Chapter 2

Construction and Design

"[Is it not] a great irony . . . that when [the] quiet equilibrium [of 18 tons of string tension and 1,000 pounds of downbearing being resisted by the plate and soundboard] is violently upset by a pianist, and when the system is relentlessly struggling to restore its natural calm, the piano is singing."

—Nick Gravagne, RPT

The history of piano design is a history of improving the efficiency of the conversion of the force of a finger to acoustical energy. Piano designers have achieved this by focusing on three aspects of piano design:

- Increasing the tension of **strings** and finding ways to resist the compression they produce
- Increasing the tension and compression in the **soundboard**
- Improving the tension and compression in an ever-heavier **hammer**, and improving the efficiency of the action to support the hammer

By around 1870, within a century and a half of the piano’s development, improvements in these areas had made the piano suitable for ever-larger theaters and music halls.111 No longer just a chamber instrument, the piano became capable of carrying a solo part against an orchestra of over a hundred musicians.

More recently, designers have experimented with stiffer materials for the soundboard and action parts, which improve the efficiency of energy transfer. Richard Dain of Hurstwood Farm Piano Studios, the designer of Phoenix features in Steinraeber & Söhne pianos, points out that the efficiency of energy conversion in a conventional piano is similar to that of a steam locomotive—about 4%—whereas it is up to 8% in pianos equipped with carbon-fiber soundboards, carbon shanks, and bridge agrafes instead of the conventional bridge pins.112

Overview of Construction

The foundation of the piano consists of the **rim** (or a wooden frame in verticals), the **beams**, and the **belly rail**, which are assembled into a strong structure (Figure 30).

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Construction and Design

In the best grand pianos, the pinblock and the stretcher are also parts of this structure as they are mortised or doweled into the rim. The case may be built together with the rim in one procedure, or may be added to it later. In grands, the key bed that is glued to the underside of the rim serves as additional structural reinforcement.

In grands, the soundboard is glued throughout its perimeter to the rim and the belly rail, while in verticals it is glued to the frame. It is gently curved upward in the middle to better resist the downbearing of strings (discussed below). This curvature, or “crown,” is supported by the soundboard ribs: wooden bars that are glued to the underside of the soundboard. The main purpose of the ribs, though, is to increase the stiffness of the board across the grain.

The long bridge and the bass bridge are glued to the soundboard. Two bridges are necessary because of the over-strung (also called cross-strung) design: bass strings cross over the tenor strings and have their own bridge. In smaller pianos, the bass bridge often has a shelf (also called “apron”) that allows bass strings to be longer while transferring their vibrations to the more flexible area of the soundboard.

The cast-iron plate (Figure 31) is installed over the soundboard to suspend the strings, which are stretched at high tension. The modern plate covers the entire piano and greatly increases its structural stability. It is fastened to the rim and to the pinblock, and does not touch the soundboard. The plate commonly rests on dowels, wooden blocks, or bolts that extend vertically from the rim and pass through the soundboard (Figure 32).

The plate is also fastened to wooden beams under the soundboard with nose bolts. The bolts are threaded into the beams and extend to the plate through holes in the soundboard. The plate is affixed to nose bolts with large, decorative nuts or “cups.” The larger the plate, the more nose bolts are needed to suspend its struts and its horizontal sections.

In longer Steinway grands (models A–D), the rigidity of the plate is increased in the treble section with a bolt that
attaches the plate to the so-called Steinway bell\textsuperscript{113} (Figure 33) through a hole in the soundboard. This massive, hollow casting is firmly attached to the bottom of the rim on the curved side of the piano. By increasing the rigidity of the plate in the treble, the Steinway bell reduces the plate’s absorption of acoustical energy (energy produced by strings when vibrating), thus increasing the length of decay and the volume of sound in that section. Since less energy is absorbed by the plate, more of it reaches the soundboard to produce a louder, longer-sustained sound. The rigidity of the plate also is increased with nose bolts and with cupola design (page 56).

The strings are attached on one side to tuning pins (Figure 34), and on the other to hitch pins (see Figure 650 on page 424). Tuning pins are inserted into the wooden pinblock through holes in the plate, whereas hitch pins are inserted directly into the plate. On the tuning pin side there is a massive flange on the underside of the plate. This flange keeps the pinblock firmly in place and counters the pressure from the strings, which passes through the tuning pins on the pinblock, then on the plate. The plate is firmly attached throughout its perimeter to the rim and the pinblock. In higher-quality grands, the plate is also attached to the metal shoe in the belly rail by one or more plate horns (Figure 36). The horns transmit the pressure that the strings exert on the plate via the shoe to the beams and the rim, which transmits it back to the plate. The strings’ pressure, therefore, is not countered by the plate alone, but by the structure of the entire piano.

Strings pass over the bridges, held tightly by the staggered and slanted bridge pins (Figure 35). The bridges transmit vibrations from the strings to the soundboard, which transduces them into sound. To ensure solid contact with the bridges and to improve the amplification of sound in the soundboard, strings exert some downward pressure on the bridges. This downbearing is made possible by constructing the bridges to deflect the strings upward (see Figure 645 on page 417).

Each string has a carefully predetermined speaking length, a segment that defines its pitch. This segment is terminated on one end by the front bridge pins, and on the other end by one of several possible devices: the capo tast, agraffes, or a raised plate flange. The capo tast is

\textsuperscript{113} U.S. patent no. 314,740 by C.F. Theodor Steinway (1885). In many publications, Steinway’s first name is anglicized to “Theodore.” I have retained the original spelling of “Theodor” because he signed most of his later patents as “C(hristian) F(riedrich) Theodor Steinway,” and also to avoid confusion with his nephew, Theodore E. Steinway, the author of People and Pianos.
GRAND PIANO CROSS SECTION
Steinway & Sons Model M

Developed from drawing supplied courtesy
Steinway & Sons, New York

1 Key bed
2 Key frame
3 Front rail
4 Front key pin
5 Front rail cloth punching
6 Balance rail
7 Glide (Balance rail glide)
8 Balance pin
9 Balance rail bearing
9A Balance rail felt strip
10 Back rail
11 Back rail cloth
11A Back rail cloth underfelt
12 Key stop rail prop
12A Key stop rail prop block
13 Key stop rail
14 Key frame stop (Dag)
15 Key
15A Key lead
16 White key top
17 Black key top
18 Front key bushing
19 Key button
20 Balance key bushing
21 Capstan screw
22 Backcheck
23 Backcheck wire
24 Key end felt
25 Action bracket
26 Wippen rail
27 Wippen flange
28 Wippen (Repetition)
29 Wippen heel felt
30 Jack (Fly)
31 Jack tender
32 Jack regulating screw
32A Jack regulating button
33 Wippen spoon
34 Repetition lever post
35 Repetition lever (Balancier)
36 Repetition lever regulating screw
36A Repetition lever regulating button
37 Repetition spring
38 Repetition felt block
39 Repetition end covering
40 Shank rest felt
41 Let off rail
42 Let off screw
42A Let off button
43 Hammer rail
44 Hammer shank flange
45 Drop screw
46 Hammer shank
47 Knuckle
48 Hammer
49–56 Backaction
49 Underlever tray
49A Underlever tray end pin
49B Underlever tray felt
50 Underlever tray spring
50A Underlever tray spring punching
51 Underlever tray cushion
52 Underlever flange
53 Underlever
53A Underlever lead
54 Underlever top flange
55 Damper wire screw
56 Sostenuto tab
57 Damper stop rail
58 Damper wire
59 Damper guide rail
60 Damper head
61 Damper felts
62 String
62A Understring felt
63 Agraffe
64 Tuning pin
65 Sostenuto rod
66 Sostenuto bracket
67 Key slip
68 End block (Key block, cheek block)
69 Fallboard (Key lid)
69A Fallboard pivot pin
69B Fallboard pivot flange
70 Stretcher (Cornice)
70A Stretcher top
71 Pinblock (Wrest plank)
72 Bellymen felt
73 Plate
73A Plate strut (Crossbar)
74 Nose bolt nut
75 Plate bolt
76 Plate support dowel
77 Hitch pin
78 Duplex termination
Hexagonal Core

Some manufacturers use hexagonal steel as the core wire (Figure 83). Its hexagonal shape prevents the copper coil from slipping on it. The advantage of this approach is that you can adjust the length of the winding simply by uncoiling it on either end of the string and cutting it off. The same string, therefore, can be installed in different pianos as a replacement for strings of different lengths but similar diameter. Most supply houses sell such “universal replacement bass strings” in sets of 20 to 30 different sizes. Unfortunately, hex strings don’t blend well sound-wise with round-core bass strings. Another disadvantage is that the sharp edges of hexagonal wire cut into agraffes and V bar, making the string “ping” or jump as it’s being tuned. In some cases a hexagonal string can’t be fine-tuned at all.

Duplex scales

When a string vibrates along its speaking segment, its vibrations, including all of its partials, excite the unmuted segments of strings to vibrate sympathetically. Those segments are:

- **Front duplex**: in grands, the segment between the V bar, agraffe, or a movable fret and the counterbearing; in verticals, the segment between the raised plate flange and the pressure bar

- **Rear duplex**: a segment between the rear bridge pin and a raised termination on the plate (duplex strip, bar, or fret)

All duplex segments in a piano are collectively referred to as *duplex scale* (Figure 86).

Since Theodor Steinway patented it in 1872, duplex scale has been used by most piano manufacturers to enhance tonal brilliance and to increase a piano’s perceived loudness. Originally, Steinway pianos were equipped with one fret per unison. Tapping the frets fore-and-aft allowed tuning the rear duplex of each unison individually under full tension. Steinway moved away from this concept and, like most other brands that have a rear duplex, now use termination strips that span entire sections (as seen in Figure 86) and are not intended to be repositioned after the strings are pulled to pitch. Individually tunable rear duplex terminations are found in Mason & Hamlins, old Baldwins, and some other older grands. Fazioli and Petrof allow tuning both the rear and front duplex scales, and have improved their tunability by placing a metal plate under the frets (Figure 87).

Some technicians question the value of the additional effort required to tune the duplex scales because these segments are short and highly inharmonic (see “Inharmonicity” on page 101), and go out of tune much more readily than the speaking segments.

Bridges

Modern pianos have two bridges: the *long bridge*, which spans the tenor and treble sections and runs diagonally throughout the soundboard, and the *bass bridge* in the bass section. The bass bridge is higher, making possible the *cross-strung or over-strung* design, in which bass strings pass over the strings in the tenor section (Figures 88 and 89). This design is considered to be an improvement over the *straight-strung* design (Figure 90) found in early pianos because it allows the bass strings to be longer, and the bass bridge is closer to the flexible middle of the soundboard. The lowest bass notes sound better in this arrangement.

The bridges transmit vibrations from the strings to the soundboard, but also reflect much of that energy back to the strings, creating a long sustain. Bridges stiffen the soundboard, and that reduces its resonances. (This is discussed in more detail in “Soundboard” on page 43.) Normally, a bridge is about 1½” [38 mm] wide, and its height is determined by the design of the plate, its thickness, and the amount of downbearing.

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117 Technically this is not a duplex segment. It is shorter than a typical duplex segment, but vibrates sympathetically and affects tone color.

118 U.S. patent no. 126,848 (1872).
bridges by bridge pins. These pins are usually made of steel and are brass-plated to reduce the friction between string and pin. Some piano makers, for example Sauter and Ravenscroft, optionally use titanium pins for extra rigidity and hardness. The front and rear bridge pins are arranged so that each string bends slightly around them. They are also angled to keep the strings in firm contact with the bridge even during the strings' upward motion.

Bridge pins are termination points for the speaking length of the string and for the duplex or muted segment behind it (see “Duplex scales” on page 36). To terminate the wire efficiently, these pins must be very rigid—they must reflect the strings' energy, not absorb it. That is why bridge pins are relatively thick.

Traditionally, bridge pins are filed on top after they are installed, but some manufacturers and rebuilders leave them rounded. The filing gives the pins a finished look, and some technicians believe that it improves the clarity of sound. Whether or not this is true, the filing raises a legitimate concern about introducing “false beats” by compressing and scorching the wood by overheating the pins during filing.

**Bridge Notching**

The top surface of the bridge in front and in back of the bridge pins is notched (cut out) so that the wood will not interfere with the vibrating strings. The notches can be cut with a machine or by hand, as depicted in Figure 107. This is time consuming and requires skill.

The notching must be very precise because, together with the bridge pins, it determines the strings’ speaking (and rear duplex) lengths. Whereas the bridge pins terminate the strings’ sideways vibrations, the wood of the bridge terminates vertical vibrations. Both terminations must be in the same spot or the string will act as two strings that are slightly out of tune with each other. This causes “false beats.” Each notch should start exactly on the line that, in a unison, passes through the center of each bridge pin. With time, however, strings create grooves by denting the bridge (cap), and the effective termination of the wood moves forward from the center-of-the-pins line. That is why the notches should be cut slightly closer to the center of the bridge (Figure 105). The notches should be deep, and form an almost vertical edge at the bridge pins.

Since the speaking segment of all strings in a unison should be equally long, bridge pins are usually installed on a line perpendicular to the strings, and the notching of the bridge cap follows this pattern. However, in some older pianos (for example, Steinway concert and semi-concert grands, models D and C, made from 1884 to the 1930s[123]) the pins may follow the contour of the bridge, especially in the treble. The bridge (cap) is either chiseled parallel to its sides or is notched as depicted in Figure 109. Since the thickness of all strings in a unison is the same but their speaking lengths vary, each speaking length has a slightly different *inharmonicity* (see page 101). This, in turn, causes the partials of each speaking length to be slightly out of tune with each other. A listener will not notice this, but a tuner will.

**Unequal Speaking Lengths**

A slight detuning of partials increases sustain through a phenomenon that occurs whenever strings or their partials are *slightly* detuned from a perfect unison. The reason for this is that the strings, which are coupled via the bridge, affect each other as they vibrate. Two strings that are out of tune with each other generate partials that oscillate between vibrating together (in phase) and opposite each other (out of phase). This causes beats. When the partials vibrate only in phase, the energy of the strings is

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transferred more quickly to the soundboard than if they are out of phase part of the time. The reason for this is that the strings, when out of phase, impede the energy transfer of each other, which, in turn, causes them to vibrate longer than if they were always in phase. In effect, encouraging the partials to go out of phase is not unlike increasing the wave impedance of the soundboard and bridge assembly. This is discussed in more detail in “Energy Transfer and Reflection” below.\textsuperscript{124}

Unequal speaking lengths are found mostly in the mid-treble (“melody octave”—see page 49), where the volume of sound is inherently weaker than in the rest of the piano. If you plan to replace the bridge cap or the entire bridge, I recommend duplicating the original design.

\textsuperscript{124} For a more complete explanation, see Arthur Benade, \textit{Fundamentals of Musical Acoustics}, pp. 335–339.
In pianos with bridge pins the soundboard is designed to make the strings press down somewhat on the bridges, creating a downbearing force. Assuming that the average angle of deflection at bridges is 1°, a typical average in a new piano, a string stretched at 180 lbs. of force (780 N or 80 kg) exerts a downbearing force of about 3.14 lbs. (14 N or 1.43 kg) (for formulas, see “Measuring String Downbearing” on page 416). Multiplying this by 230 strings in a piano, it becomes clear that the total downbearing force on the soundboard can be 720 lbs. (3,216 N or 328 kg). At an angle of deflection of 1.5°, the downbearing increases to almost 1,100 lbs. (4,900 N or 500 kg)—the equivalent of six people standing on the soundboard.

Too much downbearing constrains the movement of the soundboard and chokes off the sound. It’s like pressing the cone of a loudspeaker—the more you press it, the softer the sound. Without any downbearing, however, the strings would push the bridge and soundboard during the downstroke, but would pull away from them on the upstroke. Despite the angled and staggered bridge pins, this would cause buzzing and rattles, and energy would be lost. Some designers feel that all downbearing is detrimental, and use bridge agraffes as an alternative to bridge pins (page 43).

To resist the force of downbearing, the soundboard is crowned toward the strings to make it slightly convex or cylindrical. This also increases the board’s stiffness and thus reduces undesirable resonances. In older pianos the loss of downbearing usually is most pronounced in the tenor section where the soundboard is the widest and least stiff, and is accompanied by the loss of crowning.

Manufacturers adjust the downbearing so that it will remain positive (strings bearing down on the soundboard) even after the soundboard loses some of its crowning due to the dessication in drier seasons and a resulting loss of compression. Unfortunately, that means too much downbearing in more humid seasons, which accelerates the
long-term loss of crowning and compression. If the soundboard installer could count on the piano being climate controlled, or if the soundboard were impervious to moisture (see Figure 112 on page 45), the amount of downbearing could be much lower and the dynamic range greater. Some manufacturers use bridge affairs and very little or no downbearing (see “Alternative Bridge Couplings” on page 43) to give their pianos exceptionally long sustain.

In most pianos the downbearing angle should be the greatest in the high treble, up to 1.5°, and should taper to 0.5° in the low tenor and bass. The downbearing of low bass strings is usually too high; this, combined with short backscale (discussed below), chokes off the part of the soundboard that needs to be especially free and flexible. A downbearing of 0.25° is sufficient in that section.

Soundboards are crowned using a rib crowning or compression crowning technique. Some manufacturers combine the two techniques.

Rib-crowned soundboards (also referred to as “rib-crowned and suspended” or RC&S) have bowed ribs. The shape of the ribs is the main source of the curvature. Before it is glued to the ribs, the board is dried to 5.5 to 6.5% EMC\(^{144}\) to ensure that it will not crack during periods of low humidity. Higher levels of humidity, to which the board will be later exposed, will cause some compression to build up, but not nearly as much as in a purely compression-crowned board. U.S.-made Baldwin pianos and some Walter pianos used this technique, which is popular among some rebuilders.

Compression-crowned boards are dried to a very low moisture content (4.5 to 5.5% EMC\(^{145}\)) before they are glued to the ribs, which are either completely flat or slightly bowed (to provide some rib crowning). Moisture, as it reenters the board, increases compression because the ribs prevent the board’s underside from expanding. The unrestrained top of the panel expands, making the board bow upward in the middle. The compression is the ribs prevent the board’s underside from expanding. The unrestrained top of the panel expands, making the board bow upward in the middle. The compression is maintained by the ribs, and the rim suspends the assembly.

Compression-crowned boards that have relatively little downbearing, especially in the bass and tenor, tend to produce very long sustain combined with powerful attack, and have a high dynamic ceiling. The soundboard assembly has more “spring” in it and is less restrained in its movement than a rib-crowned assembly. However, compression boards are under greater stress, and will fail if subjected to constant changes or extremes in humidity and temperature. Exposure to high humidity makes the crown increase, but the strings restrain it from above. The swollen wood cells have nowhere to go and become crushed, forming pressure ridges in which wood fibers on the surface of the board have been pushed out of their normal position. The crushing of wood cells reduces the compression and lowers the board’s stiffness, which lowers the board’s wave impedance, increases its resonances, and reduces sustain. After the board is exposed to climate swings year after year, cracks appear, indicating further loss of compression in the board.

Many pianos, however, even some that are over 100 years old, prove that a compression-crowned board kept in reasonably constant climate conditions (page 83) can retain enough of its original compression and stiffness to sound good.

In rib-crowned boards the ribs are taller but narrower, and are taller in the middle than on the ends. Some designers shape the ribs as I-beams and make them of stiffer laminated wood. This reduces their range of motion compared to compression boards, but also reduces their susceptibility to failure when exposed to climate extremes.

Backscale

The length of strings between the bridge and a rear termination such as a duplex bar (backscale) can greatly affect the sound, especially in the low tenor and bass. A short, stiff backscale constrains the bridge and soundboard and can choke off the sound of that section, even when the downbearing is acceptable, the bass bridge has an apron, or the soundboard is “floated” in the piano’s tail area. This problem can be observed in short grands and verticals where the lowest bass strings may have just one inch [2.5 cm] of length between the rear bridge pins and the hitch pin riser felt. It’s better to sacrifice some of the speaking length than to have such a short backscale.

A long backscale, on the other hand, can cause an overly live duplex scale that may need to be partially damped, and can reduce tuning stability. When you “set” a string during a tuning with a hard blow, you are equalizing tensions in the front segments, but less so in the segments behind the bridge. The longer the backscale, the greater the tension inequality between segments.

Melody Octave, Grain Angle, and Reflection of Sound Waves

Most piano music, especially from the romantic era, presents the main melody in the fifth octave—but this is exactly where most pianos lack sustain, especially between F5 and C6. The tenor and upper bass have plenty of volume and sustain, yet one is expected to play the accompaniment in those sections very softly. This is why it is so important for the “melody octave”—or, as some call it, the “killer octave”—to have as much sustain and projection as possible.

As discussed above, sustain is a function of stiffness, and spruce is stiff along its grain. Wherever the bridge runs parallel to the grain of the soundboard is where the stiffness is greatest. Traditionally, modern grands have grain running at an angle of 45° to the belly rail, which tends to be parallel to the fourth-octave section of the long

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\(^{144}\) EMC is “equilibrium moisture content,” the amount of moisture that a certain species of wood settles to at a certain temperature and relative humidity (RH). An EMC of 5% in white spruce, for example, corresponds to just under 25% RH at 70°F [21°C]. See R. Bruce Hoadley, Understanding Wood, pp. 112–114.

\(^{145}\) W.V. McFerrin gives the figure of 5% in The Piano: Its Acoustics, p. 68. Also see Nick Gravagne, RPT, “How Much Crown Should There Be?”
Effects of Touch on Tone

Isn’t it fascinating that each pianist can have a unique sound? The piano action doesn’t let you control the motion of the hammer after it passes the let off (the point at which the jack escapes under the hammer shank), and it appears that tone can be varied only by changing the acceleration of hammers during their travel toward the strings. Still, a distinctly different tone quality can be produced by varying one’s touch, even at the same loudness level.

**Keyboard noises**

Touch affects the tone of the piano because the noises generated by the action, damper mechanism, and keyboard directly affect its overall sound. The noises generated by the keyboard are the most pronounced. As Ramon Alba and Asami T. Inouye suggest,

> the artistic use of this percussiveness [creatively controllable noise generated by the keyboard] is the very secret of virtuosity. This subtle shading ‘fills out’ the tone color with another dimension—tone ‘value’— as in painting when black, white, or greys are added to a basic color to give degrees of ‘Value.’ What we actually hear are subtle combinations of tone color and shading, allowing gradations of tone color at each level of intensity.162 [italics in original]

Noises generated when the finger strikes the key at rest, and a moment later when the key reaches the bottom, are transmitted through the keys, key frame, key bed, and rim to the soundboard, bridges, and strings. How prominent those noises are can be easily demonstrated: keeping the damper pedal depressed, depress a key, hold it loosely depressed at the bottom of its travel, then pound the key with the other hand. The noise is amplified and sustained for several seconds.

The duplex portions of strings (see “Duplex scales” on page 36), where present, amplify the noises even when the damper pedal is not used.

The amount of time between the noises generated by the key and the hammer striking the strings depends on how loudly one plays the note. A piano touch can delay the bottom-of-key-travel noise by as much as 30 ms (0.03 second), whereas a fortissimo blow can make it precede the hammer strike by almost 10 ms.163 This has a profound effect on the perception of tone. In soft playing, the key

<table>
<thead>
<tr>
<th>Myth:</th>
<th>Playing with finger and with a pencil eraser is the same.</th>
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<tbody>
<tr>
<td>Truth:</td>
<td>Each person has a unique tonal signature that is determined by the strength, shape, weight, and density of his or her fingers, arms, and the entire body. The greatest challenge in reproducing one’s playing, and the reason even the best reproducing pianos don’t fully convey the subtleties of one’s performance, is that their mechanisms don’t reproduce the noises and noise-damping effects of a player’s touch. For more, see “Effects of Noises on Player and Listener” below.</td>
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bed noise is a relatively soft part of the sound envelope, whereas loud thumps usurp the sound of the fortissimo strikes.

**Action Noises**

The noises from the action also play a role in translating the variations of touch into variations in artistic expression. The most variable action noise is that produced by the sliding of hammers on strings during vigorous attacks. The sliding generates a noise (a clank) and affects the vibration of the strings and the prominence of the partials they generate. It introduces complex distortions that give the sound a unique, unpleasant signature.

The sliding of hammers varies, even on impacts of the same force, depending on whether the player hits the key at high speed, or starts slowly and accelerates the attack toward the bottom of key travel. Different rates of acceleration, and their timing during the keystroke, make the action parts flex and twist with the hammer at different distances from the strings. That means that with one type of touch the greatest bending of the hammer shank will occur early in the stroke, whereas with the other it will occur closer to the strings. This has a subtle effect on tone color, as does the subsequent bending and twisting of the hammer head and hammer shank caused by the impact itself. The bending and twisting and, therefore, the sliding at impact depend on the state of the hammer and its shank—a shank that still needs to relax from the belated upward acceleration will produce a sound that is different from a shank that received the greatest acceleration at the beginning of the stroke.

Extra-stiff composite shanks, such as those made by Wessell, Nickel and Gross, reduce hammer sliding and have a cleaner sound during loud playing.

**Effects of Noises on Player and Listener**

By affecting the sound, the keyboard and action noises, with their spectrum and prominence (see Figure 183c), also affect the player’s perception of touch. The “crispness” of feel, and how successfully a player interacts with a piano, depend at least as much on the timbre and uniformity of these noises as on the condition of the piano’s

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162 Ramon Alba and Asami T. Inouye, “Piano Tone Color and Touch,” p. 36.

163 Anders Askenfelt and Erik Jansson, “From Touch to String Vibration” in Five Lectures.
hammers, action, strings, and overall design. Some piano makers, notably Blüthner and Pleyel, are known for their efforts to suppress these noises, from using double felt punchings to covering the back rail and hammer rest rail with multiple thicknesses of cloth. Instead of paper and cardboard punchings, Blüthner used punchings made of a softer, rag-like material.\textsuperscript{164}

The condition of key frame cloths and felts has the most immediate effect on the transmission of keyboard-related noises. Replacing them during rebuilding with high-quality materials restores resilience and gives the action the feel of a “new” piano.

Keyboard and action noises give each pianist a unique tonal signature. Several factors are at play: the “pitch” of the noises, their timing and loudness, and the amount of pressure after the strike. Playing “closer to the keys” produces lower-pitched noises and is perceived as deep, sensitive, and rich, while playing “from above” generates higher-pitched noises and is considered brilliant, crisp, and clear, but potentially “choppy” and strident. This perception is reinforced by a slightly greater delay associated with playing closer to the keys—in that case, the sound has a few milliseconds more to develop before the noises affect it. Loud noises can be appropriate when they reinforce the percussive character of music; e.g., in the works of Sergei Prokofiev and Igor Stravinsky, or in jazz. Some pianists produce an almost slapping noise by striking chords from a great height. Finally, the pressure after the strike, although it appears to be a waste of energy, actually damps the noises and makes the sound appear slightly warmer. The difference in the \textit{legato} produced by playing \textit{staccato} with the pedal, and connecting the notes with the fingers, is not merely visual.

\textbf{Tactile Experience}

The pianist’s perception of touch also depends on the tactile experience when a finger is in contact with the key. Just as the “transmission chain” passes the noises from the key to the piano belly, it also transmits the vibrations from the belly back to the key, where the player senses them. This can be easily felt in the middle section and the bass. The tactile perception of sound, even though subconscious, is an important factor in a pianist’s orientation, expression, and control of touch. In one study, for example, blindfolded pianists were able to identify pianos of different brands with remarkable accuracy, even when “deafened” by white noise.\textsuperscript{165}

Electronic pianos illustrate the importance of tactile experience. When the same electronic keyboard controller (the keyboard itself) is attached to a stand with a powerful speaker, pianists report that the action feels more like an actual acoustic piano action. Yamaha even developed their Tactile Response System to simulate the vibrations of an acoustic piano in the keys and pedals of the Avant-Grand, their top electronic piano model (http://avant-grand.com).

\textbf{Piano Action}

In its larger sense, the term \textit{action} encompasses all moving parts that make the strings vibrate, or that damp them. These include the keyboard, all action parts, and the damper mechanism (backaction). In grands, \textit{action} is often used to refer to the keyboard and the action frame with its parts, because these slide out of the piano as one unit. In this book, however, \textit{action} is used only for the action frame and all action parts. This assembly is also referred to as the \textit{top stack}.

In grand pianos, the action (top stack) includes:

- Action brackets
- Action rails
- Hammers and hammer shanks
- Wippens
- Let off buttons and screws
- Hammer rest rail (when used)
- Sostenuto monkey and sostenuto rod with brackets (in New York Steinway grands)

In vertical pianos, the action is an assembly above the keyboard that includes:

- Action brackets
- Action rails
- Hammers, hammer shanks, and hammer butts
- Wippens with backchecks and bridle wires
- Dampers and damper levers
- Damper lever rail
- Sostenuto rod or rail (when used)

\textbf{Types of Grand Actions}

In all modern grand pianos the action is of the double-repetition, or “double escapement,” type derived from the Herz-Érard design. In the U.S., almost all grand actions dating back to ca. 1870 are of the modern type, while in Germany and Austria the so-called Viennese action was still being made at the beginning of the 20th century (see Figure 12 on page 5). Blüthner pianos from the early 20th century have an action of their own design (see Figure 8 on page 4), while older Pleyel pianos have an awkward implementation of the Herz-Érard action that makes servicing them difficult (see Figure 11 on page 5). All instructions on regulation, repair, and rebuilding in this book are for the modern, double-repetition grand action.

Grand actions vary primarily in:

- Materials (wood vs. composite, wool vs. synthetic bushings, leather vs. synthetic knuckles)
- The profile of rails on which action parts are installed and, correspondingly, the profile of the action parts’ flanges that are attached to the rails

\textsuperscript{164} Thanks to Edward Sambell, RPT, for this information.

\textsuperscript{165} Alexander Galembo, “Perception of Musical Instrument by Performer and Listener.”
Figure 162 Schwander-style grand action and keyboard.

Figure 163 Vertical action and keyboard.
crease or decrease spring tensions, adjusting the effectiveness and resistance of the springs.¹⁷⁵

Piano Hammers

Piano hammers are made of firm woolen felt that is stretched and glued to a wooden molding. The mass, shape, and density of felt range from heavy, rounded, and relatively soft in the bass, to light, pointed, and dense in the treble. Mass determines the loudness of sound and how quickly the hammer rebounds from the strings. The shape determines the width of the area of contact between hammers and strings, which affects the timbre (tone quality). Density (hardness) affects both the timbre and sound volume. But it is resilience that has made felt the irreplaceable material for piano hammers since Jean-Henri Pape’s 1826 French patent. The resilience provides the “spring” that allows the hammer to quickly rebound from the strings.

A felt hammer acts as a relatively soft substance during soft blows (similar to a tennis ball), but as a much stiffer substance during hard blows (more like a baseball). This nonlinear hammer stiffness produces a tonal gradient that gives the piano its expressive range. A note played softly is mellow and has prominent lower partials; played loudly, it is brighter and has a greater proportion of upper partials to the fundamental (Figure 183). This allows the pianist to “bring out” the melody even when it is presented within a thick texture in the tenor or bass range, as is the case in much of the music of Johannes Brahms, for example.

The tonal gradient of piano hammers is made possible by cutting the felt to a triangular shape, then pressing it around a pointed, wooden molding. As a result, the outer layers of felt are under great tension, while the inner layers are increasingly compressed the closer they are to the molding (see Figure 185 on page 72).

For the sound to be clean, focused, and well sustained, hammers must quickly rebound from the strings. For that, the hammers should have high resilience, low mass, and low inertia. Defined as the resistance of mass to acceleration, inertia is particularly detrimental in the treble, where even a slightly prolonged contact between hammer and strings causes a dull, short-decay sound with pronounced impact noise.

Hammer mass must be matched to the stringing scale and belly design (soundboard mass, flexibility, stiffness, and downbearing) to bring out a piano’s full potential. If the hammers are too light, the strings and belly may not be sufficiently energized; if they are too heavy, the sound will be loud, distorted, and constrained during loud playing. The demand for mass increases with string length and tension—the heaviest hammers are used in concert grands. Mass decreases more or less evenly from the lowest hammer in the bass to the top treble hammer (see page 285).

¹⁷⁵ Ulrich Sauter, e-mail to author, July 2011.