Chapter 9

Touch, Geometry, Playability

"The playing mechanism of a piano is that much closer to perfection, the less the player is aware of it, the longer it is able to preserve its original capacity for expression and fine quality, the simpler it is to manufacture and install, and the easier it is to service later on."
—Walter Pfeiffer, author of *The Piano Hammer* and *The Piano Key and Whippen*

Modern grand action designs appear to be highly standardized, but variations in leverages, mass, and alignment of parts make each piano feel slightly (or not so slightly) different. The length of keys, weight of hammers, key dip, and even the hardness of key punchings and felts give the action a "flavor," while the piano belly, string scaling, and hammers provide acoustical feedback, boosting or diminishing the perceived effectiveness of the action. Even pianos of the same age and model can feel different.

The purpose of this chapter is to make you aware of how action design affects the elusive concept of "playability," which comprises both static and inertial touchweight, and how you can control it by manipulating:

- Hammer weight, action leverage, and weight ratio
- Placement and geometry of parts
- Friction
- Weighting of keys

The benefits of this knowledge are far-reaching. Understanding the design of the action and keyboard—and what you can do about it—will help you preserve or increase the piano's expressive potential by selecting optimal **replacement hammers** and **action parts**; planning a **key dip** and static **touchweight**; and preparing for a certain level of **inertia**. Even if you are not replacing parts, you can improve playability by manipulating hammer and key weight and altering action leverage. By ensuring that the action parts interact with the most advantageous geometric relationships, you will reduce wear and prolong the longevity of action regulation, satisfying Walter Pfeiffer's laudable goals.

We owe much of our understanding of action geometry and touch to the lifelong research by David Stanwood, RPT, the inventor of the New Touchweight Metrology and Precision TouchDesign™.[298] Although most of the terms, abbreviations, formulas, charts, and recommended values in this chapter are based on his work,[299] a few new concepts also are introduced. All measurements conform to, or are compatible with, the Stanwood protocol.

Darrell Fandrich, RPT, and John Rhodes, RPT, have made a great contribution to the understanding of inertia and how each component in the keyboard and action contributes to it.[300] The Fandrich-Rhodes™ Weightbench system[301], which comprises a measurement kit and software, streamlines static touchweight measurements and allows predicting the Inertial Touch Force, a new concept that allows comparing actions by how resistive they are inertially.

Nick Gravagne, RPT, offers an Action Geometry Program, a software application that simplifies analyzing and predicting action performance.[302]

Actions in vertical pianos share many of the same concepts, except that the static force needed to move a vertical hammer is negligible; a spring is needed to simulate the effect that gravity has on a grand hammer. As dis-

[298] Precision TouchDesign is protected by U.S. patents nos. 5,585,582 (1996) and 5,796,024 (1998). For more information, go to `http://stanwoodpiano.com`. Technical references are at `http://stanwoodpiano.com/touchweight.htm`.

[299] For a glossary of terms, see page 290; see also David Stanwood, RPT, "Standard Protocols."

[300] A series of articles on this topic by Fandrich and Rhodes is slated for publication in the *Piano Technicians Journal*.

[301] See `http://www.mypianotech.com/WB`.

[302] See `http://www.gravagne.com`.

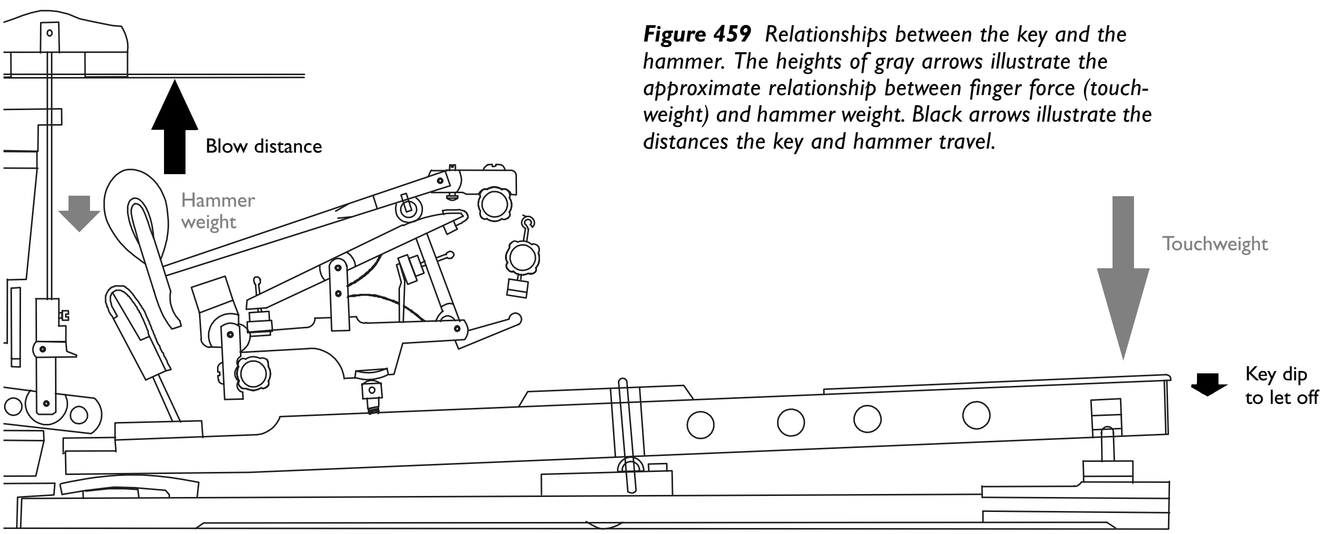

Figure 459 *Relationships between the key and the hammer. The heights of gray arrows illustrate the approximate relationship between finger force (touchweight) and hammer weight. Black arrows illustrate the distances the key and hammer travel.*

cussed in "Adjusting Touchweight" on page 396, static balancing is less critical in a vertical action, but if touchweight and friction were never made consistent, doing that will make a big difference. For more information, see David Huggins, RPT, "Affordable Vertical Touchweight Refinement."

This chapter focuses on the grand action.

How to Proceed

In this chapter, theoretical concepts are explained approximately in the order in which a novice should learn them. Each concept is followed by measurement and adjustment instructions, and may be accompanied by a worksheet with which you can log and chart the needed information. However, you may want to postpone practical work until you've read the entire chapter, to get the "big picture" first.

If you're somewhat familiar with this subject, you may want to start by reading the "Playability Improvement Road Map" on page 310, which lays out the touch-improvement process in a step-by-step format. If looking for solutions to common touchweight problems, see the "Touchweight Troubleshooter" on page 306. The "Hammer Replacement Touchweight Evaluator" on page 307 allows you to assess your options if you intend to reshape or install heavier or lighter hammers.

Equipment

You will need equipment for measuring distances and weights. You can measure distances between center pins and other points in the action directly with a precise caliper, or by setting a divider tool and measuring its spread with a ruler.

Most of the weight measurements in this chapter follow the Stanwood protocol and are best performed with the Stanwood TouchDesign Kit, available from Pianotek.[303] The Fandrich-Rhodes™ Weightbench kit includes mushroom weights and software, which you may find more efficient than stackable weights or a conventional weight kit, but to fill out the worksheets in this chapter directly, you will need standard gram weights.

TOOLS

- Precise caliper
- Optional: 8″ [20 cm] divider tool for measuring action spread and other distances
- Metric ruler (ca. 300 mm long) or tape measure
- Optional: Depth gauge (Figure 463, page 281)
- Two sets of stackable weights, as depicted on page 277, or a gram-weight kit
- Small spring clamp
- Scale with 0.1 g precision, capable of measuring up to 100 g
- Stanwood TouchDesign Kit or:
  - Flat, rigid surface, such as a granite tile or slab, for weight measurements (18 × 18″ [50 × 50 cm] or larger)
  - Small stands with low-friction bearings, or triangular pivots
- Several key lead weights (½″ [12.7 mm] preferred)

Force or Weight?

Weight is the force that gravity exerts on an object. Since the objects involved in lifting a hammer in a grand action operate close to the vertical plane, we can think of, and measure, the forces responsible for lifting those objects in terms of weight. This is convenient for evaluating static touchweight because we can use weights and a scale to

[303] Pianotek part no. STD-3K.

measure and compare the forces of the finger, friction, and inertia-reducing device, as well as the weights of the hammer, wippen, key, and leads.

Interrelated Aspects of Action and Keyboard

Since action parts in all modern pianos have almost the same basic measurements, action design revolves around variations in the following design elements. Each is discussed in detail throughout this chapter.

Hammer weight must match the belly and the stringing scale to fulfill the tonal potential of the piano. As installed, hammer #1 (bottom bass hammer) typically weighs between 8 and 12 grams. The shank adds 1.5–2.0 grams, giving the hammer a "strike weight" (the weight that acts on the strings) of 9.5–14 g. Strike weight decreases toward the treble to between 3.5 and 7 g, and should do so gradually. Hammers on the high end of the weight range produce more power, especially in lower partials, whereas lighter hammers can offer a wider range of timbre. Strike weight is the single largest source of inertia in the grand action, greater than the key leads, keys, or wippens. Keeping it low, but without compromising the desired tonal outcome, is of paramount importance for playability. Any sudden changes will create inertial (and likely tonal) unevenness despite the consistency in static touchweight.

Touchweight. The player expects the keys to provide a predictable and uniform amount of resistance or "touchweight" during soft playing. To translate a strike weight to a desirable static touchweight, the action rebuilder has two basic tools: a) change the amount of lead in keys, and b) alter the amount of leverage in the action. However, neither of those solutions is without a price: lead affects inertia of the key, whereas leverage changes key dip (or blow distance) and inertial touch force (inertia of the hammer, as reflected to the player's finger through the action). Fortunately, static touchweight can be reduced without increasing the inertia of the key, using devices that involve springs or magnets. These devices, discussed at the end of this chapter, are quite valuable for dealing with heavy hammers.

Inertia, or "dynamic" touchweight, affects how much force is needed to play loudly, and is a function of strike (hammer) weight, action leverage, and the amount of leads in keys.

Key dip can't vary much because it affects the amount of finger movement. In a modern piano, it ranges from about 0.375 to 0.435″ [9.5 to 11.0 mm] for white keys.[304] As black keys must remain above the white keys when fully depressed, they are set to 0.475–0.500″ [12.0–12.7 mm] above white tops. Large key dip gives the action power, but requires extra effort by the player because the fingers have to move farther. The problem is exacerbated by the fact that for every millimeter of extra key dip, black keys must be set one millimeter higher, resulting in two millimeters of extra finger travel. It is interesting to note that in the 19th century, when key dip was almost half what it is today, the "English" action was criticized as heavy in comparison to the Viennese action, at least in part due to its larger key dip.[305]

Blow distance. The other end of the action—the hammer—must accelerate sufficiently to energize the strings. This requires an adequate hammer-blow distance, which is standardized to between 1¾ and 1$\frac{15}{16}$″ [45–48 mm]. A shorter blow distance will rob the piano of volume—this is in fact a feature in vertical and some grand pianos, where the half-blow pedal softens the sound by bringing the hammers at rest closer to the strings. But blow distance must not be excessive either, or it will compromise repetition. Blow distance is directly proportional to key dip: all other things being equal, increasing one requires increasing the other. The amount of key dip for any given blow distance is predetermined by action leverage. As neither of those two measurements can exceed its limits, the action leverage is also limited to a fairly narrow range.

Aftertouch is the length of key travel after let off. It must be sufficient to allow the jack to escape under the knuckle so that the hammer can freely rebound from the strings. It can't be much greater than that, or it will waste finger motion, slow repetition, and interfere with the functioning of the action. Since aftertouch allows almost no variation, it provides no relief to the rebuilder in balancing the action.

In conclusion, the action and keyboard comprise a mechanical system in which the hammer weight and stroke (blow distance) needed for the desired tonal results must be matched to the physical constraints of the player's hands and fingers through a series of carefully designed levers. This requires understanding how hammer weight, action leverage, and the distribution of weight in the action affect both the static and dynamic (inertial) aspects of touch.

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304 Key dip increased over time as the hunger for more powerful tone required increasing hammer mass and lowering action leverage. Early Viennese pianos had a key dip of 4–6 mm, whereas English pianos were in the 7–7.5 mm range (see Michael Cole, *The Pianoforte in the Classical Era*, tables 18.1 and 18.2, pp. 301–302). In 1836, Claude Montal suggests a dip of roughly 6–8 mm (3 "lignes" in the treble and a little less than 4 "lignes" in the bass), and 7–9 mm in 1865 (Claude Montal, *L'Art d'accorder*, 1st ed, p. 108; 3rd ed., p. 212). In 1906, William White documents the dip as being 9.5 mm ("⅜-inch full"; see William White, *Theory and Practice*, p. 103).

305 The other reason for the criticism is that, in the early 19th century, English actions had heavier, more inert hammers, which required greater force to play loudly (explained in "Inertia" below). However, the static touchweight itself was actually lower than in most Viennese instruments, especially in the bass—this is evident when playing on well-restored historical instruments of that era. For measurements of several instruments, see Michael Cole, *The Pianoforte in the Classical Era*, pp. 304–306. See also the footnote in Edwin Good, *Giraffes*, p. 168; and Alfred Hipkins, *A Description and History*, p. 29.

Static Touchweight (TW)

Static touchweight is a term that encompasses three concepts:

- **Downweight:** minimum force required to depress the key
- **Upweight:** maximum force the key will overcome as it returns to the rest position
- **Balance weight:** the average of downweight and upweight forces

These weights or forces (discussed below) determine the perception of action as heavy or light during soft playing. Together with action regulation, touchweight is of great importance for control in soft dynamics.

Static and Dynamic Touchweight

Static touchweight, defined above, describes static forces required to depress, release, and balance the key. The finger, however, depresses the key with a wide range of forces (technically, kinetic energy), attempting to accelerate it at different rates. The resistance the finger experiences during rapid accelerations in loud playing is caused by inertia, and is referred to by some technicians as *dynamic touchweight*. This is discussed under "Inertia" below.

Myth:	**A light action repeats faster.**
Truth:	An action with low downweight and upweight requires less finger force in soft dynamics. Piano players associate that with faster repetition. However, low downweight and upweight mean that the key and action parts take more time to return after a strike, delaying a re-strike and *slowing* repetition. In extreme cases, usually associated with overly strong wippen-assist springs, keys "dance" for a prolonged period of time, making repetition unpredictable. Many pianos with low touchweight have higher action inertia due to heavy hammers and extra key leads, and require increasing amounts of finger force in loud dynamics. This compounds the problem, rendering loud repeats and trills in many "light" actions all but impossible.

Touchweight Is Downweight, Upweight, and Balance Weight

When hammer weight, action leverage, or the amount of lead in the key change, each of the three touchweight forces—downweight, upweight, and balance weight—changes by approximately the same amount. For example, in an action with a leverage of 6:1, if you reduce the hammer weight during reshaping by 1 g (e.g., from 10 g to 9 g), downweight will be reduced from 50 g to 44 g, upweight from 26 g to 20 g, and balance weight from 38 g to 32 g. Each of the three forces is reduced by 6 g, which is conveyed more conveniently by saying that touchweight is reduced by 6 g. When you encounter the term *touchweight*, mentally substitute it with "downweight, upweight, and balance weight."

Downweight (DW) and Upweight (UW)

Downweight is the weight on the front of the key needed to make the key sink slowly from a point approximately 4 mm below its rest position. The reason for measuring at the 4 mm dip is to overcome the friction and leverage at the top of key travel, where they are highest (see "Friction Changes During Key Travel" and "Leverage Changes During Key Travel" below). The ideal downweight ranges from about 50 grams in the bass to 46–47 grams in the treble, with 48 grams being a good target for the middle section. A downweight over 55 g (57–58 g in the bass and 54 g in the treble) will be perceived as heavy, especially when combined with high front weight (inertia). A downweight of 45 g or less will feel light—it is acceptable only if the upweight is at least 20 g and the front weight (explained below) is under the recommended ceiling. Variations from note to note should be within ±2 g.

Upweight is the maximum weight on the front of the key that the key will lift on its own. As stated above, upweight is related to downweight (and balance weight) more or less linearly—increasing one increases the other by the same amount. On a piano with fairly new, well-lubricated action parts and a downweight of 48 g, the upweight should be 23–24 g. A high upweight feels springy and responsive, whereas a low upweight makes the action feel sluggish and slows repetition. As with downweight, variations from note to note should not exceed ±2 g.

How to Measure

Downweight: For both white and black keys, place weights on the front of the key (Figure 460) so that the center of the weights is 13 mm in from the front edge. This is the standard measurement position (SMP). If the action is in the piano, *keep the damper pedal depressed*. Push the key down approximately 4 mm. The least amount of weight that makes the key slowly drop from that point is the downweight.

Upweight: Hold the damper pedal depressed and depress the key to the point of increased resistance (7–8 mm). Starting with about 20 grams, place the weights on the standard measurement position and release the key. Adjust the weights until the key barely returns to the 4 mm point.

Alternatively, measure downweight by slowly depressing the key, and upweight by slowly releasing it with a tension gauge, as shown in Figure 461.

Enter and plot the downweight and upweight values on the Touchweight Worksheet (page 277). For now, ignore the balance-weight area—you will learn how to calculate balance weight below.

Friction (F)

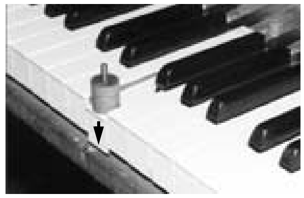
The difference between downweight and upweight is caused by *friction* in the keyboard and action parts. Given the same downweight, the higher the upweight, the lower

Touchweight Worksheet

1 Measure
Measure DW and UW

2 Log
Enter measurements

Downweight



Upweight

Piano ______________

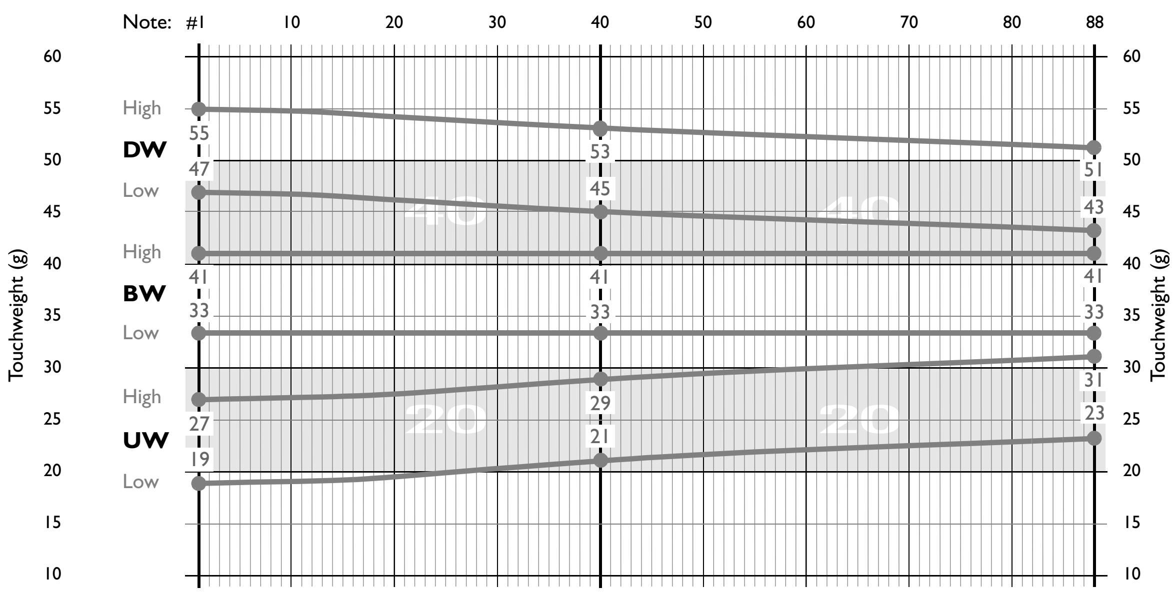
Ser. No. ____________

Date ______________

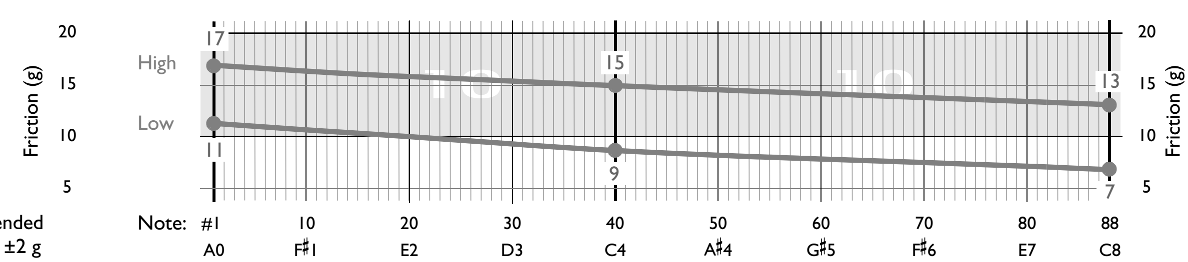
Figure 460 *Measuring downweight and upweight.*

	DW	UW		DW	UW		DW	UW		DW	UW		DW	UW		DW	UW		DW	UW		DW	UW		DW	UW
			10			20			30			**40**			50			60			70			80		
1			11			21			31			41			51			61			71			81		
2			12			22			32			42			52			62			72			82		
3			13			23			33			43			53			63			73			83		
4			14			24			34			44			54			64			74			84		
5			15			25			35			45			55			65			75			85		
6			16			26			36			46			56			66			76			86		
7			17			27			37			47			57			67			77			87		
8			18			28			38			48			58			68			78			**88**		
9			19			29			39			49			59			69			79					

3 Chart downweight (DW) and upweight (UW), calculate and chart balance weight (BW)
(DW + UW) ÷ 2 Draw a dot for each value on the chart



4 Calculate and chart friction (F) (DW – UW) ÷ 2 Draw a dot for each value on the chart



Recommended precision: ±2 g

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Action Leverage Worksheet

Piano ______________

Ser. No. ____________

Date ______________

❶ Measure

Measure action leverage

Figure 463 *Measuring hammer travel at 6 mm key travel: The front of the action-leverage tester should be at the standard measurement position (13 mm in from the key front). The extra weight prevents the tool from rocking back a little on this piano. The depicted tester is made by Erwin's Piano Restoration.*

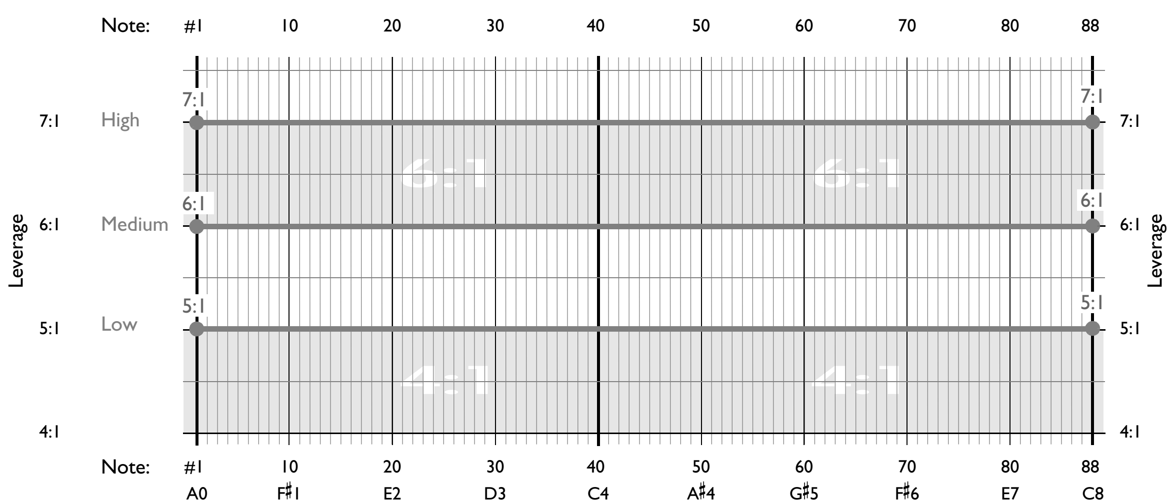
❷ Log

Enter measurements

		10		20		30		**40**		50		60		70		80	
1		11		21		31		41		51		61		71		81	
2		12		22		32		42		52		62		72		82	
3		13		23		33		43		53		63		73		83	
4		14		24		34		44		54		64		74		84	
5		15		25		35		45		55		65		75		85	
6		16		26		36		46		56		66		76		86	
7		17		27		37		47		57		67		77		87	
8		18		28		38		48		58		68		78		**88**	
9		19		29		39		49		59		69		79			

❸ Chart

Draw a dot for each value on the chart



Recommended precision: ±0.2:1 (e.g. 5.2:1 to 5.6:1)

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the wippen radius weight (WW = 0 g), we can omit WW × KR from the equation, but we have to reduce the balance weight by the leveraged amount (18 × 0.5 = 9 g), from 41 to 32 g:

$$R = \frac{32 + 40}{12} = \frac{72}{12} = 6.0 \tag{55}$$

Leads: Measuring and Calculating

Here you will learn how to express the amount of lead weights in keys, how to estimate front weight from the leads in the key, and how to calculate the amount of lead weight needed to achieve a particular front weight.

Lead Factor (LF)

Lead factor is a new concept I propose as a way of expressing how much lead is positioned, and where, along the key. Lead factor is an expression that shows the **lead weight** (LW), in grams, of a particular lead or group of leads, and a **distance multiplier** (DM), which is a number between 0 and 1 where 0 is the lead at the balance hole and 1 is the lead at the standard measurement position in the front of the key (not at the actual key front). Lead factor also can be expressed in its solved form (as a result of multiplying lead weight by the distance multiplier), but then you lose track of weight vs. position, which has implications for the inertia of the key (page 298).

Lead factor is useful simply as a way of expressing how much lead is positioned where along the key. It simultaneously conveys two pieces of information, the amount of lead weight and the distance multiplier (the relative position of weight within the key segment), but, when solved (multiply lead weight by distance multiplier), reveals the amount of weight that a lead or group of leads contributes to the front weight. The practical value of the lead factor is that, when measuring positions for lead installation, you can compare the estimated front weight to the front-weight ceiling (see the chart on page 293) without actually measuring the front weight, which requires removing the top stack and the key from the key frame. Although front weight can (and should, at least for sample notes) be measured after marking lead positions on all keys, estimating it from the lead weight shortcuts the process, identifies front-weight problems early, and saves time. This is discussed in "Adjusting Front Weight" on page 292.

In the case of a group of evenly spaced leads, distance multiplier can be measured for the whole group from the balance hole to the imaginary point in the middle of the group. For leads that are located in the rear segment, distance multiplier is negative and is measured as the distance from the balance hole toward the rear of the key, divided by the total effective length of the front segment (balance hole to standard measurement position). The total length of the rear segment doesn't matter. Note also that key-weight ratio and the position of the capstan don't matter because in this case we are only interested in how lead weight affects the key and its front weight.

Another way of remembering the distance multiplier is as a percentage of the lead position within the segment, positive in the front, negative in the back, and divided by 100.

Lead factor is written as an expression consisting of lead weight, an "x" signifying multiplication and read as "times," and the distance multiplier. For example, a 14 g lead weight placed in the middle of the front segment has a lead weight of 14 g at a distance multiplier of 0.5, and is written as "14x0.5" (and spoken as "fourteen times point five"). A 10 g weight placed 60 mm from the balance hole in the *rear* segment of a key with a 200 mm–long effective front segment has a lead factor of "10x–0.3" (0.3 is a result of dividing 60 by 200). When calculating the distance multiplier is not practical, it can be expressed as a ratio, or division, within a lead factor expression. For example, when you are logging lead factors, you may want to focus on measuring lead distances and, instead of calculating distance multipliers on the spot, record them in a raw form. To record a 16 g lead that is 160 mm away from the balance hole in a key with a 250 mm–long effective front segment, you would write "16x16:25." Later, you could reduce that to "16x0.64" or solve it completely, revealing its contribution to the front weight as being slightly more than 10 g.

If starting with keys without leads, for example when leading a new keyboard for the first time or after removing all existing leads, you can approximate the front weight by solving and adding up the lead factors of individual or groups of leads. You then add the result to the weight that represents the amount of imbalance between the front and rear segments, or **key-imbalance weight**. You can do the same in an already leaded keyboard by estimating the weights of existing leads.

Lead factor is sufficiently precise for estimating and comparing front weights if it affects the accuracy of the front weight estimation by no more than ±2 g. For example, if a lead factor is 42x0.7 and a key-imbalance weight is 5 g (see examples 1 and 2 below), the front weight estimate is 34.4 g. To keep that estimate within ±2 g, or between 32.4 g and 36.4 g, you could misestimate the lead weight by as much as ±3 g (it could be 39–45 g), or the distance multiplier by up to ±0.05 (allowing a range of 0.65–0.75). Remember, errors compound.

Key-imbalance Weight (KIW)

The key-imbalance weight is the front weight of a key with no leads. If leads are to be installed, the key-imbalance weight should be measured after drilling the lead holes; if leads were removed, after plugging the holes. Measure the key-imbalance weight per David Stanwood's front-weight measurement protocol. If the key tips backward, place a weight on the key top, right above the bearing on the scale, and deduct its weight from the reading on the scale.

Calculating Leads

Leads for 14 g Strike Weight

Taking our action model in Figure 192 on page 78 (for measurements, see Table 6 on page 287) and a hypothetical strike weight of 14 g (heavy hammer) on note #1, let's calculate the amount of lead needed to adjust the balance weight to 36 g, which, with 12 g of friction, will give us the desired downweight of 48 g and the upweight of 24 g. The action leverage, measured as hammer rise divided by the 6 mm key dip, is 5.4 (page 284).

Lead weight (LW): To estimate the number of leads we would need to install, first we need to determine the front weight (FW). Since we are seeking the balance weight of 36 g, Equation 46 on page 294 allows us to calculate the front weight. It is 48 g:

56 $$FW = (14 \times 5.4) + (18 \times 0.46) - 36 = 75.6 + 8.28 - 36 = 48$$

This exceeds the front-weight ceiling (page 293) for note #1—either the strike weight (SW) or leverage should be reduced in this action.

In this action model, the **key-imbalance weight (KIW)** is 12 g. For a front weight of 48 g, the amount of lead needed in the very front of the key would be FW – KIW, or 48 – 12, which is 36 g. Therefore, we could bring the balance weight down to 36 g if we could install 36 g of lead there (the fact that the numbers are the same is coincidental). However, due to the key mortise we can install leads between the distance multiplier (DM) of ¾ and ½, the average of which is ⅝, or 0.625:

57 $$DM = \frac{\frac{3}{4} + \frac{1}{2}}{2} = \frac{\frac{3}{4} + \frac{2}{4}}{2} = \frac{\frac{5}{4}}{2} = \frac{5}{8} = 0.625$$

The closer the lead is to the balance hole (see page 299), the less it reduces the balance weight, downweight, and upweight. To achieve the same balance weight at the distance multiplier of 0.625, therefore, we must calculate the lead weight (LW) by dividing the adjusted front weight (FW – KIW) by the distance multiplier:

58 $$\frac{48 - 12}{0.625} = \frac{36}{0.625} = 57.6$$

Doing so, we find that we will need to install 57.6 g of lead weight at or around the ⅝ or 0.625 of the length of the key front (DM). Expressed as **lead factor (LF)**, this is "57.6x0.625."

Number of leads: A ½″ [12.7 mm] lead weighs approximately 14 g, which means that we will need slightly more than 4 of them:

59 $$57.6 \div 14 = 4.11$$

The number is lower than expected because 12 g of key-imbalance weight (KIW) in this key is unusually high. A concert grand with heavy hammers and an action leverage of 5.4 may have five to six ½″ leads in the lowest bass keys.

Leads for 10 g Strike Weight

Using Equation 46, let's calculate the lead weight (LW) for a hammer in our action model that weighs 8.2 g and has a strike weight of 10 g (note #56, for example):

60 $$FW = (10 \times 5.4) + (18 \times 0.46) - 36 = 54 + 8.28 - 36 = 26$$

Reduced by the key-imbalance weight of 12 g, the front weight of 26 g becomes a lead factor of 14x1.0 (14 g at the standard measurement spot in the front of the key), which, with the distance multiplier of ⅝, translates to a lead weight of 22 g (and a lead factor of 22x0.625):

61 $$\frac{14}{\frac{5}{8}} = 14 \times \frac{8}{5} = 22$$

The number of ½″-wide, 14 g leads we need is 1.6:

62 $$22 \div 14 = 1.6$$

Key-imbalance weight should be measured with a precision of ±1 g.

To measure the key-imbalance weight of an already leaded key, balance the existing leads by placing leads of the same weight (size) on the unleaded side of the key, at the same distances from the balance hole as the existing leads in the leaded segment.

If the front of the key is heavier, the key-imbalance weight is positive; if the rear is heavier, the key-imbalance weight is negative. The effect of the lead weight (LW), expressed as lead factor (LF), on the front weight (FW) can be expressed with this formula:

63 $$FW = LF_1 + LF_2 + LF_n ... + KIW$$

or, in an expanded form (DM is distance multiplier):

64 $$FW = (LW_1 \times DM_1) + (LW_2 \times DM_2) + (LW_n \times DM_n) + KIW$$

Estimating Front Weight

As discussed in "Front Weight (FW)" on page 291, the most precise way to determine the front weight is to measure it with a scale or tension gauge. However, it is often precise enough, and much more convenient, to estimate the front weight based on lead factor and key-imbalance weight. This is particularly valuable when deciding how much lead to install, and where, in order to adjust the static touchweight. You don't need to determine the lead factor precisely, or even for each lead individually; in most cases, you can make a visual assessment and perform a mental calculation in just a few seconds. Here's how.

If multiple leads (original ones and those you plan to add) are distributed more or less evenly, visually determine the center of their distribution, then determine the ratio between the lengths from that spot to the balance pin, and to the front of the key (standard measurement position). Multiply the total weight of the leads with this ratio, add key-imbalance weight, and you have an estimate of front weight that you can enter as a colored dot in the chart on page 293.

For example, if there will be three ½″ [12 mm] lead weights around the middle of the front segment of the key (½ or 0.5 of its length), you can assume that their combined lead factor is 42x0.5, or 21 (each lead weighs ca. 14 g, and 14 × 3 = 42[320]). Key-imbalance weight is usually a few grams, which you can estimate from experience or measure on an unleaded high treble key before you start the procedure. See "Key-imbalance Weight (KIW)" above.[321]

The advantage of estimating front weight this way is that you need to measure only distance, not weight. When you get used to visually estimating the distance multiplier, you can be even faster than with the tension gauge. The immediacy of feedback allows you to address the causes of inconsistencies and unexpected trends without wasting any time.

Examples

The following examples illustrate how to calculate the front weight from the lead factor. The effective front segment of the key (from the balance hole to the standard measurement position) is 250 mm long. When front weight is measured without any leads in the key stick, the key tips toward the front with a key-imbalance weight of 5 g. The rear segment is 200 mm long, but this is irrelevant for these calculations.

Example 1. If three 14 g weights are placed in the front segment at 150, 175, and 200 mm from the balance hole, their lead factors (LF) are 14x0.6, 14x0.7, and 14x0.8. Adding them up and adding the key-imbalance weight (KIW) of 5 g gives you the approximate front weight (FW) of 34.4 g:

65 $$FW = (14 \times 0.6) + (14 \times 0.7) + (14 \times 0.8) + 5 = 8.4 + 9.8 + 11.2 + 5 = 34.4$$

Example 2. If the leads are evenly spaced, as in Example 1, you can calculate their aggregate lead factor by adding up their lead weights and using as the distance multiplier an average distance of the entire group. For example, since the distance of the middle lead, or 175 mm, is the average distance of the three leads (and the distance multiplier is, therefore, 0.7) and the lead weight (LW) of the three leads is 42 g, their cumulative lead factor is 42x0.7. The front weight estimate remains the same as in Example 1: 34.4 g:

66 $$\text{Approx. } FW = (42 \times 0.7) + 5 = 29.4 + 5 = 34.4$$

Example 3. A 16 g lead is placed 75 mm from the balance hole in the front segment: because 75 mm is 30% of 250 mm, its lead factor is 16x0.3. If this is the only lead in the key, the front weight is 9.8 g:

67 $$FW = (16 \times 0.3) + 5 = 4.8 + 5 = 9.8$$

Example 4. If a single 10 g lead is placed 50 mm behind the balance hole, in the rear segment of the key, its distance multiplier is –0.2 (50 mm ÷ 250 mm), and the lead factor is 10x–0.2. The front weight is 3 g:

68 $$FW = (10 \times -0.2) + 5 = -2 + 5 = 3$$

Calculating the Number of Leads

To determine the number of **lead weights** that need to be installed in the front of the key, start by calculating the front weight and proceed according to the calculations on page 296. If our action model in Figure 192 on page 78 had a more realistic key-imbalance weight, for example 5 g instead of 12 g, a bass hammer with a strike weight of 14 g would require five to six lead weights, whereas a low treble hammer with a strike weight of 10 g would require two to three leads.

What is the **normal number of leads**? The amount of lead in keys affects the so-called front weight, which should be kept under the "ceiling" values proposed in the "Front-Weight Worksheet" on page 293. In an action with an action leverage well matched to the hammer strike weight, that means no more than five ½″ leads in the bass, spread around the halfway point in the front of the key, three in the middle, and one or no leads in the top keys. If the leads are installed closer to the balance rail, one or two additional leads per key may be needed.

Spring-assisted wippens and other inertia-reducing devices (page 309) can reduce the number of leads by one or two. For example, if we assume that the assist spring is set to eliminate the wippen radius weight of 18 g (reducing the touchweight by 9 g), we can remove the leveraged wippen radius weight (18 × 0.47) from Equation 56. This reduces the front weight from 49 to approximately 40 g:

69 $$FW = (14 \times 5.4) - 35 = 75.6 - 35 = 40$$

The key-imbalance weight (KIW) of 12 g means that the front weight (FW) of 40 g translates to 28 g of the needed lead weight (LW) at the distance multiplier (DM) of 1.0. Since we intend to install the leads around the distance multiplier of ⅝ (0.625), the removal of wippen radius weight (WW) by wippen-assist springs translates to the reduction in lead weight (LW) from 59.2 g to 44.8 g (lead factor becomes 44.8x0.625):

70 $$\frac{40 - 12}{\frac{5}{8}} = 28 \times \frac{8}{5} = 44.8$$

As a result, the number of leads is reduced by one, from 4.2 (Equation 59) to 3.2:

71 $$44.8 \div 14 = 3.2$$

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[320] To ease mental calculations, use 15 g, then deduct a little before multiplying.

[321] Don't measure the KIW of the key C8, because its front is not notched to accommodate adjacent black keys, and has a higher KIW.

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Touchweight Troubleshooter

- This table offers suggestions for common problems in touchweight and front weight (key inertia). If you plan to alter the strike weight by replacing, reshaping, or weighting the hammers (explained in "Increasing Strike Weight" on page 308), see page 307.
- Gray cells ☐ indicate danger zones. Is the action geometry appropriate for the current strike weight? Consider changing the strike weight before resorting to other solutions, but keep in mind that altering the strike weight will affect the piano's tonal character.
- Balance weight (BW) ranges in column headers are for note C4.
- DW = BW + F   UW = BW – F   F = (DW – UW) ÷ 2
- For front weight (FW) values, see page 293.

Front Weight is:	Balance Weight is: **Very Low** (<28 g)	**Low** (28–32 g)	**Optimal** (33–39 g)	**High** (40–46 g)	**Very High** (>46 g)
Below Ceiling	• Increase strike weight • Everything in cell to the right	• Remove inertia-reducing device • Increase action leverage and reduce key dip • Install leads in keys if possible	• Remove inertia-reducing device • Install leads in keys	• Install leads in keys	• Install leads in keys • Install inertia-reducing device
At Ceiling	• Remove inertia-reducing device • Increase action leverage and reduce key dip	• Remove inertia-reducing device	• No change	• Install inertia-reducing device	• Install inertia-reducing device • Decrease action leverage and increase key dip
Above Ceiling	• Remove leads from keys • Remove inertia-reducing device	• Remove leads from keys	• Install inertia-reducing device • Remove leads from keys	• Install inertia-reducing device • Decrease action leverage and increase key dip • Remove leads from keys if possible	• Reduce strike weight • Everything in cell to the left

sive inertia. If replacement hammers are heavier, extra leads may have been installed in keys. Measure the strike weights of a few hammers and measure or calculate/estimate the front weights of the corresponding keys (pages 295, 296, 293). If the strike-weight and front-weight values are high, consider installing an inertia-reducing device, decreasing the action leverage, removing the leads, and/or reducing the strike weight.

Improving Playability

Addressing Friction

Friction has a profound effect on action behavior, and can make a huge difference in playability. Aside from focusing on center pins and their bushings, and keeping all contact surfaces in the action lubricated, friction can be reduced by retrofitting the action with Magnetic Friction Reduction, and either reduced or increased by repinning the repetition levers and hammer shanks.

Magnetic Friction Reduction (MFR)

Similar in concept to the Magnetic Balanced Action (page 311), this solution by Hans Velo repels the hammer shank from the repetition lever, reducing the friction between the jack and knuckle. By doing so, MFR is claimed to provide a significant reduction in overall action friction. For more information, visit `http://home.kpn.nl/velo68/` and click "The Magnetic Friction Reduction" link.

Repinning Repetition Levers and Shanks

When the friction of the repetition lever center pin is too low, hammers may jam even if the repetition springs are regulated normally (so that they lift the hammer decisively but with a minimal knock being felt on the key).[329]

[329] Another, possibly more important contributor to hammer jamming, is the shank rest felt being too low.

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