# LOOKING AT GRAND PIANOS
# THROUGH THE EYES OF
# THE NEW TOUCHWEIGHT METROLOGY

## A BRIEF BY

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**Abstract**

Studies of strike weight, strike weight ratio, and front weight shed new light on the enigma of touchweight and open new ways for improving the tone and touch of pianos.

**Introduction**

In June 1996 I published "The New Touch Weight Metrology" in the PTG Journal, describing the "Equation of Balance" which links measured weight, and weight ratio components, to the traditional touch weight parameters of up weight and down weight, in the grand action. This was followed in February 1999 by "Standard Protocols of the New Touchweight Metrology". In the years leading to these publications up to the present day, I have collected a huge volume of data from an ever increasing study group of piano technicians who generate data from the use of the New Touchweight Metrology in their work.

Analysis of the data allows us to see the piano action through new eyes and reveals previously unknowable facts. The news is both good and bad. The bad news is that the traditional approach of pound hammer and down weight creates variable results and a false sense of "doing what's right". The good news is that the New Touch Weight Metrology makes it possible to identify and correct elements which undermine the integrity of touch and tone, thereby making it possible to design, manufacture, and rebuild pianos to higher standards of quality, with a degree of freedom that was previously unimaginable.

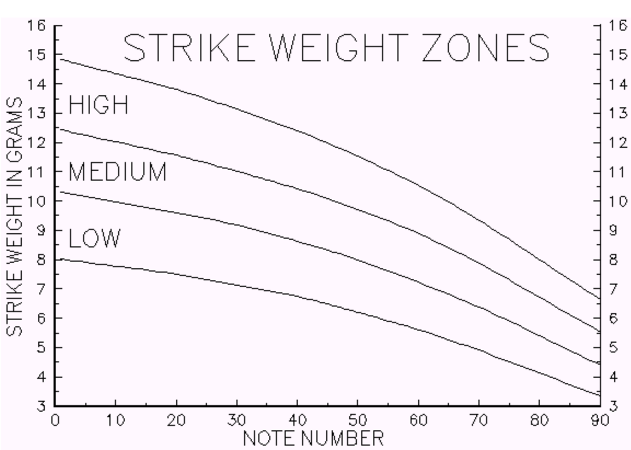
**Methods**

The study group provided data taken, using the standard protocols of the New Touchweight Metrology, of factory original, factory replacement, and various supplier replaced parts. In the examples given, parts were made within the last 5 years except when noted as otherwise. Both quantitative and qualitative assessments were made of levels and smoothness (note to note consistency) of the components studied.

**Results and Discussion**

The purpose of these studies is to give an overview of the "what's out there" in terms of strike weight, strike weight ratio, and front weight. Analysis graphs show representative characteristics of various action types. The source of common anomalies that degrade quality will be shown as well as the characteristic profiles of the highest quality actions.

**Strike Weight Zone Results**




GRAPH 1

The first result of studying strike weight was the establishment of "Normal" ranges. Nine years of data studies have yielded a consensus within the study group of Normal Strike Weight Zone Delineators as shown in Graph 1. To provide frames of reference within the zone, it is divided equally into three sub-zones that delineate high, medium, and low strike weight. The strike weight zone has two distinct characteristics; it is wider at the bass and curved. The values for the zone delineators are given in Table 1.

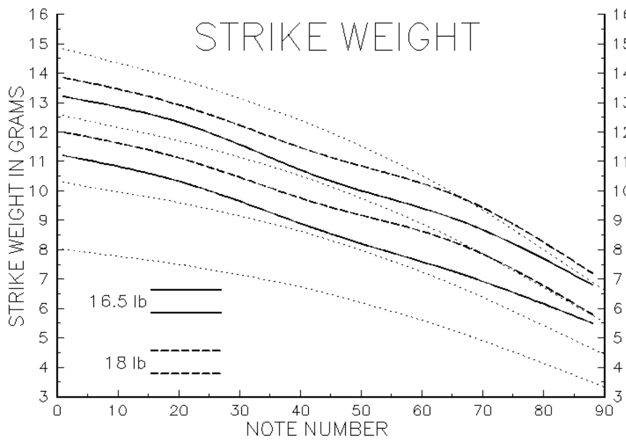
TABLE 1 - Normal Strike Weight Zone Delineators in Grams.

| Note | LOW | MEDIUM | HIGH | |
|---|---|---|---|---|
| 1 | 8.0 | 10.3 | 12.4 | 14.8 |
| 2 | 8.0 | 10.3 | 12.4 | 14.8 |
| 3 | 8.0 | 10.2 | 12.3 | 14.7 |
| 4 | 7.9 | 10.2 | 12.3 | 14.7 |
| 5 | 7.9 | 10.2 | 12.2 | 14.6 |
| 6 | 7.9 | 10.1 | 12.2 | 14.6 |
| 7 | 7.9 | 10.1 | 12.2 | 14.5 |
| 8 | 7.8 | 10.1 | 12.1 | 14.5 |
| 9 | 7.8 | 10.0 | 12.1 | 14.4 |
| 10 | 7.8 | 10.0 | 12.0 | 14.3 |
| 11 | 7.7 | 9.9 | 12.0 | 14.3 |
| 12 | 7.7 | 9.9 | 11.9 | 14.2 |
| 13 | 7.7 | 9.9 | 11.9 | 14.2 |
| 14 | 7.7 | 9.8 | 11.8 | 14.1 |
| 15 | 7.6 | 9.8 | 11.8 | 14.1 |
| 16 | 7.6 | 9.8 | 11.7 | 14.0 |
| 17 | 7.6 | 9.7 | 11.7 | 14.0 |
| 18 | 7.6 | 9.7 | 11.7 | 13.9 |
| 19 | 7.5 | 9.6 | 11.6 | 13.9 |
| 20 | 7.5 | 9.6 | 11.6 | 13.8 |
| 21 | 7.5 | 9.6 | 11.5 | 13.7 |
| 22 | 7.4 | 9.5 | 11.5 | 13.7 |
| 23 | 7.4 | 9.5 | 11.4 | 13.6 |
| 24 | 7.4 | 9.4 | 11.3 | 13.5 |
| 25 | 7.3 | 9.4 | 11.3 | 13.5 |
| 26 | 7.3 | 9.4 | 11.2 | 13.4 |
| 27 | 7.3 | 9.3 | 11.2 | 13.3 |
| 28 | 7.2 | 9.3 | 11.1 | 13.3 |
| 29 | 7.2 | 9.2 | 11.1 | 13.2 |
| 30 | 7.1 | 9.2 | 11.0 | 13.1 |
| 31 | 7.1 | 9.1 | 11.0 | 13.1 |
| 32 | 7.1 | 9.1 | 10.9 | 13.0 |
| 33 | 7.0 | 9.0 | 10.8 | 12.9 |
| 34 | 7.0 | 9.0 | 10.8 | 12.9 |
| 35 | 7.0 | 8.9 | 10.7 | 12.8 |
| 36 | 6.9 | 8.9 | 10.7 | 12.7 |
| 37 | 6.9 | 8.8 | 10.6 | 12.6 |
| 38 | 6.8 | 8.7 | 10.5 | 12.6 |
| 39 | 6.8 | 8.7 | 10.5 | 12.5 |
| 40 | 6.7 | 8.6 | 10.4 | 12.4 |
| 41 | 6.7 | 8.6 | 10.4 | 12.3 |
| 42 | 6.6 | 8.5 | 10.3 | 12.2 |
| 43 | 6.6 | 8.4 | 10.2 | 12.2 |
| 44 | 6.5 | 8.4 | 10.2 | 12.1 |

| Note | LOW | MEDIUM | HIGH | |
|---|---|---|---|---|
| 45 | 6.5 | 8.3 | 10.1 | 12.0 |
| 46 | 6.4 | 8.3 | 10.0 | 11.9 |
| 47 | 6.4 | 8.2 | 9.9 | 11.8 |
| 48 | 6.3 | 8.1 | 9.9 | 11.7 |
| 49 | 6.3 | 8.1 | 9.8 | 11.6 |
| 50 | 6.2 | 8.0 | 9.7 | 11.5 |
| 51 | 6.1 | 7.9 | 9.6 | 11.4 |
| 52 | 6.1 | 7.9 | 9.6 | 11.3 |
| 53 | 6.0 | 7.8 | 9.5 | 11.2 |
| 54 | 6.0 | 7.7 | 9.4 | 11.1 |
| 55 | 5.9 | 7.6 | 9.3 | 11.0 |
| 56 | 5.9 | 7.5 | 9.2 | 10.9 |
| 57 | 5.8 | 7.5 | 9.2 | 10.8 |
| 58 | 5.7 | 7.4 | 9.1 | 10.7 |
| 59 | 5.7 | 7.3 | 9.0 | 10.6 |
| 60 | 5.6 | 7.2 | 8.9 | 10.5 |
| 61 | 5.5 | 7.1 | 8.8 | 10.4 |
| 62 | 5.5 | 7.1 | 8.7 | 10.3 |
| 63 | 5.4 | 7.0 | 8.6 | 10.2 |
| 64 | 5.3 | 6.9 | 8.5 | 10.1 |
| 65 | 5.3 | 6.8 | 8.4 | 10.0 |
| 66 | 5.2 | 6.7 | 8.3 | 9.8 |
| 67 | 5.1 | 6.6 | 8.2 | 9.7 |
| 68 | 5.1 | 6.6 | 8.1 | 9.6 |
| 69 | 5.0 | 6.5 | 8.0 | 9.5 |
| 70 | 4.9 | 6.4 | 7.9 | 9.3 |
| 71 | 4.8 | 6.3 | 7.8 | 9.2 |
| 72 | 4.8 | 6.2 | 7.6 | 9.1 |
| 73 | 4.7 | 6.1 | 7.5 | 8.9 |
| 74 | 4.6 | 6.0 | 7.4 | 8.8 |
| 75 | 4.5 | 5.9 | 7.3 | 8.7 |
| 76 | 4.4 | 5.8 | 7.2 | 8.5 |
| 77 | 4.4 | 5.7 | 7.1 | 8.4 |
| 78 | 4.3 | 5.6 | 6.9 | 8.3 |
| 79 | 4.2 | 5.5 | 6.8 | 8.1 |
| 80 | 4.1 | 5.4 | 6.7 | 8.0 |
| 81 | 4.1 | 5.3 | 6.6 | 7.9 |
| 82 | 4.0 | 5.2 | 6.5 | 7.7 |
| 83 | 3.9 | 5.1 | 6.4 | 7.6 |
| 84 | 3.8 | 5.0 | 6.2 | 7.5 |
| 85 | 3.7 | 4.9 | 6.1 | 7.3 |
| 86 | 3.7 | 4.8 | 6.0 | 7.2 |
| 87 | 3.6 | 4.7 | 5.9 | 7.0 |
| 88 | 3.5 | 4.6 | 5.8 | 6.9 |

(Note: To find the hammer weight associated with these strike weight figures, subtract the shank strike weight from the strike weight. If you don't know the shank strike weight I would recommend a value of 1.7 grams as a generic average.)

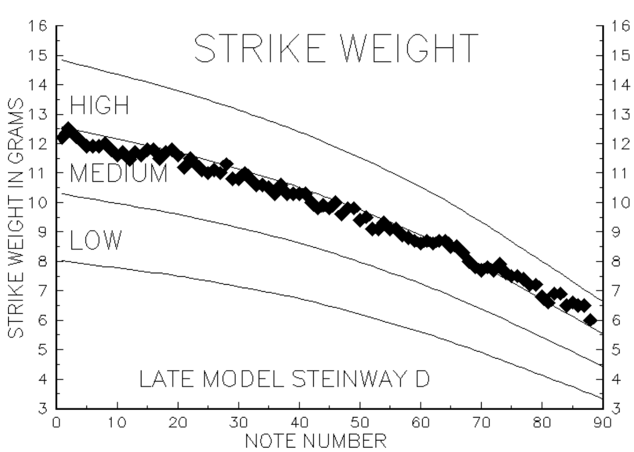
When looking at strike weight of one piano compared to another it is common to find wide variations in level. Overlap of hammer weights with different pound ratings was frequently found. For example, Graph 2 shows outlines of two strike weight groupings of late model pianos of a major high quality make. Both groupings are from hammers made in the same factory between 1994 and 1999. One grouping is of pianos with 16.5 lb hammers and the other from pianos with 18 lb hammers. Note that there is considerable overlap and in many cases the 16.5 lb hammer is heavier than the 18 lb hammer. Significant variations of strike weight levels where found when comparing hammers of the same pound rating but made by different manufacturers. In pianos that were custom rebuilt we found even more extreme variations. This was traced to the fact that some rebuilders go for extreme weight reduction by maximizing hammer taper and removing material from the hammer and shank, while others may taper and shape their hammers minimally.



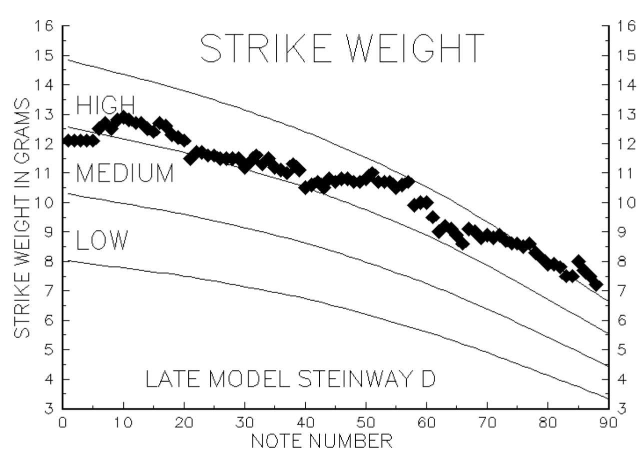

GRAPH 2

In regards to the quality of sound from different levels of strike weight, it was generally observed that high zone strike weights produce more sound energy. For instance it was noticed that pianos with high zone strike weights will produce higher microphone signals than low zone strike weights. The listener perceives this higher sound energy as an enhanced ability to distinguish the piano in combination with other instruments as in symphony concertos or Jazz combo. Also, pianos with high zone strike weights are generally easier to hear in the back of a big hall or outdoors. Another example is when listening to a piano in a busy restaurant full of talking people; the piano with high zone strike weights is more easily heard through the din than the piano with low zone strike weights. From a practical stand point it was found that ideal voicing of low strike weights is easier to achieve with a softer hammers and higher strike weights produce ideal voicing more easily with harder denser hammers.

Wide variations in strike weight smoothness from piano to piano were found to be quite common. To get an idea of the extremes, consider two examples of factory produced strike weights in late model NY made Steinway concert grands. An example of an unusually smooth set of strike weights is shown in Graph 3, and a set of unusually jagged strike weights is shown in Graph 4. Note the difference of 0.8 grams between notes 57 and 58, as well as the 1.6 gram difference between notes 56 and 62. This degree of strike weight anomaly is not unusual in all makes of piano.



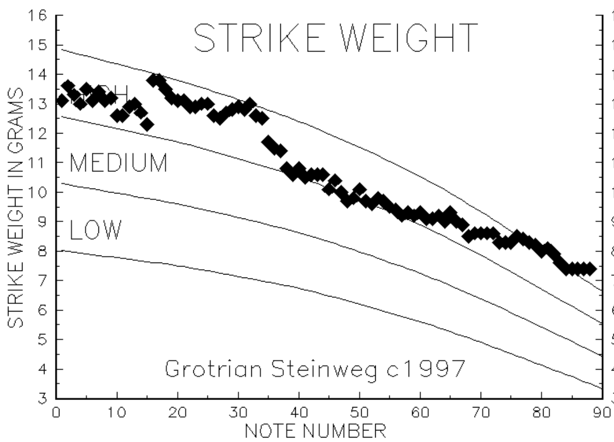

GRAPH 3




GRAPH 4

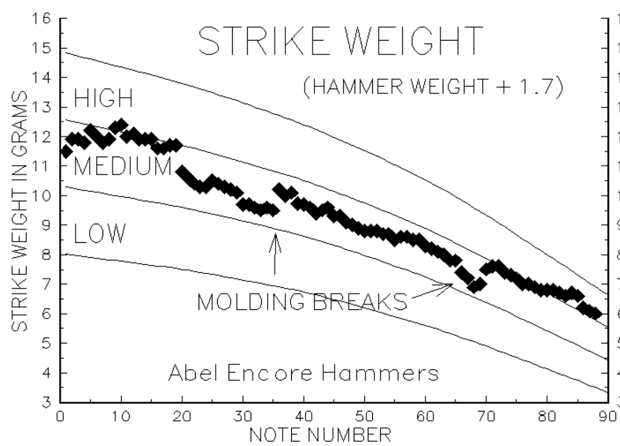
Investigations turned up several common variables that contribute to producing strike weight jaggedness.

Variations in hammer width cause variations in strike weight and this was found to be an industry wide problem. An example which clearly demonstrates the relationship between hammer width and strike weight is shown in Graph 5 which shows strike weights, from the factory, of a late model Grotrian Steinweg with Renner hammers. Hammer widths for the same piano are shown in Graph 6. Note the elevated section of hammer widths between notes 16 and 34. In this case a hammer width increase of about 1.6mm translated into an increase in the strike weight of about 1.0 grams or about 0.6 grams per mm. Strike weight jaggedness was found to be especially common in the bass section where a small variation in hammer width causes a larger difference in strike weight due to the larger area of felt.



GRAPH 5

GRAPH 6



GRAPH 7

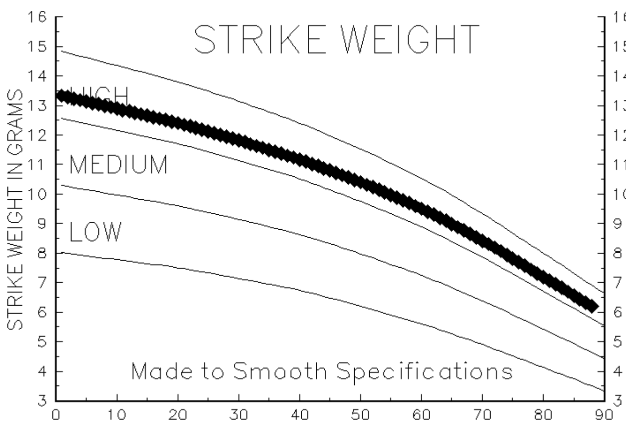
It was a surprise to find that a very common source strike weight anomalies comes from variations in the wood density of the hammer moldings that produce jags in the strike weight where a section of heavy molding adjoins a lighter section of molding. A typical set of recently made German replacement hammers by Abel are shown in Graph 7. Note the jags in strike weight that coincide with joints in the hammer molding wood. Note that the difference in strike weight between notes 35 and 36 is 0.7 grams.

Yet another cause of strike weight jaggedness comes from variations in shank strike weights. Analysis of typical set of high quality German shanks made by Renner is shown in Table II Note that in this case the difference in weight between the heaviest and the lightest full shank is 0.6 grams. Also note that the lightest full shank is lighter than the heaviest narrow shank.

TABLE II

Shank Count vs. Shank Strike Weight in grams

| FULL SHANKS | | NARROW SHANKS | |
|---|---|---|---|
| | 2 - 2.1 | | 2 - 1.7 |
| | 8 - 2.0 | | 8 - 1.6 |
| | 10 - 1.9 | | 6 - 1.5 |
| | 23 - 1.8 | | 2 - 1.4 |
| | 17 - 1.7 | | 2 - 1.3 |
| | 7 - 1.6 | | |
| | 1 - 1.5 | | |




GRAPH 8

A marked correlation of strike weight smoothness with the tone and touch was found. Pianos with smoother strike weights generally had a more satisfying quality of tone and touch. Much of the data came from studying actions in which qualities of tone and touch were noted, the strike weight measured, hammer weight added subtracted as needed to produce a smooth strike weight curve as shown in graph 8, then action quality was reassessed. Time and time again pianists noted improved tone and touch with smoothed strike weights. A significant reduction in the need for conventional voicing methods, such as needling, in pianos with smoothed strike weights was also noted.

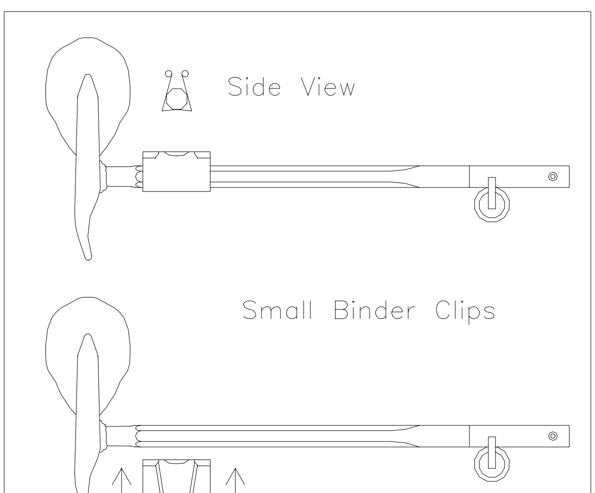



FIG. 1

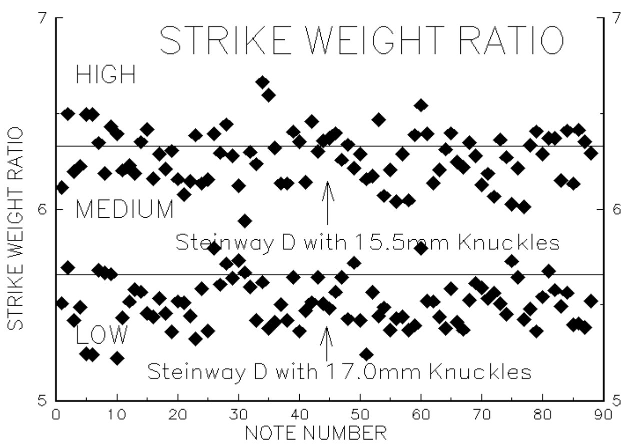
In an effort to know more about the threshold of perception to strike weight changes we first used pianos that had been strike weight smoothed as in graph 8. Then we raised the general level of strike weight by uniform increments with the addition of "small binder clips" to the shanks. Attaching the clips as shown in Fig.1 increases the strike weight by 1.0 grams. Pianists commented on the tone and touch before the addition of the clips. After a short wait while the clips were being attached, they were able to try piano again and comment on the change. It was found that a 1.0 gram increase produces such a large change in quality that pianists consistently felt it was "like a different piano", with a marked increase in dynamic touchweight and a distinct mellowing of the tone. An increase of 0.5 gram produced a significant change that could be perceived even by the average amateur pianist.

**Strike Weight Ratio**

The "Normal" zone of strike weight ratio was determined to be from 5.0 to 7.0. As a frame of reference the zone is sectioned equally in thirds as in Table III. The leverage is referred is the leverage that the pianist exerts on the hammer. Low strike weight ratios correspond to a high leverage (more like a crow bar) and vice versa.

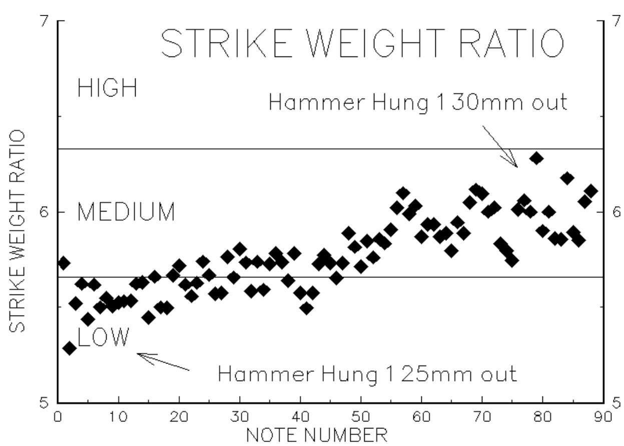
TABLE III STRIKE WEIGHT RATIO ZONES

| | | |
|---|---|---|
| HIGH | 7.0 - 6.3 | (Low Leverage) |
| MEDIUM | 6.3 - 5.7 | (Medium Leverage) |
| LOW | 5.7 - 5.0 | (High Leverage) |




GRAPH 9

Wide variations in strike weight ratio levels exist throughout the industry. Graph 9 shows two pianos of the same make and model but with radically different ratio levels. In this case the principle variable was traced to the fact that the action with the higher ratio used shanks with knuckles mounted 15.5mm out from the center pin to knuckle core, as opposed to the other with knuckles 17mm out. Additional principle variables that effect overall strike weight ratio levels include key ratio and capstan/heel position.

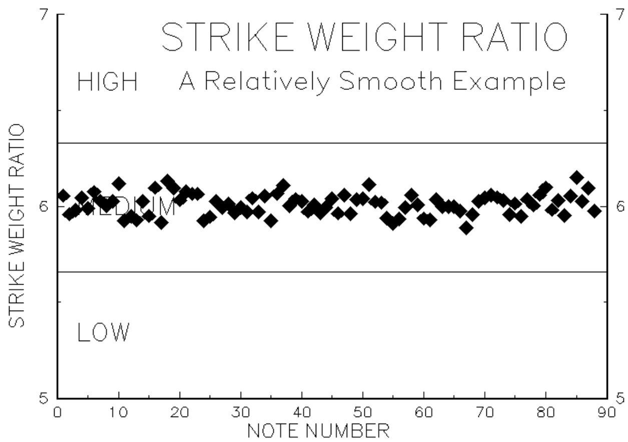



GRAPH 10

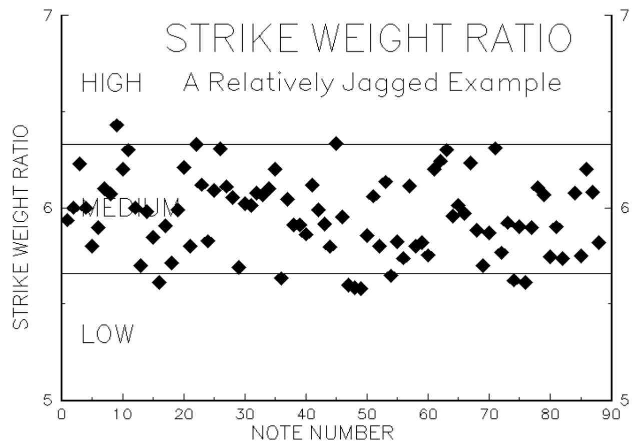
Also the distance that the hammer is hung from the hammer center effects strike weight ratio as shown in Graph 10. Note that in this example the bass end the strike weight ratio is 5.5 with the hammers hung 125mm out on the shank, whereas in the treble end with the hammers hung out at 130mm, the ratio increases to 6.1.

Generally it was found that pianos with higher strike weight ratios require lower strike weights to produce a normal feeling action while actions with lower strike weight ratios require higher strike weights to produce a normal feeling action. If strike weight ratio is below 5.0 actions usually require too much dip, a short hammer blow distance, and they tend to loose power. If strike weight ratio is above 7.0 actions become too heavy (even with) very light hammers), with very shallow dip, and long hammer blow needed.

Strike weight ratios were found to be generally jagged.  An example of very smooth strike weight ratio as in a late model Hamburg Steinway D is shown in Graph 11. An example of an extremely jagged strike weight ratio is shown in Graph12 which depicts strike weights in a rebuilt action that had replacement knuckles glued in rather poorly with many cocked to the front or back. Sometimes specific anomalies may be traced to such things as a capstan or knuckle out of line.  Jagged strike weight ratios are part of normal background variation.




GRAPH 11




GRAPH 12

**Front Weight**

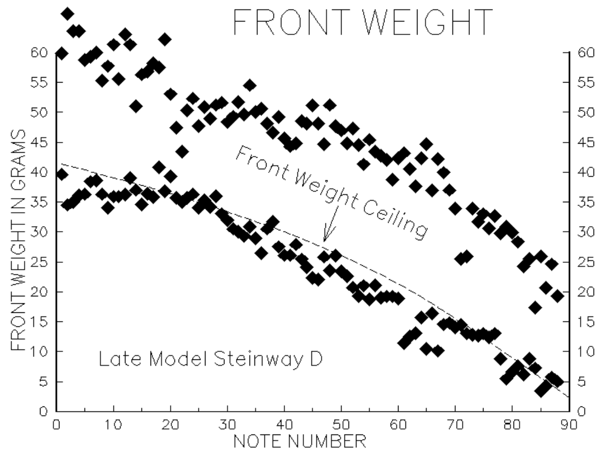
The question “is there too much lead in the keys?” may be partly answered by measuring front weight because its value is determined mainly by the number and displacement of key leads in the key.  Table IV gives a proposed set of values for maximum recommended front weight.  If front weight is above these values it may be considered excessive.  At this stage this may serve as a frame of reference called “Front Weight Ceiling”.

TABLE V1 – Front Weight Ceiling in grams

| Note | Ceiling | Note | Ceiling | Note | Ceiling | Note | Ceiling |
|---|---|---|---|---|---|---|---|
| 1 | 41.3 | 23 | 35.5 | 45 | 28.1 | 67 | 17.4 |
| 2 | 41.1 | 24 | 35.2 | 46 | 27.7 | 68 | 16.8 |
| 3 | 40.8 | 25 | 34.9 | 47 | 27.3 | 69 | 16.2 |
| 4 | 40.6 | 26 | 34.6 | 48 | 26.9 | 70 | 15.5 |
| 5 | 40.3 | 27 | 34.3 | 49 | 26.4 | 71 | 14.9 |
| 6 | 40.1 | 28 | 34.0 | 50 | 26.0 | 72 | 14.3 |
| 7 | 39.8 | 29 | 33.7 | 51 | 25.6 | 73 | 13.6 |
| 8 | 39.5 | 30 | 33.3 | 52 | 25.1 | 74 | 13.0 |
| 9 | 39.3 | 31 | 33.0 | 53 | 24.7 | 75 | 12.3 |
| 10 | 39.0 | 32 | 32.7 | 54 | 24.2 | 76 | 11.6 |
| 11 | 38.8 | 33 | 32.4 | 55 | 23.8 | 77 | 11.0 |
| 12 | 38.5 | 34 | 32.1 | 56 | 23.3 | 78 | 10.3 |
| 13 | 38.3 | 35 | 31.7 | 57 | 22.8 | 79 | 9.6 |
| 14 | 38.0 | 36 | 31.4 | 58 | 22.3 | 80 | 9.0 |
| 15 | 37.8 | 37 | 31.0 | 59 | 21.8 | 81 | 8.3 |
| 16 | 37.5 | 38 | 30.7 | 60 | 21.3 | 82 | 7.6 |
| 17 | 37.2 | 39 | 30.4 | 61 | 20.8 | 83 | 7.0 |
| 18 | 37.0 | 40 | 30.0 | 62 | 20.2 | 84 | 6.3 |
| 19 | 36.7 | 41 | 29.6 | 63 | 19.7 | 85 | 5.6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20 | 36.4 | 42 | 29.3 | 64 | 19.1 | 86 | 5.0 |
| 21 | 36.1 | 43 | 28.9 | 65 | 18.6 | 87 | 4.3 |
| 22 | 35.8 | 44 | 28.5 | 66 | 18.0 | 88 | 3.7 |

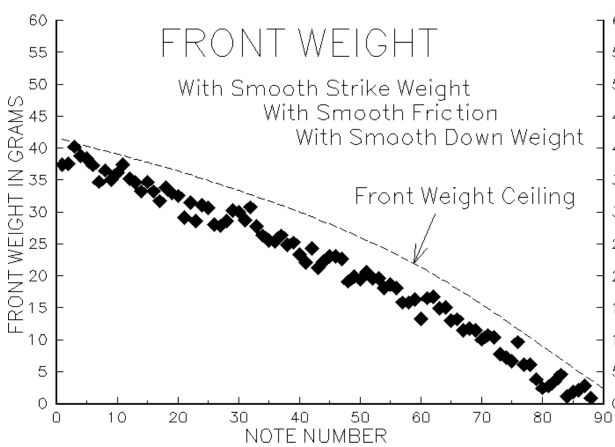
It is an understatement to say that wide variations in front weights levels are found throughout the Industry. Consider the two late model NY Steinway concert grands, weighed off in the factory, as shown in Graph 13.



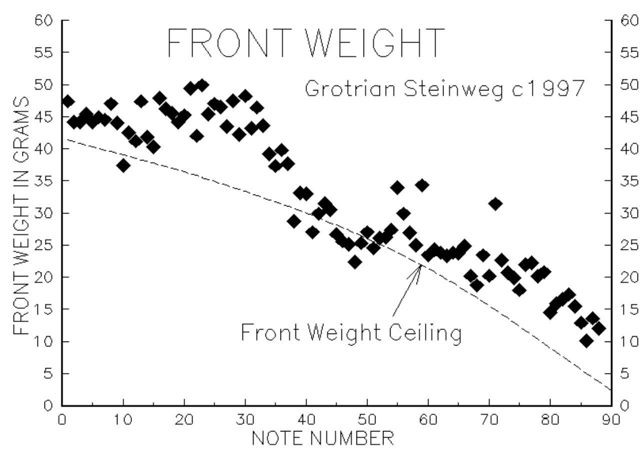

GRAPH 13

As to the quality of various front weight levels, it was found that actions with high zone front weights tend to be heavy and slower in repetition, while actions with lower front weights tend to feel lighter and have faster repetition. The best repetition was found in actions with high strike weight and low front weight.

It is also an understatement to say that wide variations in front weight smoothness exist throughout the industry. An example of very smooth front weights as produced with the traditional approach, that relies on pound hammer weight and down weight specifications, is shown in Graph14. This kind of result is produced if keys are balanced when strike weight and balance weight are quite smooth or when strike weight, down weight, and friction are quite smooth. The jags in the front weight are the result of jags in the strike weight ratio. The smoother the strike weight ratio the smoother the resulting front weights. The more jagged the strike weight ratio, the more jagged the resulting front weights. For instance the smoother ratios of graph 11 would produce smoother front weights than the more jagged ratios of graph 12. An example of a very jagged front weight is shown in Graph15. This kind of result is produced when strike weight and friction are very uneven at the time of a down weight-only weigh off. In this example we see how the elevated strikes weight between notes 16 and 34 (see graph 5) are mirrored with elevated front weights in that section. The elevated front weights of notes 55, 59, and 71 are attributed to tight hammer flanges in those notes at the time of weigh off. More lead was added to the key to overcome the extra friction and make the specified down weight. Friction anomalies, especially from tight key bushings, may well be the most common cause of front weight anomalies when down weight is the primary weigh-off specification.

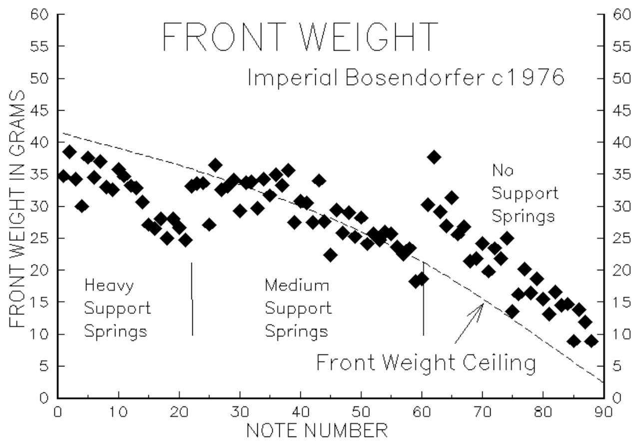



GRAPH 14



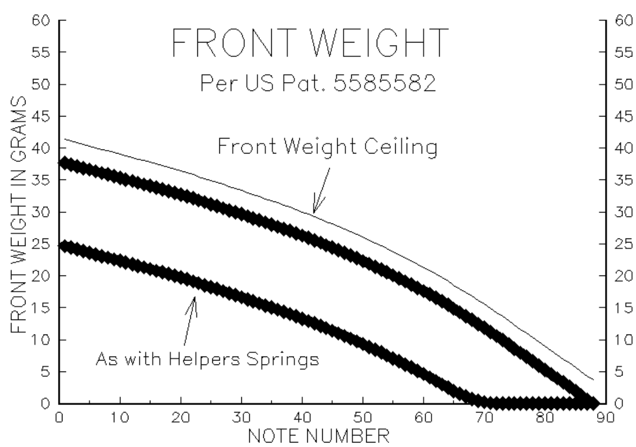

GRAPH 15

Major front weight jaggedness was found in almost all factory balanced pianos that incorporate wippen support springs (also known as helper or wippen assist springs). The example shown in Graph16 is an Imperial Bosendorfer. Note the jag in front weights where support spring size changes at note 22 and again where springs end at note 61. These jags are the result of balancing the keys with the springs engaged and without precise regard for their tension at the time of weigh-off. It was found that this problem could be eliminated by first balancing the keys with the springs disengaged to an elevated balance weight. Then the springs may be hooked up and individually tensioned to produce the final balance weight. The result was found to be a smoother feel and response in the keys when playing. When not asked to work to hard and matched with the right leverage, wippen support springs allow for the use of high zone strike weights and very low front weights. This was found to produce incredibly fast repetition most likely because the repetition spring pushes against the heavier hammer to return the lighter key.




GRAPH 16

A definite correlation between smooth front weights and smooth action response was found. Jagged front weights are associated with uneven action response and smooth front weights are associated with smooth action response. The highest ideal of front weight smoothness is exhibited in keys that have been digitally scale balanced using smooth front weight specifications as described in US Patent 5585582 Dec. 17, 1996. The examples in Graph17 show two sets front weights balanced with the patented process. The lower set of front weights represents a design that incorporates 88 wippen support springs.




GRAPH 17

Conclusions

Based on the findings it may be concluded that the pound rating of a hammer is useful only in the most general sense and as a hammer weight specification it is essentially meaningless. Considering that 0.5 gram changes in strike weight were found to be significant to the pianist and that multiple strike weight variables commonly produce note to note variations of 0.5 grams or greater, it may be concluded that a majority of pianos may be significantly improved by taking efforts to eliminate these anomalies. Furthermore, the first hand experience of the study group supports the conclusion that strike weight smoothing is a voicing foundation which is essential for the production of best-possible tone, with the added benefit that it significantly reduces the need for smoothing the voicing of individual hammers with needles or hardeners.

The linked relationships between strike weight, strike weight ratio, and front weight offers the best clues for understanding dynamic touchweight. Whereas down weight gives a false reading of how the piano will feel when played, the measurement of actual key pressure needed in the act of playing requires high tech measuring devices and is beyond the scope of practical utility. However, associating particular action qualities with particular combinations of strike weight, ratio, and front weight offers a practical approach to designing the dynamic feel of an action.

Adding key leads to make a specified down weight without regard for strike weight, strike weight ratio, and friction is analogous to taking valium and sweeping your problems under the rug. Technicians who take on the task of balancing actions as well as piano manufacturers should learn to choose design components that yield a desirable strike weight ratio level to match a compatible strike weight level. Key leads should be added to the keys using methods that produce the smoothest possible front weight.

Wippen support springs are misunderstood by many and this valuable resource has been crudely applied in the past due to the lack of touchweight knowledge. Technicians who proclaim they should be "cut off" only display their own ignorance. Rather than discard this valuable heritage we should look more deeply into the benefits of wippen support springs and learn how they may be successfully incorporated into the design of touchweight.

End

# GLOSSARY

Terms and abbreviations of the New Touch Weight Metrology:

BALANCE WEIGHT (BW) - The amount of weight placed on the measuring point that causes the key to be balanced.

Found as: BW = (D + U)/2

DOWN WEIGHT (D) - The minimum amount of weight, to the nearest gram, placed on the measuring point that causes the key to drop while maintaining a slow controlled motion of the hammer.

EQUATION OF BALANCE

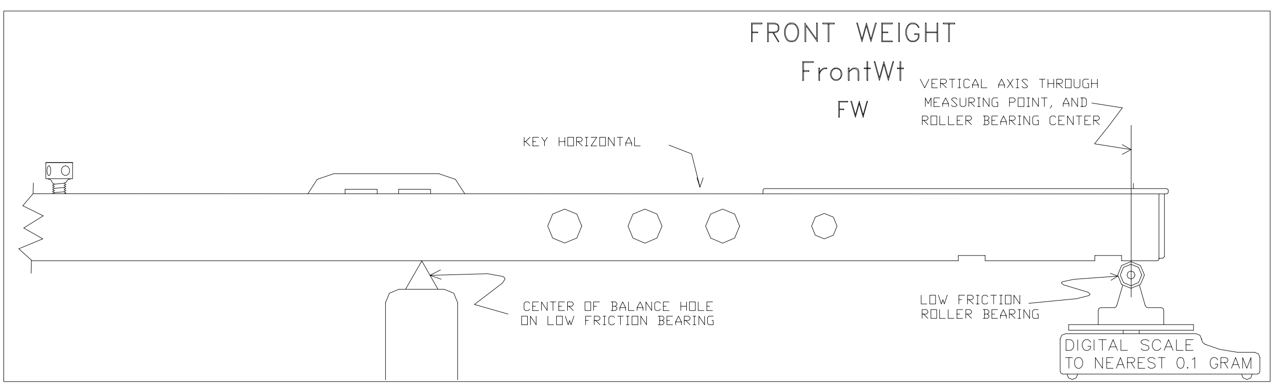
The algebraic expression that describes the working key in a state of balance in terms of the New Touchweight Metrology. Described in the June 1996 PTG Journal as:

$$BW + FW = (WW \times KR) + (SW \times R)$$

FRICTION WEIGHT (F) - The minimum amount of weight added to the balance weight that causes the key to drop while maintaining a slow controlled motion of the hammer or the minimum amount of weight taken away from the Balance Weight that causes the key to rise while maintaining a slow controlled motion of the hammer.

Found as: F = (D - U)/2

FRONT WEIGHT (FW) - The amount of static weight, to the nearest 0.1 gram, that the level key, tipped on its balance pin point, exerts at the measuring point.



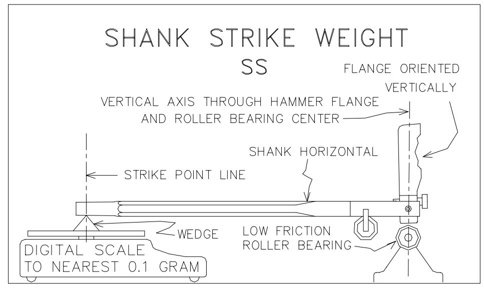

KEY FRICTION WEIGHT (KF) - A component of Friction Weight which is the minimum amount of weight, to the nearest gram, placed on the measuring point of a key that causes the key to fall, with the Front Weight(FW) set to zero with temporary weight and with the key on its frame and the stack removed.

HAMMER WEIGHT (HW) - The weight of the hammer with shank removed.

KEY WEIGHT RATIO (KR) - The ratio of downward force on the capstan/heel versus the corresponding upwards force at the measuring point as translated through the key or the amount of weight at the measuring point needed to balance 1.0 grams of weight at the capstan/heel contact point.

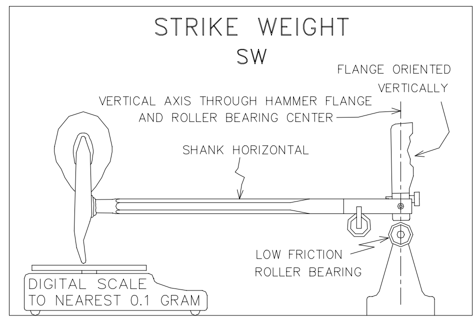
MEASURING POINT - The datum point on the top of the key 13mm or ½" back from the front lip of the key. Weights are centered on this point when measuring Up Weight and Down Weight. When measuring Front Weight(FW) the key rests on a roller bearing on the scale pan. The point at which the front of the key rests on the bearing is directly below the Measuring Point. Any measures that contain the term to Balance Weight refer to static up or down forces at the front of the key through the Measuring Point.

SHANK STRIKE WEIGHT (SS) - The amount of weight to the nearest 0.1 gram, of the shank, pivoted without friction at the hammer center with shank level, measured at the strike line radius.




STRIKE BALANCE WEIGHT (SBW) - The upward static force at the measuring point resulting from the static weight of the hammer and shank, leveraged through the shank, wippen, and key: Found as: TBW - WBW

STRIKE WEIGHT (SW) - The amount of weight to the nearest 0.1 gram, of the shank and hammer, pivoted without friction at the hammer center with shank level, measured at the strike line radius.




STRIKE WEIGHT RATIO (R) - The ratio of downward force at the hammer versus the upwards force at the measuring point as translated through the shank, wippen, and key, or the amount of weight placed on the measuring point needed to balance 1 gram of Strike Weight (SW). Found as: SBW/SW

SUPPORT SPRING BALANCE WEIGHT (BWS) - The difference between the balance weight with the wippen support spring disengaged and with it engaged.

TOP ACTION BALANCE WEIGHT (TBW) - The combined upward static force at the measuring point resulting from the static weight of the wippen leveraged through the key and from the static weight of the hammer and shank, leveraged through the shank, wippen, and key. Found as: BW + FW

UP WEIGHT (U) - The maximum amount of weight, to the nearest gram, placed on the measuring point that the key can lift while maintaining a slow controlled motion of the hammer.

WIPPEN BALANCE WEIGHT (WBW) - The upward static force at the measuring point resulting from the static weight of the wippen leveraged through the key, found as: KR x WW

WIPPEN WEIGHT (WW) - The amount of weight, to the nearest 0.1 gram, of the level wippen, pivoted without friction, at the wippen center, and measured at the capstan/heel contact point.