kapsel to prevent binding. Filing the inner faces of the kapsel would only be done if necessary. This precaution is also a reaction to a problem, and indicates that Stein's fat bushing cloth might cause too much play.

It is not absolutely clear how the fortepiano action with prellen, or escapement levers, developed from the simple prelleiste, or bump rail. There must be a stationary object that the hammer beak can bump up against when the hammer shank is attached to the key lever. It is common practice in harpsichord making to have an up-stop rail that limits the travel of the key levers at their tails and it is easy to transfer this idea to another moving part. Thus, there is a direct parallel in design between the key up-stop rail and the prelleiste.

The Cristofori action of 1726 has a jack--another type of escapement lever--that is positioned on the key itself. The hammer is attached to its own separate rail.[46] This setup is the basis for an action design by J. H. Silbermann from 1776.[47] The hammer must be attached to a separate rail when the means of escapement is attached to the moving key lever. All three parts cannot move without reference to a fixed point.

The prellen in the prellmechanik must be attached to a fixed rail, since the hammer shank is attached to the key lever. The Stein-type prelle is a very different design from the Cristofori/Silbermann jack, even though they have the same function. Cristofori's jack bears little resemblance to Stein's prelle and cannot serve as a model.

So much of the early piano is clearly derived from the

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[46] Harding, 28, figure 18.

[47] Harding, 38, figure 26.

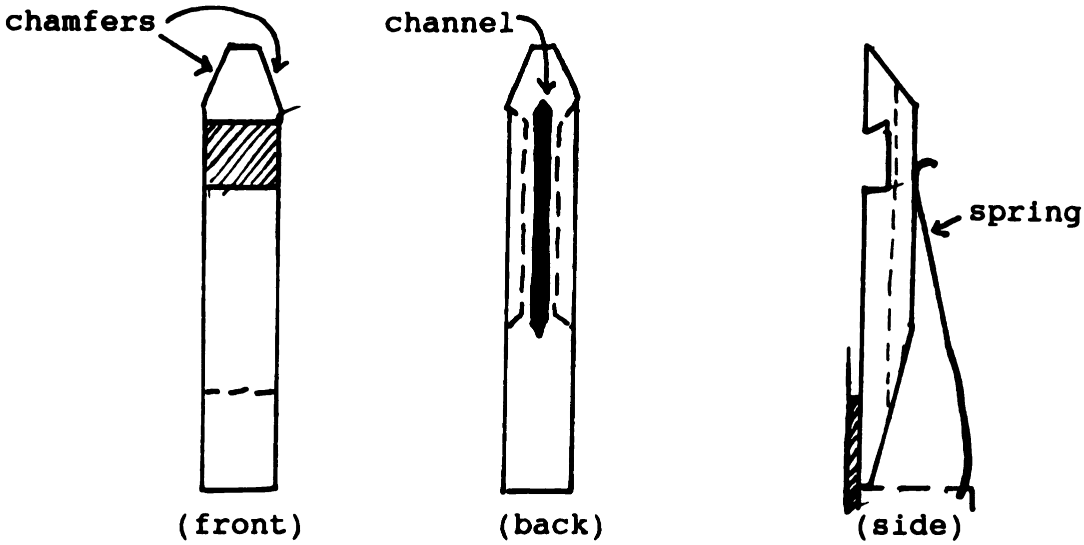
harpsichord that it is not unreasonable to search for adaptations in the action as well. The keyboard, along with the keyframe and key up-stop rail, are nearly identical. There are obvious parallels between harpsichord jacks and a number of piano action parts as well. A fortepiano maker does not necessarily have to create a new part from past experience. The piano increasingly took on a life and character of its own as the harpsichord fell from use. An instrument maker like Stein, who built both harpsichords and fortepianos, would have drawn on his knowledge from one instrument and applied it to the other.

The harpsichord jack tongue clearly stands out when one examines the harpsichord action for parts that look and function in a manner analogous to Stein's prelle (see Figure 13, page 103). The jack tongue is a small, rectangular slip of wood that rotates on a metal pin. The pin is laterally inserted through the lower half of the tongue. The plectrum is inserted into the upper half and projects out one side. A spring, resting in a V-shaped groove, pushes on the backside of the tongue and keeps it in rest position. The lower end of the spring is inserted into the jack body. The plectrum, when pushed past the string, not only plucks the string but is partially deflected backwards. Upon release, the plectrum falls past the string and is again partially deflected. The spring provides an elastic restoring force in both instances.

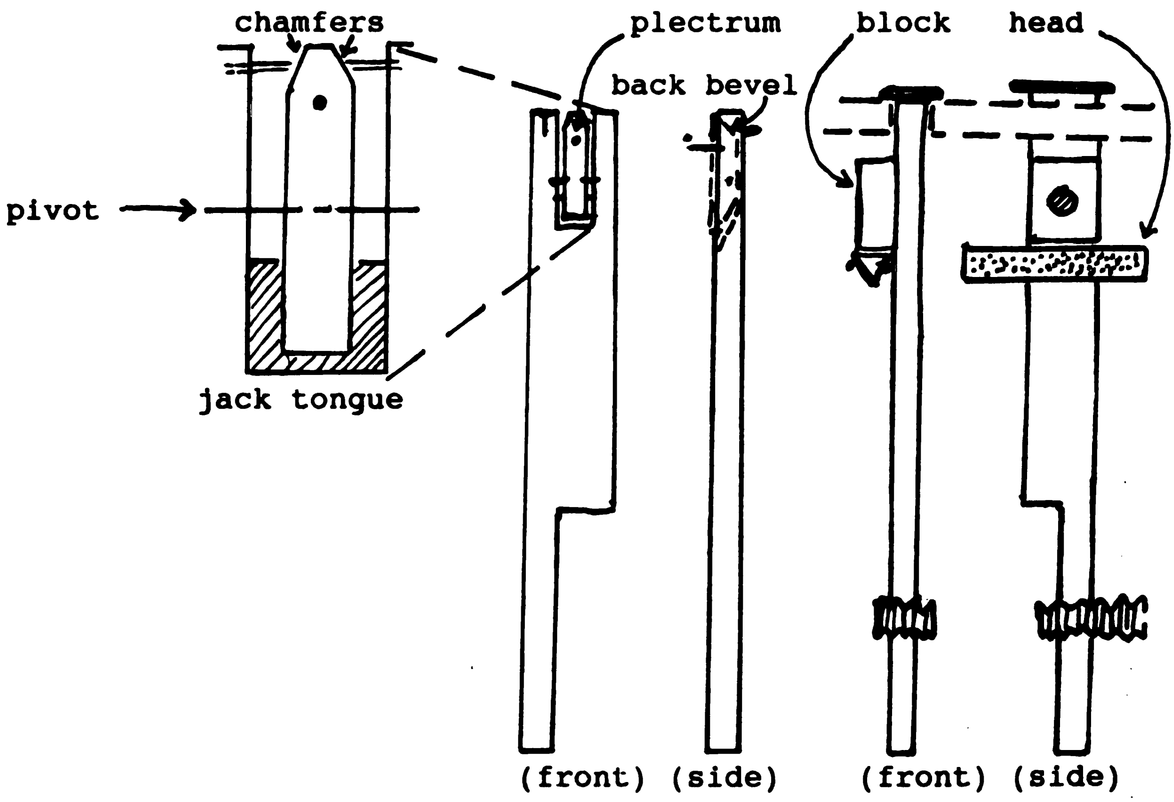
The bevel at the base of the jack tongue meets a parallel face on the bottom of the jack slot that maintains its rest position. The top of the tongue is also bevelled in back, where a metal pin spans the jack brackets to limit the tongue's rear-ward deflection. There are additional chamfers on the sides of the tongue head that eliminate potential binding at sharp corners.

Stein's prellen have a remarkable similarity to jack tongues, both in function and profile. The gross proportions are the same: long and slender, and wider on its working face. However, the prellen are several times larger than a jack tongue, being about two and three-quarter inches in length. Both stand upright and pivot down low, although the prellen pivot on a leather hinge. Both have v-shaped grooves on the back which channel a support spring. Both are also bevelled on the back side, top and bottom, but for slightly different reasons.

The lower bevel on the prellen prevents binding with the top of the spring rail. The lower bevel also allows clearance for the spring, which otherwise would contact the prellen too low, increasing its stiffness and causing return problems for the hammer beak. The upper bevel in back helps the prellen to avoid the belly rail, which otherwise causes an irritating clicking noise and also interferes with beak return. The belly rail does limit the backwards motion of the prellen, just as the metal pin spanning the jack



Stein Prelle



harpsichord jack   damper jack

Figure 13. Stein Action Parts vs. the Harpsichord Jack

supports limits the tongue's backwards travel, but it should not cause binding.

The prellen heads on Stein's actions also have chamfered corners. There is no clear reason for this, since there is little danger of the rectangular corners binding on anything near them. This practice does have a practical application for a jack tongue, however, and further proves the analogy.

The prellen have a broad notch in their front face instead of a plectrum-like protrusion, since they must receive the pointed beak of the hammer shank. The bevels on the back of the prelle are cut in such a manner as to avoid this area, thus maintaining structural strength for the whole piece.

Beak and prelle function much the same as the plectrum and string on a harpsichord, though in reverse. One part (the beak) slides past the other (the prelle), which also temporarily deflects in order to accommodate the return to rest position.

It is hard to deny the positive correlation between the two parts from different instruments with the above evidence. A conclusion as to whether or not Stein invented this type of escapement mechanism could be drawn by comparing the jack tongues on Stein's harpsichords with his fortepiano prellen.

Fortepiano dampers must be located near the striking point and within the gap. The dampers in English actions operate off the tail end of the key lever. However, each damper is activated by a platform positioned midway on the key lever, near the hammer head, in Viennese actions with reversed hammers.

Stein's damper bodies are another unmistakable example of a part transferred from the harpsichord to the fortepiano. The shape of the body is wholly analogous to a dogleg harpsichord jack with its flat, rectangular upper portion, and its rounded, dowel-like lower stem (see Figure 13, page 103).

The head of the damper jack is modified for a new purpose, with a square block attached to the side that holds a lead weight, and which also serves as an upper platform to hold the damper head and/or damper cloth. The upper edge of the block regulates the travel of each individual damper when activated by the key lever.

Dampers are problematical, since they are the only action part that functions both above and below the strings. The other half of the mechanism, the part typically thought of as "the action," is easily removable for service, while the dampers are compromised by their location between the strings. Dampers are the most sensitive, difficult and hard-to-reach parts of the action.

Design variations suggest that a satisfactory solution for holding the dampers in place was somewhat elusive to early makers. Most harpsichord jacks are held in place at two points, the movable upper register and the fixed lower register. The lower register, a mortised rail that runs across the width of the case, cannot be set low in a fortepiano because it would interfere with the moving hammer shanks. Therefore, Stein and others created ways of dangling individual guides between each set of unison strings that are mated to each damper jack.

Stein has two damper guide designs, one where the guides are attached to the damper rack, and another where the guides are attached to their own separate rail.[48] Stein's first design, similar to other makers, has guide wires inserted into the bottom of the upper rack. The adjustable wires have a set of wood blocks inserted at their lower ends, which have wide loops of pleated card extending forward to catch the lower ends of the damper jacks. The Toledo Stein has neat and orderly slips of wood that descend from a wood batten glued to the front edge of the soundboard, fitted with the same pleated card loops. There is no connection between the damper rack and the lower damper guide in this design.

The Nuremberg Walter has a lower guide rack similar to that on a harpsichord, but it sits much closer to the undersides of the strings. It is also attached to the front

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[48] Based on the instruments at the Toledo Museum of Art and the Boston Museum of Fine Arts.

batten of the soundboard but has no descending support slips. Since Walter's hammer moldings are much longer than Stein's hammer moldings, the hammer shank stops much lower at its maximum height--which is the point at which the hammer strikes the strings. The shank thus avoids striking the lower rack guide. Stein's hammer shanks lie much higher at rest position, and the hammer moldings are shorter, so the flexible shanks are in danger of hitting a solid rack guide of this type. More fortepiano hammer moldings are of the Stein type, so the individual lower guides attached to the upper rack is also the more common type.

The damper rack fixes the upper part of the damper jacks and is also a means to simultaneously raise the entire set of dampers. It is a batten with individual mortises that are open on the front side in order to insert the damper bodies into the rack. The ends of the mortises are then closed with a front batten pinned to the rack and leathered on its inside face. The rack has a back support beam glued to the bottom of the mortised batten which strengthens it and serves as a base for the lower guide wires. The rack is supported at both ends by uprights that travel in guides attached to the inside walls of the action well. The tops of the damper jacks are covered with overhanging leather ovals that catch on the top of the rack as it is raised by the knee levers.

The damper rack is a transformation of the harpsichord jack register, and functions nearly the same in all Viennese fortepianos. There is little controversy between makers regarding rack design. In some cases, the rack is exposed and subject to ornate decoration. In Stein's instruments the rack is only functional and is hidden by a simple cover. The damper cover is similar to a jack rail in that it ultimately controls the travel of the damper rack but it primarily is a means of protection.

The knee levers lie at the front of the instrument so there must be a transverse intermediate lever that connects them to the damper rack supports. These transverse levers are set on either side of the action sled, and rotate on screws turned into the inside frame walls. The levers have approximately one-quarter inch clearance to operate in and must be very narrow. The inside cheek faces are veneered with pieces of this same thickness in order to create an obscured alcove for these levers.

The tails of the transverse levers serve as platforms on which rests the damper rack supports. They are connected to the knee levers by metal hooks that travel in holes drilled through the bottom boards.

Knee levers are a simple and clever method of raising the entire set of dampers. They free the hands from using stops, which are clumsy and impractical for "pedalling." They utilize the legs in one of the most characteristic and important aspects of piano playing, the ability to sustain and damp the entire string band at will. Knee levers require no extra legs or lyres and no transverse roller bars or other sticker mechanisms. In other words, they are quite efficient.

The knee levers ultimately control the travel of the damper rack and are controlled in turn by the travel of the individually-raised dampers. Good regulation insists that the rack does not raise the dampers higher than will the key lever, preventing an annoying jolt to the finger.

The two knee levers can serve different functions. They can be permanently linked at the center in order to evenly raise the bass and treble rack supports or can be detached to separately raise either end. Separate sustain of the bass and the treble has musical advantages.

The bass lever sometimes operates the moderator, a slender batten with felt or leather flaps that sits between hammers and strings to muffle the tone, i.e. a "piano" stop. Knee levers later were abandoned in favor of a multiplicity of foot-operated pedals, as Janissary music waxed in popularity. This smorgasbord of special effects was eventually replaced by the two or three pedals still used today.

Stein's fortepiano actions are so condensed that they seem to be missing parts. They are shorter in height, lack intermediate levers, and have little means for adjustment. The prellen, for example, rest against a rail padded with felt or leather that is actually the back of the same rail used as a key up-stop rail. This rail serves three purposes and is typical of the efficiency and simplicity in Stein's action design. Most parts, apparently, are presumed to not need regulation. Letoff can be adjusted by shimming the prellen rail or trimming the beak leather, but seems to be fine-tuned by merely bending the kapsel fore and aft. This can critically affect the striking point, but only in the high treble. Walter and others have adjustable letoff buttons which allow for finer regulation. Stein's early pianos also lack backchecks, which is somewhat bewildering. Other makers quickly acknowledged the need to prevent double-striking hammers, and this method soon became universal. Stein's large kapsel bushings may create enough friction to prevent double-striking, and thus eliminate another part.

Stein's constant and clever experimentation with various combination-instruments, and his groundbreaking work with piano-like framing and the Viennese prellmechanik proves that he was very influential on the following generation of fortepiano makers. His designs served as a firm foundation for the next step in the evolution of fortepiano design.

PERFORMANCE PRACTICE

Some conclusions about fortepiano technique can be drawn from instrument design itself. Stein's action rests poorly supported on the sled. Since forceful playing clearly flexes the keyframe, one might conclude that the keys were not intended to be played with much force. A builder might otherwise have made a much more rigid support for the action if this were the case. Walter's fortepianos do not have a sled but they do have a unified keyframe/keyslip that drops down when pulled forward.

Since Stein's fortepianos had no backchecks, one might presume that the keys were not intended to be played with much more than finger pressure. Backchecks catch the hammers on more powerful blows, and prevent them from double-striking. Backchecks on modern pianos work for all but the softest sounds. There is no repetition lever to bring the hammers back close to the strings in the fortepiano, and consequently it takes a firmer blow to cause the hammer to bounce all the way from its rest post to the string. Double-striking is very annoying, and no builder would purposefully ignore it. It is interesting to note that Cristofori's pianos and Walter's fortepianos both have backchecks, and this fact is more telling with regard to fortepianos built by Stein and his disciples than to all fortepianos of this period. All later fortepianos had backchecks, so the idea obviously won out over time.

These two factors indicate a light touch, and they also infer that the instrument should speak promptly and easily. Forte should be accomplished without much effort, and the instrument should seem bright by nature. Hammers that are too soft and muffled will not be able to produce a loud dynamic without pounding the keys beyond their prescribed working distance, i.e. the key dip, and even then there is no guarantee that a loud sound could be produced. The shallow key dip on fortepianos--one-quarter inch (5 mm), reinforces this argument. This key dip is a small deflection, compared to the modern grand piano.

The relationship between key dip and aftertouch on the fortepiano is also telling. Key dip on modern pianos is the distance a key moves vertically from its rest position down to where it meets the moderate resistance of the felt punching below it, measured at the front of the key. Key dip on a fortepiano, like other continental instruments of the time, is controlled by a felted stop rail at the back of the key lever. Aftertouch, the sensation of the key falling further after the hammer has escaped, is negligible in a fortepiano, but nevertheless escapement must occur just before the key meets the modest resistance of the up-stop rail and never afterwards. The same uncomfortable bottoming out that occurs in a poorly regulated modern grand with no aftertouch also is apparent in a fortepiano, even when the aftertouch is so subtle. Forcefully playing the keys will push right through the aftertouch to the hard resistance of the up-stop rail felt, causing the same uncomfortable and undesirable sensation of touch. The fortepiano action was intended to play forte with little effort.

The fortepiano has a narrow dynamic range by modern standards. The possibilities for playing loud seem cut short to modern ears. Eighteenth-century musicians also may have felt that the fortepiano had a limited dynamic range, and thus we find devices on the instrument to extend dynamics in both directions, namely the moderator and the damper pedal.

The moderator, a soft stop not found on all instruments, is usually operated by hand. This indicates that it would be used only for entire pieces or movements, e.g. the slow middle movement of a sonata, or to accompany a song. Devices to lift the entire set of dampers, i.e. a "loud" stop, were sometimes operated by hand in earlier instruments, which indicates that they too were meant to be raised for an entire piece or movement. It is impossible to operate the damper stop by hand like one operates a damper pedal.

Damper hand stops quickly died out. Instead, the legs were put to work, or really the knees. The ability to create a sustained and amplified sound is a true novelty by comparison with the harpsichord. The knee levers allow the performer to phrase dynamics in a subtle manner, and also can be used for coloristic effects. They increase the loudness range in a manner the harpsichord cannot, and they allow for prolonged notes without resort to trilling or other ornamental expediencies. The thin strings of the fortepiano quickly lose their tone, and can make great use of this easy boost in their ring time.

Amplification by sympathetic vibration is a concept that was later applied to reinforce the high treble in modern grands, best exploited by C.F. Theodore Steinway. Freely-ringing waste ends of strings (running between the back of the bridge and the hitch pins) are damped by listing cloth on fortepianos. This manner of reinforcing the weak, problematic treble is not acceptable because the string coils that form the end loops buzz against the hitch-pin rail.

Damping the entire set of strings is just as important as letting them freely ring. The hammered dulcimer or even the pantalon has a quite different effect and application with its constant wash of ebbing tone.

Stops become much more useful as soon as the hands are freed from operating them. Pedalling took on those musical uses that it has today, and is one of the prominent characteristics of performance on any type of piano.

Stein apparently experimented with an even softer dynamic. The instrument built by him in the Boston Museum of Fine Arts has evidence of a device, later removed, that was intended to extend down to silence the faintest dying tones of the struck note by somehow activating a third string.[49]

This device relates the fortepiano to the clavichord, since it focuses on the intimate, barely audible tones of a decaying note. It is yet another indicator--along with the moderator and damper registers--of efforts to extend the instrument's dynamic range other than through finger control. Performers and builders alike were seeking greater dynamic range than could be achieved by the fingers alone. Beethoven and other pianists later demanded a louder, stronger, more powerful instrument. Instrument makers, applying new technology, led the search.

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[49] Koster, " Grand Piano...Saitenharmonika" (Boston, 1989).

SECTION II

CONSTRUCTING THE INSTRUMENT

GENERAL METHODS

I used consistent methods throughout the entire project in order to construct a fine instrument. I gained ever-growing ease in responding to the next challenge through the gradual acquisition of tools and skills. Skill is largely a muscular habit, built through repetition. The ability to efficiently perform mean tasks with the proper tools frees the maker to refine his work, just as technical proficiency at a keyboard allows a performer to be musical.

The construction of an entire instrument is different from restoration of an antique, and presents many new challenges. At first, the intimidating prospect of failure can paralyze a novice. However, each further step is easier to tackle as one learns to correct and later to avoid mistakes.

There are several precautions to take when working with physical materials. First, one should try to reason the operation out, anticipating sources of error. Ever-increasing experience makes this approach more valuable in itself. Next, one should make a practice attempt, either with scrap material or in a dry run, to insure that parts function as intended. If there are multiple repetitions of an operation, as is common on a keyboard instrument, one should then do representative samples on the real work. All these efforts aim to prevent a grievous and costly mistake that can impair or destroy previous work.

A dry run is imperative in any operation involving clamping. All clamps, cauls, glue and cleanup materials must be tested and ready prior to doing the work. All work pieces should fit properly beforehand. It is important to practice on scrap pieces in operations where reversing a mistake is impossible without severe damage to the material. This is particularly true of veneering and French-polishing, where mistakes are costly and easily seen.

Because the enormous cost to outfit an entire workshop is foolish for building just one instrument, I only acquired tools as the need arose. This policy sometimes made earlier operations more difficult--an expensive table saw would have been useful from the beginning.

The construction process is divided into seven major categories of work: the framing, the soundboard, the case, veneering, finishing, stringing, and the action. The work progressed in the same order, and each step built upon the previous ones.

It was clear to me that working on musical instruments in a real-life situation would be very useful, so I found employment in a piano rebuilding shop. Not only was the hands-on experience valuable, but I also gained a true understanding of keyboard instruments, the discipline necessary to produce high-quality work, and a self-assured sense of the tonal ideal in pianos.

THE WORKSHOP

A well-equipped workshop is necessary in order to build a musical instrument with ease. There is a distinction between a manufactory--where the entire instrument and all its parts are made--and a small operation. Even two centuries ago, instrument makers acquired most of their supplies from others, and thus worked in relatively small shops.

For this project, the workshop had to be large enough to assemble and finish one instrument at a time. The author's workshop is a basement area of approximately 500 square feet. The small size requires careful maneuvering. I avoided potential conflicts arising from overlapping operations, however, since only one instrument was being assembled.

Relatively-large keyboard instruments need ample floor space. There must be enough room to set the instrument up on its legs, although the case can be left on a bench top through most of the work. One can manage with just one workbench--the go-bar deck--but two are better. Also, power tools require plenty of clearance around themselves, especially when one is working on long pieces such as framing members.

Furniture finishing requires a temperature- and humidity-controlled room with no dust. This is the greatest conflict in a small workshop. All dust-making activities must be suspended while finishing in a small shop. Dust has a pernicious way of infiltrating everywhere. Merely covering up work is insufficient protection. Dust is also a health hazard. Proper ventilation is necessary for woodworking as well. Explosive and toxic fumes can build quickly in a closed room, with dangerous consequences.

Heating and humidity control are very important when working with wood. Since wood and wood finishes are affected by both--but in particular humidity--the modern workshop must address this issue. Special rooms or devices are needed to control the moisture content of soundboards. I used an electric heating blanket with good results in this instance. Another inexpensive method to control soundboard moisture content is a heat lamp. A more professional solution is to build a hot box, which is an enclosed cabinet or closet that is large enough to hold several soundboards, ribs and wood stock.

Good lighting in a workshop is absolutely necessary. Old illustrations depict workers laboring in the natural light from large windows--a less than ideal situation.[50] Shadows can cause miscalculation and alignment errors. One should always be able to inspect a finished surface from all

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[50] See Hubbard, plate XLI. Also see David Wainwright, Broadwood: by Appointment (London: Quiller, 1982), 150, for illustrations of eighteenth- and nineteenth-century workshop lighting.

angles. The reflection off the working surface is the only method to judge one's effect while applying a finish. This is particularly true of French polishing.

Storage is another important consideration. There must be shelves for storing tools and supplies as well as finished work. Scrap wood for various purposes, e.g. clamping cauls, jigs, shims, etc., must be kept in an organized manner. Wood stock must be kept in a dry, stable environment.

A workbench is the most indispensable item in any shop. It is where most fine woodworking and assembly takes place. Workbenches come in many forms, suitable to the type of work. There are three workbenches in the author's shop. One is a small bench with a bench-top vise, suitable only for light work. The second bench is four feet by eight feet and stands approximately forty-one inches high. The benchtop is higher than the normal height of about thirty-seven inches. The top is large enough to accommodate an entire instrument. This workbench also has a shelf at knee level for tool storage.

The third workbench in the shop is the go-bar deck. This bench has an adjustable table top. The go-bar deck must be able to encompass the entire case and is therefore four feet by eight feet in size. The go-bar deck is intended for keyboard instrument-making. It is a convenient way of clamping glued pieces to large-area forms, such as a soundboard. Long, thin, flexible sticks called go-bars apply clamping pressure between the bench top and a firm ceiling. My go-bars are poplar, and come in slightly varied lengths and thicknesses that provide different clamping strengths. The lengths of the go-bars range from fifty-four to sixty-four inches and their widths vary slightly from three-eighths to three-quarter inches. A room with an eight-and-one-half-foot high ceiling allows the deck top to stand at a comfortable working height.

If craftsmen in earlier times had access to electrically-powered woodworking machines they surely would have used them. Power tools are labor-saving devices that perform large amounts of work quickly, but they have limitations. Hand tools like planes and chisels produce a cleaner, more accurate joint surface for finishing joints in fine cabinet-making. The two types of tools complement each other, and both are necessary.

The tablesaw is the power tool equivalent of the workbench. It is the most useful of all power machinery because of its ability to cut through large boards and to make precise cuts on finer work, such as action parts. A high-quality table saw quickly pays back its investment through convenience.

A drill press and a bandsaw are the other two power machines in the author's workshop. The drill press is almost as critical as the table saw for drilling precise holes. A hand-held power drill is subject to excessive variation, and only is good for cruder work. The bandsaw is not as accurate as a table saw, but it is useful for quick cutting. I purchased all three power tools from Delta, a firm known for balancing economy and accuracy in its products.

Closed storage for tools and supplies provides protection and convenience. Felt and cloth is kept in a tight cabinet, separated from ever-present dust. Tools must be stored where they are easily accessible and yet their cutting edges are not subject to nicking and dulling. Small tools like chisels can be kept in a cabinetmakers case, leather roll, or tool box. Larger items like saws and planes are better stored in a large cabinet with wooden racks or hooks to keep blades free from resting surfaces. It is best if all tools can be segregated from the open workshop when they are not in use.

Storage shelves for keyboard actions and case parts also are necessary. A disorganized shop poses a greater danger of damage to finished work if the work is left laying around and if it constantly must be moved. Shelves must be wide enough to handle all types of actions, legs, and smaller case parts. With a larger volume of work one also needs separate racks to store big case parts, such as lids.

The cost to commission a one-time production of a special tool or jig would be prohibitive for a small shop.

All the shop-made tools and jigs are simple in design, and easy to build. The largest tool is a rack that holds the case sideways (see Figure 14, page 125). The rack provides a horizontal working surface for veneering and finishing the case sides. Vertical surfaces--or gravity, compound the problems in these tasks. The string looping machine, a very useful tool, allows one person to make end loops in music wire with a treadle-controlled rotating hook (see Figure 15, page 127).

A jig is a device to hold wood stock and turn and manipulate it in a regular manner while the stock is cut on a saw. Thus, one can make multiple parts that are uniform in dimension with power machinery designed to cut only straight lines. The number of jigs needed is proportional to the amount of manufacturing performed. Since most parts in the fortepiano kit are pre-cut, few jigs are necessary. Jigs are also useful when cutting small pieces of wood that are too dangerous to hold by hand.

I made several jigs in order to complete the kit. One is a form with two holes, located one on top of the other, to hold a leg square for drilling a centered hole in its end. This is much easier to do on a lathe, and the leg maker should have performed this operation. A useful jig for the table saw holds a prelle in place while recutting the angled notch.

Other useful clamping devices are cauls and forms.

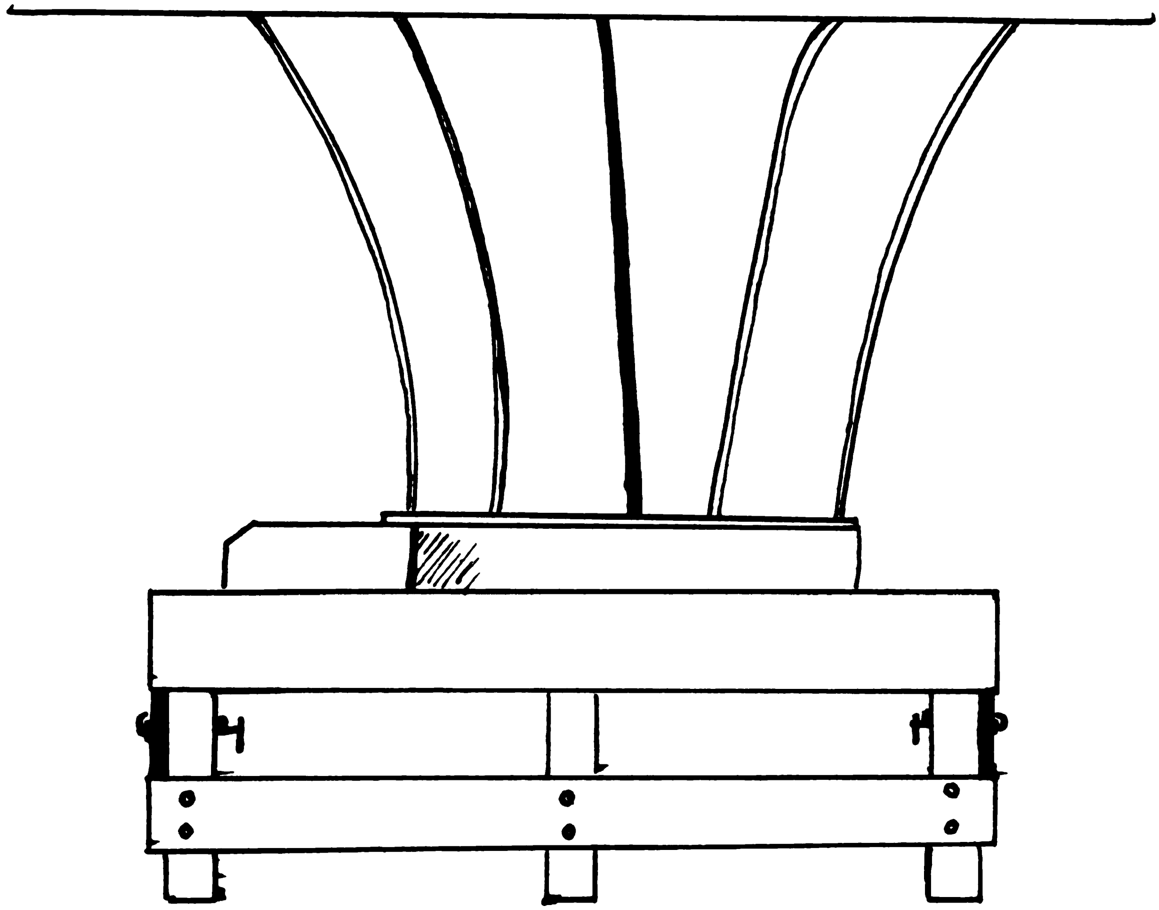

Figure 14. Go-bar Deck.

Cauls are softwood spacers which evenly distribute clamping pressure over a piece to avoid dents and splitting. For curved surfaces, cauls are best formed from the off-cuts, or waste wood, left from the shaping of the piece, since both the caul and the work piece have parallel faces. Forms are molds upon which laminated pieces are glued up and clamped, to take on the shape of the mold. The bentside plywood was glued together on such a mold at the factory. Most molds deal with curved shapes, as these are difficult to cut with a saw. I used a form to glue on the case moldings, with small go-bars spanning the gap. I also used forms to support the fallboard sections when gluing together the mitered joint, and as a support beneath the soundboard when the bridge was glued on--in order to protect the ribs and cutoff bar.

An experienced instrument maker takes every precaution when building a fine instrument while it is in the shop. A diligent worker treats unfinished and incomplete pieces with the care normally reserved only for the final product. What happens to a completed instrument when it leaves the workshop, however, is out of the hands of the maker. A well-constructed instrument that is carefully maintained, and which is kept in a controlled environment, will last decades.

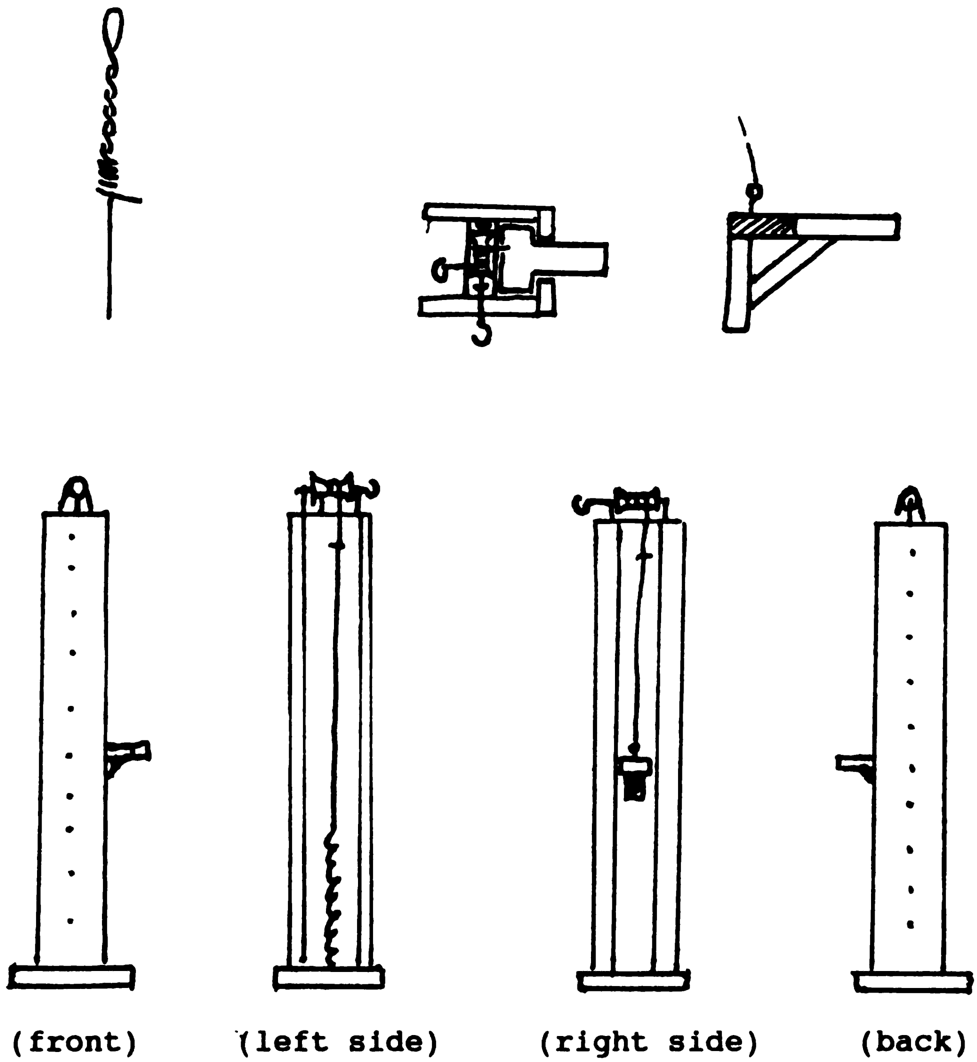

Figure 15. String Looping Machine

THE KIT

The fortepiano kit, purchased from Hubbard Harpsichords, Inc. of Waltham, Massachusetts, is a copy of the instrument now in the possession of the Toledo Museum of Art in Toledo, Ohio. Philip Belt, an early entrant in the present era of antique-instrument restoration, contracted with the Museum to restore this instrument in 1974. Based on the Museum's records and a personal inspection of the fortepiano, the restoration is judged by the author to be thorough and excellent, with the purpose of returning the fortepiano to playing condition.

There is reasonable assurance that this instrument was actually built by Johann Andreas Stein, since Belt found Stein's signature and the date 1784 inscribed on the bottom boards when he took apart the case. This area is inaccessible to would-be forgers, and there was no evidence that the instrument had been disassembled since it was first built.

The restoration work was extensive, since the fortepiano was in rather poor shape. The bottom boards were entirely replaced, as was the concave section of the bentside frame. The wrestplank had been mutilated in a previous alteration, and was also cracked and twisted. It was completely replaced. The strings were presumed not to be original, as the bass end of the nut and its wrestpins had been moved towards the gap by a previous "rebuilder." The dampers and damper rack were entirely missing, and the action had broken and missing parts. Mr. Belt made new dampers and damper rack, repaired or replaced action parts, and restrung the piano with brass wire in the bass and beryllium-copper wire in the treble.

As stated above, this instrument had endured a previous refurbishment--probably sometime in the early nineteenth century, whereby the scaling was altered, particularly in the bass, and the case and raised-panel lid were provided with gilt embellishments. Belt also repaired and restored these decorations, although they are not original.

This fortepiano is still a good example of J.A. Stein's work, even though Mr. Belt replaced an alarming percentage of the instrument, and despite the fact that a poor and sloppy alteration had been performed upon at an earlier time. Besides the changes wrought by time, the doubtful authenticity of the new wire and the replacement damper system, this instrument and the restoration work performed upon it leave a sound basis from which to design a replica.

Mr. Belt, working on his own and with Frank Hubbard, devised the initial design of both the Hubbard and the Belt fortepiano kits. Hendrik Broekman, Hubbard, Incorporated's chief instrument-maker, further modified the kit in 1983.

The kit is a modification of the original fortepiano. The economics of profitably producing a kit for a low price, along with consideration for modern working methods and presently-available materials, impose themselves on such an enterprise. Some parts of the kit are surprisingly good, while others are less admirable.

The frame members are made from quarter-sawn sitka spruce, and are straight and true. They are better than the originals. The dado cuts in the frames are neat and precise. The bentside is one long board with several pieces glued on either end to encompass the curved shape. The whole piece is then cut to its final form. With few exceptions, these pieces are well-matched with their original counterparts.

The inch-thick bottom is cut from five-ply sheets of softwood, which is faced with birch veneer. The lid, flap and fallboard pieces are also patterned out of similar but thinner plywood. This type of plywood is a much finer and expensive grade, made with poplar or other softwood cores. It should not be confused with the construction-grade material commonly found in retail lumber yards.

Plywood is noted for its stability, but it has several drawbacks. It does not hold fasteners such as screws well, it does not plane evenly on its edges, and it is weaker than solid wood.

Viennese fortepianos often have raised-panel lids, but this is not always true. It is not unacceptable for the kit to have a veneered lid, even with a plywood core. The bottom is also made from plywood, but it is less important in resisting string tension than the other frame members. The plywood saves cost in material and labor while not unduly compromising the instrument.

The company also cut costs by simplifying the case ornamentation. The cheek bevels and fronts, as well as the drawer front, are fluted on original Steins, while on the kit they are plain pieces of cherry. This is not unattractive to modern sensibilities. The top edge of the case is veneered, and has no cap molding. This flat edge makes the instrument look very modern. The lower case molding appears to be a commercially-produced piece, with a petite cove on each edge. This molding compensates in part for the elimination of ornament elsewhere. The green baize backing found on the original music desk was thankfully omitted.

The legs are turned in a slightly different style from the originals, with a bead inserted in the coves and other minor variations. The leg blocks and moldings are made of solid cherry and are plainly chamfered. The knee lever molding has a pleasing curve, but it is difficult to drill accurate holes in a curve. The prop stick is tapered and rather plain, but the instruction book includes an optional sketch of a carved one.

Cherry veneer is provided with the kit, and walnut is also available. Both types of veneer are found on the eighteenth-century instruments. The quality of the kit's veneer is acceptable, and the graining is modestly attractive, although there is no spectacular figuration. Many original instruments did not have veneer on the spine at all. They were simply stained or painted black. It is to their credit that Hubbard provides enough veneer to cover this unobserved side as well.

The soundboard is made of quarter-sawn, close-grained sitka spruce boards edge-joined together and cut as a blank to be finished after assembly. Many parts are left oversize in one or more dimensions for this same purpose. The hitch-pin rail is made out of s-shaped laminated strips of beech hardwood. The nut and bridge are made out of beech also, as are the hammer shanks and prellen, two very important action parts.

The wrestplank is solid maple, with spruce soundboard stock veneered on both the top and the bottom--as is proper. The wrest pin holes are all tightly drilled and accurately spaced.

The spine and cheek case sides--the ground pieces between the frame liners and the veneer--are made of the same plywood material as the lid. The bentside, however, is composed of two sheets of a thinner, birch-faced, three-ply material that is glued together in the Hubbard shop. This thinner plywood is used because it is easier to bend around the curved form that gives them their shape. Early fortepiano makers used thinner bentsides for the same reason, and also lined the inner rim in order to thicken the top edge of the case.

In summary, all critical parts of the case are executed very well, and compromises for economy are made only with the parts not directly involved in load bearing.

The action of the instrument, being so important, has some unfortunate compromises. The prellen rail is made of a light-weight and flimsy plywood, inadequate for its purpose. I later replaced this with a maple slip, along with the sloppily cut poplar up-stop rail. The less than ideal chamfering of the hammer shanks at the end of the beak leaves the beak leather unsupported at its corners. The prellen notches are cut slightly incorrectly, and so is the depth of the shank dadoes cut into the hammer moldings. The felts and cloths are, in some cases, cheap and unattractive. The backcheck system is a strip of cowhide glued to the back edge of the wrestplank. This is a clever solution, but it leaves no means for individual adjustment of back-checking. Also, the hammer striking point is altered in the sensitive high treble and the length of the hammer shank is slightly reduced by the protruding cowhide.

In the company's favor, most of the action parts are well machined and are usable with little alteration. The keyboard and frame are sub-contracted out, and have few flaws. Most of the felts provided are piano supply house standard high quality. Some items are clear improvements over the originals, such as the chrome plated balance pins. Overall, the action is well conceived and executed, but some important aspects are too compromised for economy's sake.

A plan and an instruction book are provided with the kit. The plans, with two elevations, are printed on a heavy mylar plastic which avoids the problem of distorted measurements inherent with moisture-absorbing paper. The plans are, for the most part, clear and easy to read.

Instruction books hold out the false promise of containing all the necessary information to complete a given task. The instruction book provided with the kit is no exception. In spite of a sincere effort to be thorough and clear, it does not meet everyone's different level of skill and experience.

The instruction book approaches the work in two ways. The first method assumes that the kit-builder has limited tools at his or her disposal, and presents clever but cheap ways of working. The second method assumes that one has access to the proper tools, or is capable of building or acquiring them. The latter method is always preferable to the former, so much so that the author considers the first method an insufficient means of doing good work.

A kit, by the very term, implies simplicity of construction with little effort by merely following the instructions. Reality proves this false. It is unreasonable to assume that a novice can perform a complicated task as well as a craftsman with years of experience. The kit and the instruction book overlook many nuances that are very important to the final results. In short, not only must one study the provided instructions, but one must think independently as well, and know when to rely on one or the other means when solving problems.

Finally, it must be noted that Hubbard Harpsichords, Inc. was always willing, through numerous telephone conversations, to supply information and advice concerning the construction of the instrument. This assistance proved to be invaluable throughout the entire process.

PROCEDURES

Job specialization was not invented with the assembly line. Even in an eighteenth-century instrumentmaker's shop there would undoubtedly be a cabinetmaker, a finisher and an apprentice to do the menial labor if business warranted. Many roles are taken up alone in a one-person shop, and each role requires a professional level of skill. Veneering is a specialty all by itself, as is cabinetmaking, stringing and finishing. This chapter outlines the major operations of building the fortepiano, and focusses on innovations and experiments intended to improve the kit.

Framing

There are seven primary framing members that form the outline of the case. These are the spine, bentside, cheek, belly rail, wrest plank and two cross-frames. In addition, the bottom and three diagonal braces add strength to the case. Dado joints hold most of the framing members in place. The instruction book suggests using screws as clamps at these joints. I initially intended to replace these with wood dowels, but after consideration and study felt this was unnecessary. Dowels might not adjust to humidity and stress in the same manner as the frame member into which they are driven cross-grained, and later they might show up as unsightly bulges in the sides of the case.

The diagonal braces are poorly conceived, since they are nailed in and do not make a good match with their mating surfaces. I filled the gaps between mating surfaces with a gap-filling epoxy resin to resist any structural shifting.

I planed the whole structure flat on the bottom after the main framing members were joined together. I then applied glue to the flipped-over frame and located the bottom on the frame with guide pins. Squared flooring nails inadequately clamped the bottom to the frame, since the inch-thick bottom does not easily flex. F-clamps provided the extra force to draw the two together. Some makers use wood screws as temporary clamps, then drive wooden tenons or dowels in after the glue joint has dried.

The wrestplank is an integral part of the load-resisting structure. It fits onto a step in the spine and cheek liners that prevents it from pulling away. Two flat-head wood screws, inserted through the case sides and into the wrestplank, add extra strength to each joint.

Soundboard

The soundboard comes slightly oversized, and is uniformly one-eighth inch in thickness. It is composed of eight boards of quarter-sawn sitka spruce, between four and one-half and six inches wide, with the grain running parallel to the spine. It is ostensibly flat, but some warpage is inevitable with changes in moisture content for such a thin piece of wood. Although the instruction book is silent on the issue, I planed the board thinner at its edges all around, and also tapered the thickness of the board from the cutoff bar towards the spine side. I did all planing on the bottom of the board. Soundboard thinning supposedly compensates for the deadening effect of the glued-down edges of the board by adding flexibility to it.

Warpage, splitting, and maintaining the overall shape of the soundboard are important considerations. The soundboards in some of the original instruments have serious deformations between the cut-off bar and the hitchpin rail, where the bridge lies. Some makers maintain this warpage has no effect on the tone. One possible, negative effect if the board warps downward is that the downbearing on the bridge will be reduced, which imperils the positive contact between the string and the board. This less-positive contact between string and bridge diminishes the tone of the piano. Sometimes the soundboard warps upward so much that it presses against the strings, particularly in the bass where there is the largest area of board.

Crown, in reference to a soundboard, is an upward doming of the board that resists string tension. The ribs on a modern piano soundboard travel across the entire breadth of the board, from one edge to another. I crowned the fortepiano board like a modern piano board to insure stability.

There are two methods of imparting crown to a modern soundboard: plane the tops of the ribs in an arch, and glue them to the board in a bowl-shaped form, or lay the board on a flat surface and force the arched ribs down onto it. The first method gives a natural arch to the board, the second presumes that the arch of the ribs will make the board conform to that shape. I chose the former method as the better one.

The instruction book theorizes that the soundboard can be crowned by manipulating the moisture content of the board when its various members are attached to it, much the same way the second method above presumes that the ribs will force the board to conform to their shape. Instead of using a concave form, however, I placed wedge-shaped shims around the edges of the soundboard, which created the same effect. The ribs were arched on the face that is glued to the soundboard, from extremes of 4/32" on rib number two (second from the tail), 5/32" on rib number three, 6/32" on rib number four, 7/32" on rib number five, to 6/32" on rib number six (near the treble). The arch, or taper, on each rib begins just before the cut-off bar, and reaches its greatest point where the ribs meet the spine. I later glued on the cut-off bar and the bridge without any arch to their shape.

I also manipulated the shape of the soundboard by altering its moisture content with an electric heating blanket. Moisture content refers to an equilibrium level of moisture that a particular type of wood can hold, and which is relative to the humidity level in the surrounding air. I artificially reduced the board's moisture content before gluing on the ancillary structures to the bottom of the board so that when the board re-expanded to the normal environment its unrestricted side (the top) would expand further than the ribbed side. I did not alter the board's moisture content when gluing on the bridge, since the ribs already had overarched the board. The compensatory warpage caused by the bridge--which was glued on the opposite side of the board--resulted in a reasonable crown.

I again shrunk the board before gluing it to the frame lands. Afterwards, the board performed in a predictable manner when tested with a tuning fork. The bridge resonates louder with the vibrating fork directly touching it than when the fork touches the board itself. The board also impressively passed the "drum test," where one pounds it with a fist to judge its resonant properties.[51]

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[51] Cf. Nick Gravagne, "The Tap Test: or, If Your Soundboard Talks, Listen to It," The Piano Technicians Journal 31 (October 88): 24-7.

Case

Properly speaking, the case sides cannot be separated from the framing. They are bonded together as one unit. The case sides tenuously meet each other in simple miter joints, since they are not load-bearing parts. The large area of glue contact between the case sides and the frame members prevents any joint failure.

The instruction book suggests clamping the bentside, cheek and spine with 4d ("four penny") nails through evenly-spaced battens to prevent marring of the case while the sides are glued to the frame. I used this awkward method since I could not devise a simpler one. This method is effective, but it unfortunately causes a lot of damage to the case sides. The nails leave three even rows of holes all around the case that telescope through the overlay of veneer, even if the holes are filled. Also, some of the poplar battens stick to the case with the glue that seeps out around the nails. The battens themselves leave damaging dents. This method is a prime example of how the inexpensive solutions presented by the instruction book are often poor compromises due to the real and potential damage they inflict on the finished work. Damage to the case sides contradicts the purpose of having a smooth ground, which is to have smooth veneer on the surface.

An instrument like the Stein, where the bottom and the soundboard are both installed before the case sides, presents this clamping problem. Since the spine and bentside are not parallel it is nearly impossible to clamp one to the other. Clamps will merely slide off of non-parallel clamping surfaces. There also is no guarantee of sufficient clamping pressure if one makes a complex form that matches the shape of the bentside and uses small go-bars to clamp the bentside to the frame. The best way to clamp the sides on is with handscrews, c-clamps, or f-clamps, whose jaws touch both the outside face of the case side and the inside face of the frame. Matching cauls--which evenly distribute pressure across the face of the veneer ground (the case sides)--insure against damaging the case sides when they are clamped.

There are two methods of gluing together a case on modern grands. Some manufacturers glue the soundboard to the laminated inner rim and then glue both to the laminated outer rim. There is no assurance of a flawless fit between the two rims with this method. Any looseness between rims is detrimental to the structural integrity and tone of an instrument.

Most piano manufacturers today simultaneously glue together the laminated inner and outer rims, and then fit the soundboard to the rim by tracing its outline on the bottom of the board. Any tracing errors are hidden by the cast iron plate and a quarter-round molding at the spine, as well as a black line painted on the edge of the board to obscure possible gaps. In both cases, there is no bottom with which to contend.

An alternative method with a Stein-type instrument is to attach either the bottom or the soundboard <u>after</u> the case sides have been attached, leaving access to the frame members for clamping. There is no way to insure that there would be a flush fit between the bottom and frame since the case sides would cover the bottom's edges. The soundboard is the only piece that reasonably can be attached after the case sides.

There are several factors to consider. First, the bentside inner rim, a piece glued on to the inside exposed face of the bentside, overhangs the hitchpin rail (which is flush with the edge of the soundboard). This piece adds strength, and it also makes the top edge of the bentside as wide as the spine and cheek. Thus, it creates an illusion of thickness for the bentside laminate. Second, it is difficult to mark the precise location of the ribs on the bottom of the soundboard--in relation to the dadoes in the spine liner and the cutoff bar--since the ribs do not reach all the way across the frame. Rib misalignment means that the board will not sit on its lands--the tops of the frame members. The first problem can be overcome by using a different material for the bentside case, or by gluing on the inner rim after the soundboard is installed. The second problem might be solved by leaving the ribs long enough to reach across the frame in order to mark their positions on the bottom of the soundboard and then later trimming them short.

The case sides are taller than the frames by one inch on the bottom and two and one-half inches on the top. At the cheeks, two triangular blocks are added to increase the height and thickness of the ground. These bevelled blocks add rigidity to the case corners. They also present another illusion of solidity in case construction.

The lid is made of the same plywood as the spine and cheek case sides, and is divided into three parts: the lid proper, the flap, and the fallboard. Each part is cut overlength, and is to be trimmed slightly overhanging the case sides. The fallboard miter joint must be glued together on a form (any joint faces that are not at right angles are miter joints), or the boards will simply slip past one another. The instruction book says to attach two battens equidistant from the miter joint on the outer faces of the fallboard with hide glue, apply the jaws of the clamps to these battens, and then plane the battens down and scrape the last bit off with a scraper. This is a workable method but the joint may slip if the battens are not exactly parallel. To prevent this, I made an angular form in the shape of the fallboard and then clamped the two sides with go-bars that pressed on the battens. Prior to this operation, I veneered the inner faces of the fallboard in order to avoid the problem of trimming bevelled edges on the veneer at the inside corner of the fallboard.

Veneering

Three separate flitches of cherry veneer were provided with the kit, in addition to smaller case accessories and battens cut from solid cherry stock. The flitches were of varying quality and figure. The first flitch was obviously intended for the spine, as it is nondescript in appearance. There is nothing objectionable about this from the standpoint of cabinetmaking. The best effort and materials are reserved for the most prominent faces of fine furniture and common items alike.

The second flitch has the appearance and cut of crotch veneer, but is really tangentially-cut. I glued this veneer to the bentside and cheek, since it is the most attractive flitch. The third flitch, longer, wider and also tangentially-figured, was intended for the lid.

The grain, or figure, of the wood must be carefully aligned on the case parts. Any variation in figure between adjacent panels will be slight and seem natural, so the flitches should also be kept in order. The vertical alignment of the grain between adjacent panels must be considered along with the lateral order of the flitches. The simple, straight outlines of the case will seem crooked if the figure is askew in a row of panels. The entire case side will not be aesthetically pleasing if the grain is not well matched. Rather, it will be hodge-podge. Color variations should be even, slight, or eliminated altogether for a unified effect.

The instruction book suggests attaching the veneer with contact cement as an easy alternative to hammer veneering with hide glue. Experience and advice from others shows that contact cement performs poorly over time as an adhesive. Contact cement is quite unforgiving. Once the contact cement on the back of the veneer contacts the cement on the face of the ground the veneer cannot be picked up again without wrecking it. It is also nearly impossible to remove any bubbled areas in the center of a piece of veneer once it has been laid down with contact cement.

The company also supplies hide glue with the kit. Hide glue comes in many different grades and qualities, but for most uses one grade is available. Behlen's brand of flakes is a very fine and reliable product. As an added bonus, it does not have the putrid odor of some low-grade hide glues. Hide glue works best the first time it is heated up for use after being dissolved. It is an animal protein slowly cooked by the heat, which eventually destroys its bonding ability.

Hide glue is a satisfying adhesive to work with if one diligently regulates its temperature and consistency. Hide glue must be used hot--it sets up at seventy degrees Fahrenheit. Thermostatically-controlled glue pots which keep the dissolved glue at a constant temperature are readily available. The hot glue pot causes rapid evaporation, however, since hide glue is dissolved in water. Evaporation can be prevented by using a covered glass jar.[52] The hide glue will maintain a consistency slightly runnier than honey with occasional stirring and small amounts of water.

Hammer veneering is the traditional method of attaching veneer, but it is no longer a common practice. I purchased a fine veneer hammer from a mail-order tool catalog. It has a rounded brass head and a steel shaft wrapped with insulating tape. I also had on hand extra veneer tape and a veneer saw.

There are various approaches to hammer-veneering with hide glue. Some craftsmen advocate soaking the veneer with hide glue and forcing it through to the ground--the surface to which the veneer is attached. Others apply the glue to the back of the veneer and to the ground simultaneously. Others also suggest that the ground be sized beforehand with hide glue to prepare a smooth, flat surface. The hide glue

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[52] An empty one-quart jar of Sunrise instant coffee perfectly fits into my Hold Heet automatic glue pot.

is best applied with an artificial-bristle brush of a width proportional to the veneer panels.

There are various opinions as to how pieces of veneer should be jointed and joined. Veneer has a tendency to curl up at the joints. Veneer tape is a gummed brown paper that can be used to hold a seam together. Later, it is dampened and scraped off after the glue has dried. One can also run a veneer hammer over the seam multiple times. When a veneer press is used, the pieces are taped up, laid flat and clamped tightly in a big press. There is no access to the veneer until it dries, and no way to correct any mistakes. When hammer veneering, the hammer is the only true tool one has with which to work the veneer.

Another way to joint veneer is to overlap one piece above its neighbor and then to trim them flush with a veneer saw or a knife. This is the method that I used. It produced good results, but other factors continued to cause problems at veneer joints. The wood expands from the moisture and heat absorbed when the glue is cleaned off the surface of the veneer with a hot, damp rag. This expansion is severest at the joints, where the two edges are free to warp upwards, curl off, or even overlap each other. Joints should be clamped with wax paper and battens, where possible.

It is imperative that the excess hide glue be completely removed or it will leave stains. Cabinet scrapers do not catch all of the glue, and their sharp corners can easily dig into the moisture-softened veneer. A hot, damp rag best removes excess glue, despite potential warpage problems.

Warpage is unavoidable when veneer is cut off a log in very thin sheets--in this case .025" to .035." The natural variation in the grain of the wood will cause one type of fiber to absorb more moisture than another. This warpage can be difficult or even impossible to overcome completely with hammer veneering. My experiments with flattening the veneer by moistening it slightly and laying clamped sheets between dividers of wax paper showed an alarming tendency by the veneer to develop mildew. A fungicide mixed in with the water might have prevented this or might have had unforseen consequences, like staining the wood.

Areas of unacceptable warpage remained despite my gallant efforts to flatten the veneer with the veneer hammer and a hot iron. Warpage that is greater than half the thickness of the veneer threatens to be worn completely through to the ground when flattened with abrasive tools. A cabinet scraper cannot clean excess surface glue out of the low spots, and removes too much material from the high spots.

Veneering a vertical surface is awkward, and almost impossible with dripping glue. The previously-described rack proved very useful when veneering the case sides. The work surface must also be well clamped, in addition to being horizontal. Vigorous hammering slides the veneer panel all over the bench top or rocks the instrument in the rack. The clamps cannot be in the way of the work, and one cannot apply clamps on a freshly-veneered surface. Since it takes 24 hours for hide glue to completely harden, the work would deform if clamped.

The overhanging edges of the end pieces should be no longer than one-eighth inch, else they tend to curl up. The excess glue squeezed out at the edges should not be pulled off when it is gummy, or it will take with it some of the glue underlying the panels. The edges will then be loose from the ground.

Every surface holds different veneering problems. Special care must be taken not to tear the veneer while hammering cross-grained on curved surfaces. Large sheets of veneer, like those used on the lid, must be glued down one-half or one-third at a time, since the hide glue will set up before the whole piece is flattened. Small pieces of veneer for edges, like the top edge of the case, must be stuck on and not hammered, or they will crumble (see Appendix B).

Finishing

The protective finish applied to an instrument is an integral part of its furniture style. A nitro-cellulose lacquer or oil-based finish makes a period replica seem too modern. I selected the challenging and rewarding method of French polishing for the authentic look it would lend to the case. All types of French polishing involve shellac, a secretion of the lac bug, an insect from South Asia. The method I used is the original French method, according to George Frank.[53] There are other national interpretations of French polishing that use linseed oil along with the shellac. The French method uses only shellac.

Shellac is dissolved in alcohol and has the property of melding together into one thin layer, unlike other finishes. The shellac is put on with a solution-dampened pad which is carefully and continuously glided across the work surface. A thin coat of mineral oil serves as a lubricant. Pumice powder is used both to fill the grain and as a polisher. With a thin coat and extremely careful application, one achieves an unsurpassably clear and glossy finish.

The pad, or tampon in French, is traditionally made of linen, with a wool ball inside that stores the solution. The tampon is twisted tight and held in the palm, and then rubbed across the surface of the work. Hand pressure controls the amount of solution released onto the work. Small amounts of both dissolved shellac and plain alcohol are periodically added to the tampon. As the finish builds

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[53] George Frank, Wood Finishing with George Frank (New York: Sterling, 1988). The chapter on French polishing is the best available explanation.

up, the ratio of alcohol to shellac increases, and the total amount of solution added steadily decreases, until finally the polisher is adding nothing at all to the finish. At all times the polisher needs to see the light reflected in the work surface in order to judge the immediate effect. Needless to say, this is a very delicate and demanding skill.

Like veneering, every surface to be finished presents different challenges. The carved and tapered legs must be coated with a heavier solution, rather than rubbed. Large areas use up great amounts of solution quickly from the tampon, and small areas use little. The dampness of the wool ball must be accordingly adjusted. Edges are attended to at the same time as the faces, and they also get heavier coats, since it is difficult to work on tiny surfaces. Inside corners, like the cheeks and the case above the moldings, need careful and creative padding.

Shellac is a durable and beautiful finish, and needs little maintenance once applied. However, it is particularly vulnerable to water and to alcohol. A shellac finish is rarely found on modern furniture because of its labor-intensive procedures.

French polishing, like hammer veneering, is a lost art that I taught myself. It was imperative that I first learn the method on scrap wood. Afterwards, I cautiously approached the case itself, first working on the spine. I tackled the other case parts after conquering and repairing my mistakes. Easy repair is a strong point of shellac. The learning process continued up to the very end, since each surface presented different problems. I did not feel that I had mastered French polishing until I had proved it to myself in each circumstance.

The stubborn, rippled veneer demanded a thicker coat of shellac in order to have a flat surface than otherwise would have been needed. I sanded the finish with sandpaper from 400 grit which is rough in this instance, up to 2000 grit, which is extremely fine, and then I added a final padding to bring up the gloss.

I used fine badger brushes, in addition to the tampon, to quickly build up a thick coat. Generally, only one coat is applied at a time, stretching the finishing operation out over many weeks. The entire finish can suddenly be ruined with too much vigorous work. If a brush is used to build up coats, then a couple of coatings should be brushed on the entire case before working on any one section, in order to avoid drip stains (see Appendix C).

Stringing

Stringing non-modern instruments is a more tedious job because each string must have an individual loop on its far end. There are 136 strings in this fortepiano, and it was imperative that I devise a method whereby one worker could loop and string the entire piano.

The simplest way to make a loop is to firmly hold the ends of the wire at an acute angle while the bight of the wire is looped around a smooth metal hook. A neat loop is obtained by rotating the hook while feeding the wire at a steady rate and maintaining a constant tension and angle on it as well.

There are several easy ways to make loops. One can form a crude hook, insert it in the chuck of a hand drill, and have an assistant turn it while the loop maker holds the wire, as suggested in the instruction book. One can also purchase a foot switch and attach it to a power hand drill, thus leaving the loop maker's hands both free to hold the wire. Alternatively, one can make a looping machine with a treadle to manually accomplish the same thing. I chose the third option, since I could not find a foot switch with the proper power rating (see Figure 15, page 127).

The loop maker holds the wire, loosely coiled, in both hands. The wire runs through his fingers, which act as tension regulators. The wire, secured on the rotating hook, forms a loop with five spiraled coils when the loop maker pushes the treadle to the end of its travel. The loop maker removes the looped wire from the hook and then returns the treadle to its rest position. He places the loop back on the hook and forms five tight coils by manually looping the end of the wire at a right angle around the standing part of the wire. The angle at which the loop maker holds the ends of the wire and the regularity of finger tension determines the tightness and uniformity of the spiral loop.

The loopmaker or stringer then places the loop on the hitch pin and draws the wire down past the wrest pin hole, cutting the wire six inches beyond the wrest pin hole. The stringer then threads the wire through the becket hole in the zither pin that is provided with the kit, and neatly coils the wire around the pin until the pin is even with its wrest plank hole. He then drives the pin into the hole, sets the wire on its nut and bridge pins and brings the wire up to tension.

The s-hook on the looping machine is brass so that it will not be stronger than the brass music wire and possibly cut the loop. None of the brass or steel wires, of modern piano supply-house quality, broke during the stringing operation. The looping machine worked without a hitch.

The Action

I altered the action more than anything else in the kit, with the aim of making it more elegant and easier to regulate (see Figure 19, page 168). A well-regulated action has an even touch and is reliable and pleasant to play. I also experimented a great deal with the hammers themselves, since tone quality is the very heart and soul of the instrument. I made many of the alterations at the back of the action, where most of the moving parts make contact with each other.

The back face of the key up-stop rail serves as the prellen rail on the Toledo Stein, but the kit comes with a vertical piece of one-eighth inch thick plywood to be attached to the back of the keyframe. The prellen consequently stand one-eighth inch closer to the belly rail. This close proximity can cause the escapement levers to bind. The replacement prellen rail cannot be moved forward because the kit uses metal guide pins for the key tails instead of wooden slips as in the original.

I sawed a replacement prellen rail from a hard-maple board. The new prellen rail runs the entire length of the keyframe and overhangs each end by one-eighth inch. The overhangs fit into dado slots in the key end blocks which provide additional stability. I cut a new key up-stop rail out of poplar and glued it to the front face of the prellen guide rail. This provides firm support for the brass prellen guide pins. I then marked holes in the rail for the prellen guide pins, and drilled through the prellen rail and into the key up-stop rail. The guide pins now have three times as much wood to support them than before.

The action felts, cloths, and leathers supplied with the kit are very different from indications on the elevation drawing. The beak leather is much thicker in order to accommodate the thinner action cloth for the back rail, and vice versa. The beak leather, an antelope hide, endures the most work of all felts and leathers in the action. Antelope hide is soft and spongy. It compresses more and can cause a great difference in action regulation. The original instruments all have rather thin beak leather--not antelope--and it seems sensible to make the beak leather thin on the kit as well. I therefore flattened the beak leather with a hot iron applied to both sides of the hide and then reduced its thickness with a razor blade to one-third its original size.[54] I replaced the back rail cloth with a thicker felt, and then shimmed it to the proper height with a strip of leather.

The prellen rest rail was intended to be padded with extremely thin green felt circular pads. Although these pads are effective at quieting the returning levers, there is no means of adjusting the point of letoff through regulation of the rest position of each prelle. I therefore used pads of red bushing cloth, glued at their lower half, as replacements. The pads can now be shimmed with paper to adjust letoff.

I simplified the method of securing the individual prellen springs by merely looping the waste end through the

[54] Suggested by Hendrik Broekman, phone conversation of August 13, 1990.

double holes two-and-a-half times. The end of the spring wire now cannot scratch the finish on the front batten when the action is withdrawn, since it is either buried in the wood of the spring rail or left pointing upwards. I attached the spring rail to the bottom of the prellen rail with screws instead of nails in order to facilitate its removal and repair. I also trimmed the front of the keyframe one-sixteenth inch to pull the entire action forward, since the prellen were too close to the belly rail. This gave the prellen a bit more room for free, backward movement. This foreshortening also did not adversely affect the length of the hammer shanks, as compared with the elevation drawing.

I replaced the hammer rest felts and the damper lifter block felts respectively with thick white action cloth and a heavy calf suede. I trimmed the action cloth to match the profile of the octagonal hammer rest blocks, as on the original instrument.

I achieved the proper key dip not only by felting the up-stop rail and shimming the back-rail felt, but also by padding the tail shelves on the key levers themselves with bushing cloth. This extra shimming was necessary not only because the supplied felts were replaced but also because I attached the up-stop rail level with the top of the prellen rail for a neater appearance.

The endblock stop blocks, which are attached to the top surface of the endblocks, prevent damage to the hammers by preventing anyone from pulling the action forward while it rests on the sled. The stop blocks also allegedly serve as a fine seasonal regulation of backchecking, and are therefore supplied with modern regulating capstans screwed into their back faces. I replaced the supplied capstans with elegant brass grand capstans for the sake of appearance.

The beak leather, such a critical part of the action, proved to be problematical. The beak leather prevents clicking noises and provides a regular and reliable escapement. The beak leather also must be firm and short enough not to bend or flap, since it slightly overhangs the end of the hammer shank. It also must be firm enough not to compress much with heavy use, yet still be soft and quiet.

The antelope hide supplied as beak leather for the kit was uncooperative. When the beak slid down the face of the escapement lever after letoff, the inner fibers of the hide spread apart. The top fibers would hang up at the very corner of the prelle notch, causing the hammer to miss when the key was next played. This problem disappeared when the lost motion between the beak and its prelle notch was increased, but it left noticeable play in the keys.

One experiment to resolve this dilemma involved gluing a glossy, thin goatskin around the beak. Not only was the top of the beak covered, but so was the underside. This left no exposed wood to click against the prelle, and only allowed for lost motion at a level imperceptible to the finger. The rounded shoulder of the beak provided a smooth, continuous surface to the prellen, preventing any hanging up. The round shoulder theoretically provides unreliable letoff, however, so I reluctantly abandoned the experiment.

The beak leather on the original instruments is very thin. It overhangs the end of the wood very little, and it is never found wrapped around the point of the shank. It is somewhat surprising that the original makers' solution poses none of the problems encountered with the kit (see Figure 16, below).

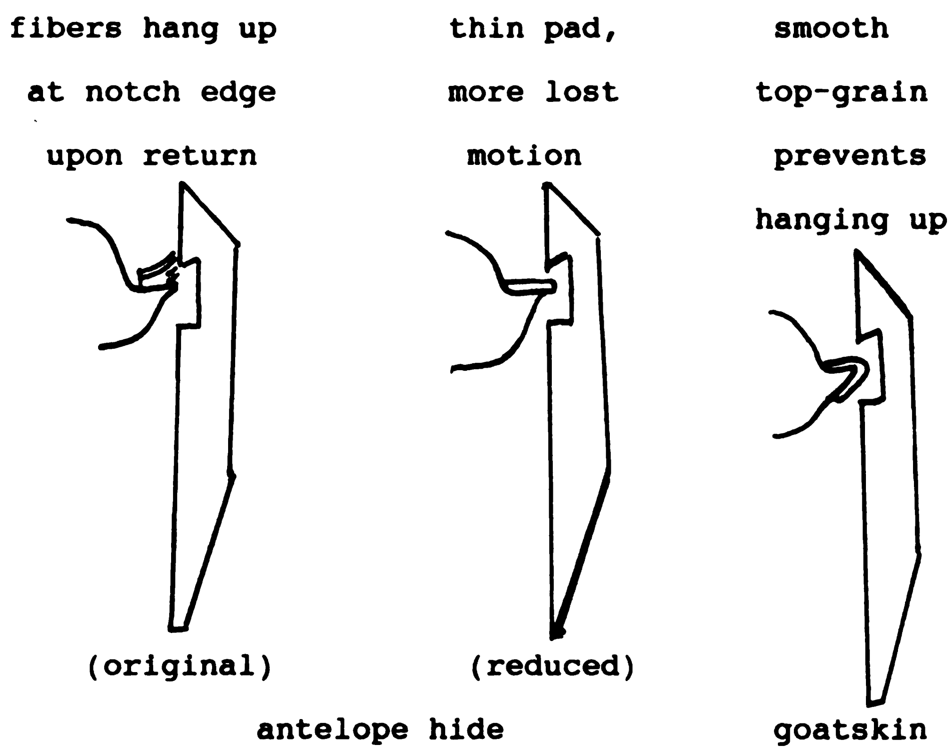

Figure 16. Beak Leathering Experiments.

Because the hammer heads are the most important factor in tone production, I focussed special attention on them. My lengthy experimentation with leather and cloth produced satisfactory results.

Initially, I covered sample hammers with the provided leathers, in accordance with the instruction book. I glued an underlayer of split calfskin on the hammer moldings from the top two octaves and kid suede on the bass hammers. I then coverd the entire set with an outer layer of kid suede. The tone from these hammers (all F hammers) was bright and overly harsh. I aimed all my experiments at eliminating the harshness, mitigating the brightness, and adding a bell-like quality to the tone without losing the loud dynamic.

The experiments proceeded along three lines: layers of leather, layers of felt or felt cloth, and combinations of the two. I employed two thicknesses of organ pneumatic, an alum-tanned kid suede, kangaroo hide, the above-mentioned glossy goatskin and two thick, hard, calf suede hides in various combinations, in addition to the provided leathers.

I made several attempts at creating a more elastic cushion with cloth. I tried wool damper felt in several thicknesses, thick back rail cloth, thick and medium action cloth, and two thickness of bushing cloth, usually with a strip of leather on top. It was clear that the strings would quickly destroy the felt or cloth itself in the sample hammers where it was directly exposed to the strings. As a rule, the thicker the cloth, the worse were the results. The tone was weak, muffled, and ugly. It soon was clear that felt cloth in any form was undesirable. Cloth proved detrimental to the tone, even when layered between leather, or at the very bottom of several layers of leather. Felt hammers apparently can be utilized only when the felt is attached to the molding under tension, and the strings are strong enough to withstand heavier blows. These experiments illustrate one reason why fortepiano makers turned to leather.

The experiments with leather provided several lessons of their own. Hard leathers produce a harsh tone. Soft leathers produce an indistinct tone, as did the cloth, and quickly rob the instrument of volume. Multiple layers of leather are not necessarily beneficial in themselves.

Dynamic loudness must be preserved in a fortepiano, since it has such a delicate tone. An instrument that has a limited dynamic range cannot afford to lose any of it.

I obtained somewhat satisfactory tonal results--initially in the low bass, by overlaying the kid suede with three layers of organ pneumatic leather. This experiment cut the harshness but retained the volume of the tone. I eventually extended these sample hammers up to a^1, where split calfskin replaced the previous underlayer. I reduced the top layers to only two pieces of organ pneumatic in the tenor, and maintained this arrangement through most of the treble.

The high treble sounded strongest with bare hammer moldings. The accompanying wooden sound unfortunately precluded leaving them in that state. Nowhere was it more clear that striking point was a critical factor in volume than in the high treble. The early makers were surely aware of this fact. The nut is brought right up to the edge of the wrest plank in order that the hammers may strike as near as possible to the end of the string, and the hammers must remain there.

The volume of the high-treble hammer heads was somewhat endangered when I covered them with just one layer of kangaroo leather, but it was the best compromise. The additional thickness of the leather on the shoulder of the hammer head forces the head into a position further from the wrest plank in order to clear its vertical back face, and thus alters the striking point. Although a good dynamic balance with the rest of the range remains present with the kangaroo leather, the treble hammers could easily benefit from any additional tone (see Figure 17, page 164).

The composition and gauging of the wire plays an obvious role in the tone quality elicited from the strings. The steel strings in the low tenor, just before the conversion to brass wire, are very weak and ugly. The hammers in this area consequently lack volume. The tone became still weaker in this area when trying to mask the

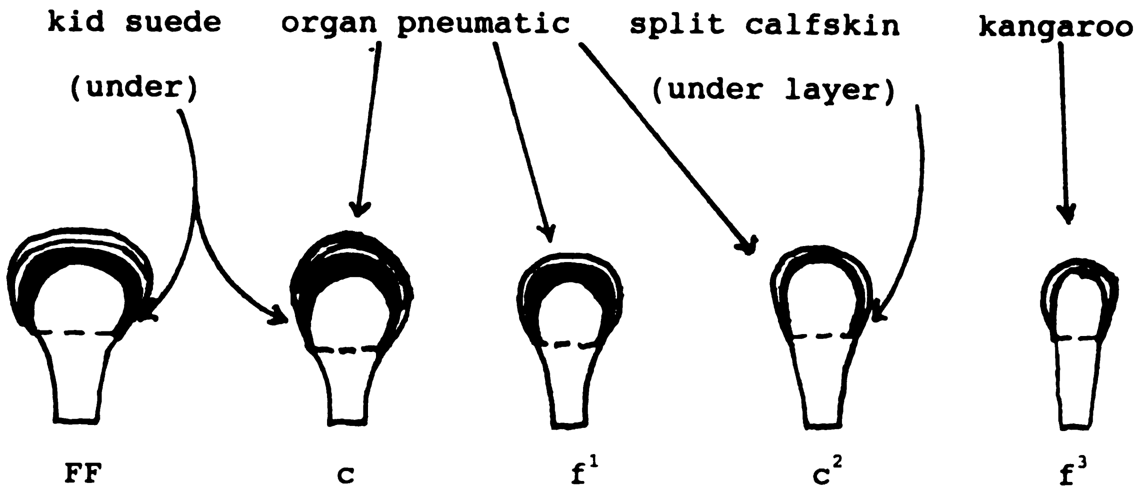

Figure 17. Hammer Leathering Modifications.

harshness with another layer of leather.

By contrast, the sweetest-sounding tonal area centers on f^1. One finds there the clearest, loudest and most-pleasing tone. I used this area as a tonal model for the rest of the instrument. The tonal results in the rest of the range did not match this superior area. One can only speculate that Stein used f^1 as the starting note for his scaling, since the stringing material is not authentic--being steel instead of iron. However, the determination of a maker's starting note by its superior tonal felicitousness is a sound concept in need of further exploration.

I modified the damping system more than any other part of the kit. The original upper damper guide/rack was made from one piece of pine in a thrifty design, and the damper bodies were reduced to short heads with thin birch lifter dowels extending downwards. The lower guides are thicker dowels with a loop of mylar used to secure the damper lifter dowels.

I replaced the damper rack with a mortised cherry batten that has a wooden reinforcing bar attached to the bottom in back. This new rack has the appearance of the original Stein rack. I invented a separate rack--which was drilled and installed just below the strings, to replace the individual lower damper guides.[55] The damper lifter dowels fit freely through the oversize holes in the new lower rack guide. I replaced the treble damper felts with modern damper flats, trimmed to size.

I altered the felting of and connections between the transverse levers and knee levers, for better appearance and function. The transverse levers, which connect the damper rack supports with the knee levers, are screwed into the insides of the case. I fashioned connecting rods for the the two levers out of threaded damper connecting rods intended for modern vertical piano pedals, and secured them top and bottom at the knee lever with a hex nut and wing nut. This arrangement provides a more positive linkage between the two levers. It also allows for quick release of the knee lever for easy servicing.

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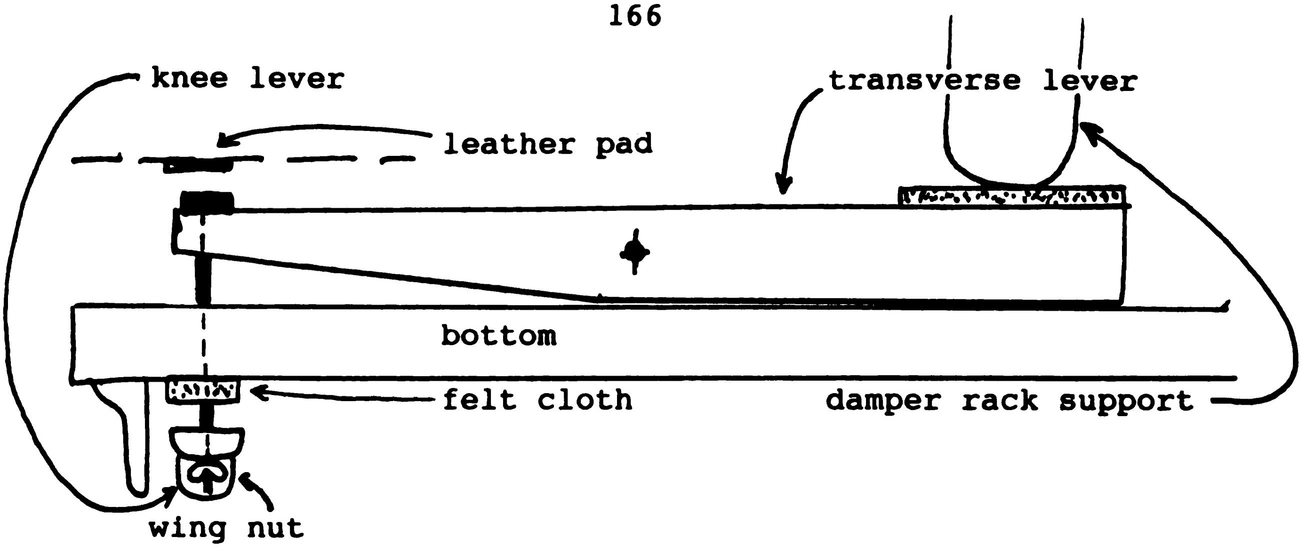
[55] I later discovered that this lower guide rail is very similar to the one devised by Anton Walter.



knee lever/transverse lever connection

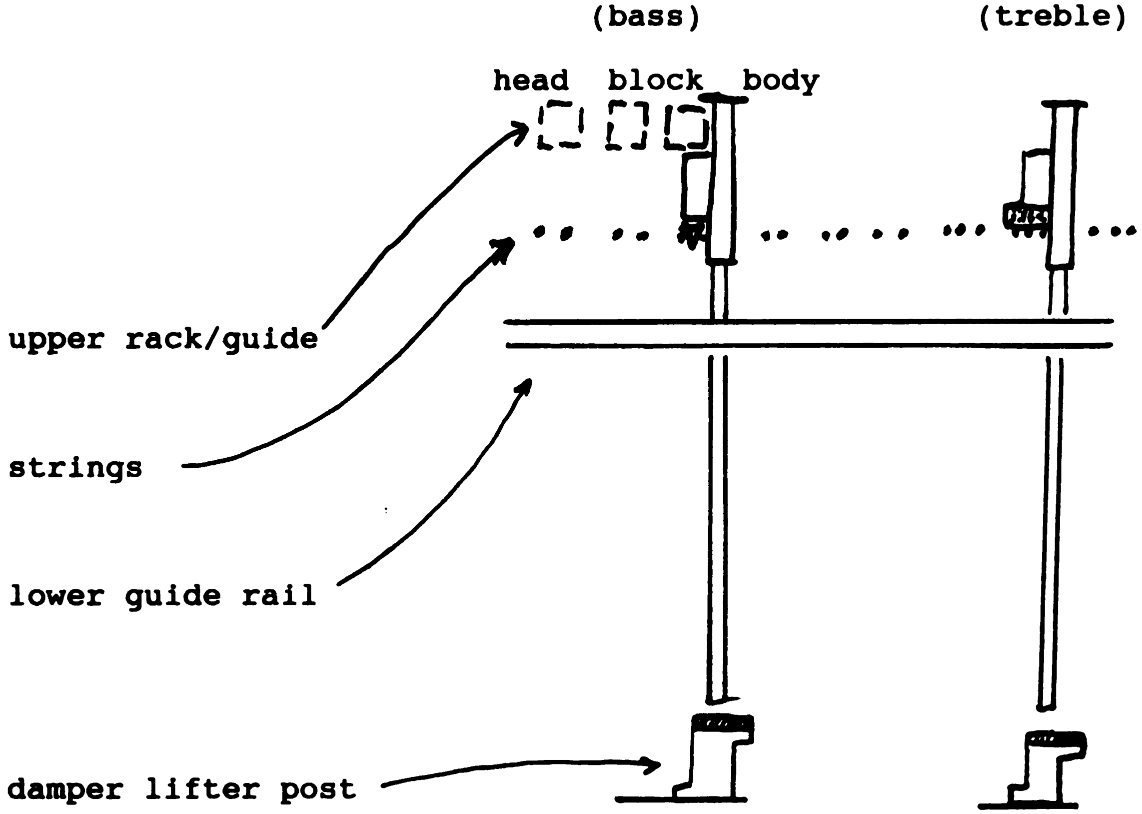


Figure 18. Alterations to the Damping System.

Stein's action design is simplicity itself. Other makers like Walter anticipated later trends by making a more adjustable action. I strove to bridge the gap between the two methods by changing only a few aspects of Stein's action. I intended the other modifications to give the action elegance and sturdiness as well as reliable function. In regards to the rest of the instrument, not only did I wish to learn as much as possible about fortepiano construction, but I used the opportunity to explore experimental designs and methods. For example, I benefited from French polishing in two ways: not only by having a beautiful instrument but by acquiring proficiency in a highly-regarded art. The hammer leathering experiments revealed a great amount about tone and materials. My work on this instrument and on the entire project is an effort to uncover the reasoning processes and applied procedures used by the original makers to build a fortepiano.

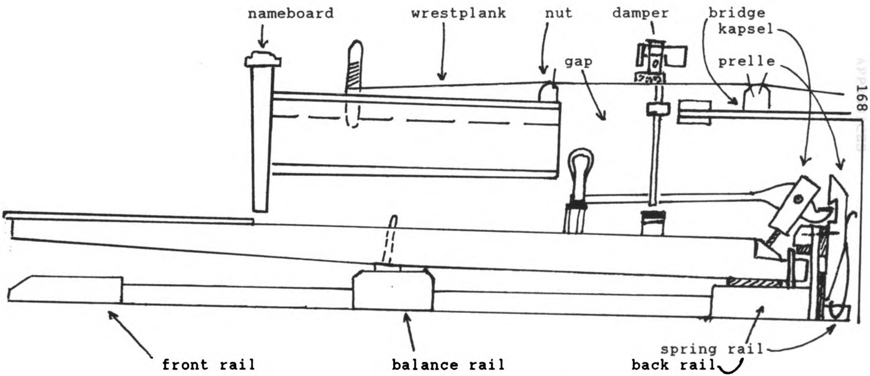


Figure 19. Profile of Modified Kit Action

APPENDICES

A. CHRONOLOGY

The sequence of constructing an instrument is not the same as the sequence of designing one. This first instrument involved much learning, pondering and capital investment, so the time spent building it gives a distorted impression of how much time an established, professional and efficient workshop would need if these prolonging factors were eliminated. It is interesting to note that the sequence one follows in constructing an instrument is not always readily apparent. One strange, insignificant operation may be performed seemingly out of the blue. Then again, there is little room for altering the order of events in constructing an instrument. These convolutions are not necessarily apparent in this list, since it includes only major events and not all the minor details. There are some intervals left unexplained in the flow of events that are mostly time spent in research and practice. The interactive process of learning and refining new skills makes it difficult to determine exactly how long a particular operation should have taken. Most of the work on the instrument was accomplished in a two-and-a-half year period, from May, 1988 to November, 1990.

CHRONOLOGY

Dec 85	Kit packed at Hubbard Harpsichords, Inc. shop
Mar 86	Kit shipped Final payment received, totalling $3,610.00 Kit arrives by Consolidated Freightways Kit opened and inspected
Jun 86- Apr 88	Apprentice at Wm. J. Schneider Piano and Pipe Organ Service (piano rebuilding)
Sep 87	Build workbench
Nov 87	Purchase Delta drill press
May 88	Dry run assembly of frame parts and bottom Glue frame members together: bentside, spine, belly rail, cheek, (2) cross-frames
Jul 88	Plane bottom of frame members flat with each other Attach bottom with Titebond glue and flooring nails; trim flush Glue and nail diagonal frame members (3) Mark and cut spine dadoes for ribs
Aug 88	Build go-bar deck (4'x 8' adjustable-height workbench)
Oct 88	Purchase Delta bandsaw Make app. 300 go-bars, of poplar (wooden spring-clamps) Visit to Smithsonian
Nov 88	Visit Toledo Museum of Art, original Stein Dimension ribs and sounboard cut-off bar
Mar 89	Plane soundboard thickness at edges Arch ribs Soundboard dried in electric blanket for 19 hrs. Ribs glued onto arched soundboard
Apr 89	Soundboard left in heating blanket 30 hrs. Glue on cut-off bar Fit and glue on Bridge Glue soundboard to frame

May 89	Fit and glue hitchpin rail Drill nut and bridge Drill hitchpin rail Pin bridge Glue on bentside and liner Glue on spine and cheek
Jun 89	Learn veneering techniques, acquire tools and supplies Build rack Veneer spine Veneer bentside and cheek
July 89	Visit Shrine to Music Museum (Vermillion, S.D.) Veneer inner rim Veneer top edge of case
Aug 89	Glue on cheek veneers Veneer lid and flap Build jig, glue fallboard together Cut veneer slips, veneer lid edges
Sep 89	Visit Boston Museum of Fine Arts Visit Metropolitan Museum Veneer fallboard Mortise and hinge lids
Oct 89	Fit and assemble music desk, damper cover and name board Scrape and sand case Acquire French-polishing materials
Nov 89	Attach case moldings Sand legs, drill for threaded rods Fit leg blocks and legs Glue on sharps Stain key levers, front rail Felt key-frame Level keyboard Sand hammer shanks and kapsels Glue on damper rack guides Glue on damper-cover blocks Assemble entire case for fit Shellac wrestplank and soundboard
Dec 89	Re-sand entire case Practice French-polishing
Jan 90	Begin French-polishing spine
Feb 90	End French-polishing spine

Mar 90	Visit instrument maker, San Fransisco Shellac leg blocks, paint bottom Begin French-polishing bentside Begin French-polishing lid
Apr 90	French-polish legs Begin French-polishing other parts
Jun 90	End French-polishing cheek/bentside
July 90	End French-polishing accessories, case Insert hitch pins Design and construct looping machine String piano List waste-ends of wire (damps vibrations)
Aug 90	Bush kapsels Epoxy kapsel stems Pin hammer shanks Drill key levers for kapsels, and attach Space and travel hammer shanks Glue on hammer rest posts Glue on damper lift posts Sand prellen, build jig and recut notches Hinge prellen with leather Make maple prellen rail Make new key up-stop rail Drill and pin prellen rail Attach prellen rail to keyframe, dado endblocks
Sep 90	Drill spring rail, make springs Regulate springs Make new damper blocks Assemble damper heads Leather damper wedges Make new damper rack Devise and assemble underlever/knee lever system Re-level keys, regulate key dip Regulate prellen Chip (pluck-tune) piano strings, several times Experiment with leather and piano hammers Leather piano hammers Leather hammer shank beaks Glue on hammers Regulate action
Oct 90	Assemble dampers Tune fortepiano, several times Glue leather caps on dampers Fine regulation and tuning
Nov 90	Finish details

B. PREPARATION AND PROCEDURE FOR VENEERING

Preparation

veneer hammer
smaller hammer for curved surfaces
hot water, bucket
damp rags
dry rags
sharp scrapers
glue pot
glass glue jar
dissolved, heated hide glue at proper consistency
veneer saw
sharp knives for overlaps
chisels for removing underlap
iron, on low setting
hot plate for veneer hammer
brushes
straightedge
veneer tape
two extension cords
clamps
hot room, preferably
square to align panels
clock
wax paper

Procedure

case parts must be at their final dimensions before veneering
number flitches, keep in order
locate and arrange pattern on ground
flatten veneer
cut slightly oversize (overlapping removed when panel is glued down)
prepare ground (fill, sand or scrape, size)
glue on veneer
clean surface with hot, damp rags and scrapers, wipe with dry rag
insure all panels are on completely, and flat
allow glue to set 24 hrs.
trim edges flush
scrape and sand veneer to prepare for finishing

C. PREPARATION AND PROCEDURE FOR FRENCH POLISHING

Preparation

ample lighting
low to moderate humidity in finishing room
securely clamped work surfaces
flat surfaces, scraped, sanded, stained and/or filled
three handy containers with pure alcohol, 250 gm-cut shellac solution, and 350 gm-cut shellac solution
4"x 8" sheets of linen and wool, for the tampon
sandpaper in grits from 400 to 2000
pumice, rottenstone, and red tripoli abrasives
air-tight containers for tampon storage
two air-tight glass or plastic containers for large amounts of the two solutions
mineral oil
paper towels or lint-free rags
filters
scale
1" and 2" badger brushes
smaller, natural-bristle brushes for edges

Procedure

With tampon alone:

a well-prepared surface is half of the finish
apply generous amounts of shellac the first day to fill pores and flatten the surface
continue building the finish the second day
delicate final polishing, removing mineral oil on third day

With brush coats:

about ten thick coats sanded as flat as possible in between will provide enough finish to cover most distortions in the veneer
when surface is flat, sand with high-grit paper, 1000-2000.
pad final surface as above, removing mineral oil and bringing up to a high gloss

On carved pieces:

coat thickly with a rag, brush or foam pad
sand any runs in between coats
gradually decrease shellac solution, until only alcohol is used; gradually decrease alcohol until nothing is left on pad.

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