The Aural Tuning of Pianos

By Norman Brickman, MPT

In this article, we'll walk through all the steps involved in the aural tuning of a piano. I've enjoyed working on pianos for well over 30 years, and I'd like to share my enthusiasm for aural tuning with you. You will learn how to achieve the highest quality of musical responsiveness for which a particular piano's scale is designed.

The alternative to aural tuning (using your ears) is to tune with your eyes; that is, to use an electronic tuning device or aid. A commonly expressed opinion is that with an electronic tuner you can achieve "an expert aural quality tuning." I hope to convince you that you can achieve and appreciate the best tuning of pianos using just your ears.

To keep the focus on tuning, we will avoid music theory, music structure, and music notation where possible. Whether you have professional musical training will not matter; you will find aural piano tuning to be interesting and practical to learn. If you can read the notes on a music scale and understand the concept of an octave, you're ready to learn about aural tuning.

Aural Tuning Works for Everyone

Piano Tuners: Whether you tune aurally or use an ETD, the real test of quality of the tuning and the piano's sound is based on what you hear. You will learn significant subjective decisions to make during a tuning, whether for unisons or scale stretch or tonal aspects, for which your ears are at least every bit as accurate as an electronic device. Your ears are the true judges.

Piano Players: A quick playing of a few musical intervals across the keyboard can quickly let a pianist know if the piano has the appropriate sound quality for which its scale is designed. You will learn what to listen for.

Administrators: You will learn how to get a clear, unambiguous sign of when a piano needs to be tuned. Most people can play a few notes on a piano and tell if it is drastically out of tune. But by learning a little about the musical intervals used in aural tuning, you can develop a much more discriminating ear with regard to a piano's need for tuning.

Equal Temperament

On a modern piano keyboard, each octave is split into twelve keys, and these keys are tuned in an approach called "equal temperament" that was adopted for use worldwide in the 1800's. Another name for this tuning of the 88 notes on a piano keyboard is "Twelve-Tone Equal Temperament." Professional musicians know that it does come with some loss of the different key tonal qualities, but it simplifies the piano tuning and supports generic musical needs. This method is in nearly universal use today. (A small number of musicians are still interested in historic temperaments.)

In equal temperament, each note on the piano has a frequency (or pitch) that is a fixed amount (multiplier) more than that of the preceding note. And every twelfth note is up by a factor of two, referred to as an octave. In practice, the octave winds up being slightly bigger than two-times since a vibrating string is slightly inharmonic. Since the aural tuning techniques automatically incorporate the slight octave inharmonicity in its procedures, you don't need to explicitly deal with it.

For terminology, each adjacent note as you go up or down the scale is referred to as being a half-tone (or semitone) up and down. As explained in Wikipedia, for equal temperament, "the frequency interval between every pair of adjacent notes has the same ratio[1]."

The Vibrating String

A vibrating string that produces a musical note on a piano simultaneously produces more than just the fundamental frequency. It also produces harmonics, also

known as partials or overtones. The partials are harmonically related to the (1x) fundamental, again with a very slight stretch or inharmonicity mentioned earlier. So beside producing the 1X (fundamental) frequency, a vibrating string also produces audible sounds of 2x (octave), 3x, 4x (double octave), 5x, 6x, and on-up with decreasing intensity or volume. This in turn leads to the topic of the next section, intervals, which are fundamental to the aural tuner.

Existence of the partials is very easy to verify and hear for yourself or to demonstrate to others. Go to the 28th note on the piano, which is known as C3; play and release it. All you heard was C3, right? So far! Now slowly press C4 and hold it down, to hold its damper off the strings. Now play and release C3 and you will hear C4 (the second partial of C3) still sounding since its damper is being held off. But if you play and release C3while holding the C#4 damper off, you will hear silence. Next, in a similar manner, hold the G4 damper off its string while playing and releasing C3 and you will hear G4 (the third partial) still sounding. Now try the same with C3 while holding off the G#4 damper, and there will be silence. Same with C3 and C5 (fourth partial), C3 and E5 (fifth partial), etc. The section on intervals (below) and its included Table of Intervals will help you to better understand the location of the partials and what you were hearing in these tests for partials.

Intervals

For our purposes, we will refer to the keys on the piano as simply “naturals” and “sharps.” This ignores a lot of musical theory but should suffice for our needs. When two notes of the piano are played together this is called playing an interval. The table below gives you information about the intervals on the piano that are important in aural tuning.

For illustration purposes, consider the following two intervals:

a) 5:4 Interval. When a fundamental note and the note four half-tones above it are played together, the two are considered to be a 5 to 4 ratio of their fundamental frequencies. The 5:4 interval, in its pure form, is what musicians refer to as a major-third.

b) 4:3 Interval. When a fundamental note is played simultaneously with a note five half-tones above it, the two are considered to be a 4:3 ratio of their fundamental tone and is what musicians refer to as a fourth.

Each of the intervals in the interval table have a characteristic that is very important to a tuner as well as to a musician. Each has at least one partial on each of the two notes that are at, or very near, to the very same frequency, known as coincident partials. (A more-accurate literal name would be near-coincident partials.) For musicians, this

Figure 1, Table of Intervals

Interval	Musically Known As	Number of half-steps in the interval	Where to listen for the beats from coincident partials	Equal Tempering does the following to the interval	Beat Rate when the low note is C3 (BPS)
2:1	Octave	12	At high note + at one octave above high note + at 2 octaves above, etc.	Exact	0
3:2	Fifth	7	One octave above the high note	Slightly narrowed	0.4
4:3	Fourth	5	Two octaves above the low note	Slightly widened	0.6
5:4	Major Third	4	Two octaves above the upper note	Widened	5.2
6:5	Minor Third	3	Two octaves above the “4” in 6:5:4	Narrowed	7.1
5:3	Major Sixth	9	Two octaves above the “4” in 5:4:3	Widened	5.9
8:5	Minor Sixth	8	Three octaves above the low note	Narrowed	8.2
7:4	Minor Seventh	10	Two octaves above the high note	Widened	10.5

supports musical quality in their compositions, and for piano tuners it gives us the beats (or the lack of beats in the octave) that we listen for as we tune. Learning where those beats are, what to expect, and how to listen for them is what the rest of this paper is all about.

Everything in aural tuning is about coincident partials. The following sections explain how to hear their beats or pulsations, which occur at their coincident frequency. If the coincident partials are different by 1 Hertz (Hz), you will hear the coincident frequency with a 1 beat-per-second (bps) pulsation; different by 2 Hz produces a 2-bps pulsation, etc. The aural piano tuner learns the intervals listed in the table above through practice.

An important trick is that with equal temperament tuning, as a given interval is played moving up the scale in half-tones the rate of beating of its coincident partials will slowly increase, and when moving down in half-tones they will slowly decrease. And for every octave of movement, the beat rate will double (going up) or halve (going down). This is a nice feature of equal temperament. Also, you will learn that some intervals are useful only in certain parts of the piano scale due to the rate of beating; if you go too far up, the beat rate gets too fast; while going down too far can render the beat rate too slow to accurately discern.

Finally, in aural tuning you'll never be expected to measure or set a precise beat rate for an interval, such as 4 bps, or 7 bps, etc. No counting of beats per second. But you will learn to do comparisons of two separate intervals producing the same beat rate, and of the two intervals as to one beating faster than the other. This will soon be part of your skill set.

Hearing the Beats from Musical Intervals

I have had many occasions over the years to demonstrate how to hear the beats of coincident partials in an interval. Once you learn where to listen and where to "ignore" listening to the fundamental tones, you will hear the beats. If not immediately, with practice and patience you can hear the beats.

For piano tuner-technicians, it is best to start with a piano scale that has been felt-strip muted such that only a single string per note is sounding (or use rubber mutes to achieve the same effect). For the general public that is testing a piano, if the bi-string and tri-string unisons are in tune (such as if recently tuned) there is no need for the muting. Finally, you will find that even a piano with out-of-tune unisons and no strings muted that is tested with a few intervals will quickly reveal its tuning status.

I recommend starting or learning to hear intervals through use of the 5:4 (or major third) interval. It plays an important role in any tuning, it demonstrates the types of accuracy achievable in aural tuning, it is relatively very easy to hear, and is expandable to multiple octaves in conjunction with the addition of one octave (a "tenth" or 5:2) or two octaves (5:1) to the base interval.

5:4 Interval: If you play C3 along with E3, that 5:4 interval will produce beating at E5 with typically a beat rate of the coincident partials of 5 bps or so when the two notes are properly tuned (see the table presented above). If you want to speed up the beating a little, try a little higher on the scale at F3 and A3, and listen for the beating at A5 – at a little less than 8 bps when the piano is at proper pitch. Always, when listening for the beats, try to mentally ignore the two fundamental notes that you are playing.

6:5 Interval: Hopefully you have been successful hearing the 5:4 interval, which is related to the musical major third. The 6:5 interval is also important, related to what is called a minor third. Play C3 and D#3 and listen for the beats (about 7 bps) at two octaves above G3 at G5.

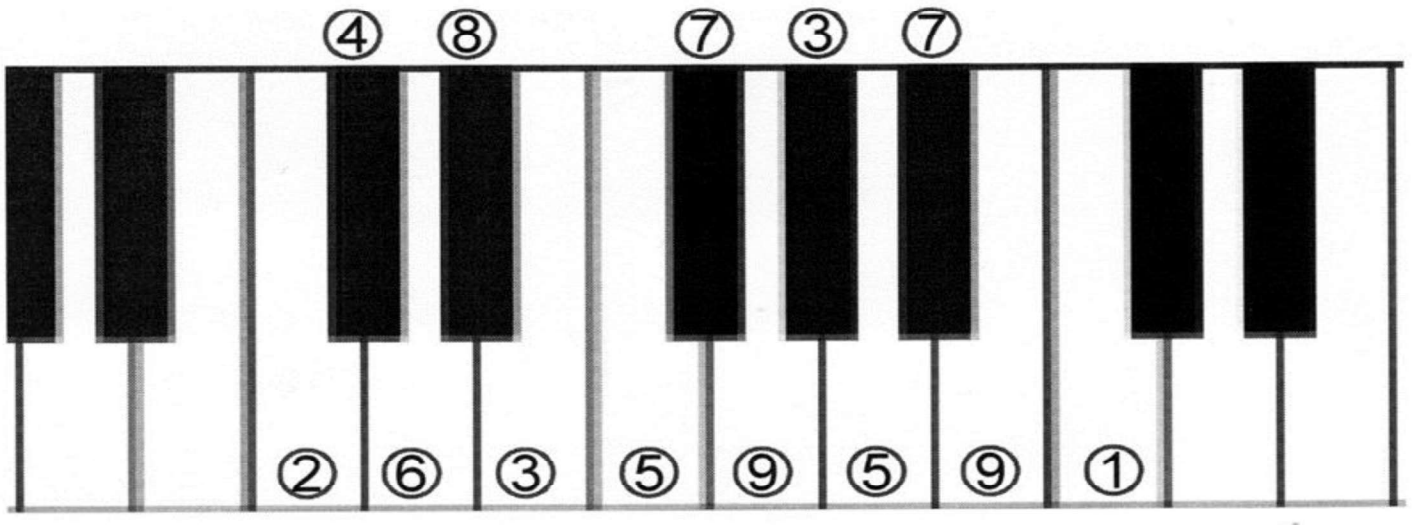
2:1 Interval: The octave (2:1), double octave (4:1), and triple octave (8:1) etc. are very important to a tuning and to a musician. The octave is tuned pure; or at least nominally pure if the intrinsic stretch of piano strings is ignored. Try playing C4 and C5 together and see if you can pretend you are playing a single note, or alternatively listen for beats. Or try playing C3 and C4 and C5 simultaneously and listen the same way.

Now you can refer back to the table and try other intervals that are listed there.

Setting a Starting Note for Tuning

With modern pitch or frequency, the 49th note on the keyboard of a piano is an A (A4) and must be tuned to 440 Hz, with middle C (C4) being at 261.63 Hz. A tuner needs some means of establishing one starting note, such as using a tuning fork or some type of simple, inexpensive digital meter. I suggest that you buy a C-261.63 Hz tuning fork; it needs no batteries and is inexpensive, lasts forever, and has

Figure 2, Setting a C Temperament



high accuracy. The C-261.63 fork is preferred in my opinion over the A-440 fork because when setting the initial temperament octave that is described in the section "Setting a Temperament Octave" below, the interval beat rates will be more manageable2.

Your skill of listening for beats with a 5:4 interval (major third), which you practiced in the preceding section, can now be put to use to set C4 as a starting note for a tuning. Strike a C4 tuning fork and while holding its handle, place the handle on the wood of the piano (such as on the keyboard cover or under the key frame) to hear it well. Then simultaneously play the G#2 piano key and listen for the beat rate of the 5:2 interval. (We could have used G#3 here for a 5:4 interval, but the halved beat rate of the 5:2 interval should be easier to hear in this range of the piano scale.) Then play together the G#2 and C4 keys on the piano and again note the beat rate of the 5:2 interval. If the two beat rates are not equal, the C4 key needs adjustment to match the frequency of the tuning fork. The next section will teach you how to find out if the C4 note will need to be adjusted up or down in frequency.

Enlarged and Narrowed Intervals

The reason that the coincident partials of the intervals in the above table produce beats (except for the octave) is due to the method of placing the twelve notes for an octave in equal temperament. The notes are placed approximately where they belong musically rather than precisely, as the tempering column implies. The net result is a close approximation. As you gain experience, you'll learn and memorize which intervals are narrowed and which are enlarged.

A couple tempering examples are described in the following few paragraphs. If this is too technical for you, skip these and use just the tempering summary presented in the interval table. 5:4 intervals are enlarged (5/4 x 5/4 x 5/4 = 1.953). Close but still a way less than 2.0 (the octave) and hence you need to expand the 5:4 interval (major third) in tuning to equal temperament. You can hear coincident partials beating when the 5:4 interval is played.

6:5 intervals are narrowed (6/5 x 6/5 x 6/5 x 6/5 = 2.074). Close but a little more than 2.0. To satisfy the purity of the octave in a twelve-note keyboard, the 6:5 interval (minor third) is a narrowed interval. Expect to hear coincident partial beating when the 6:5 interval is played.

With similar reasoning, the 5:3 interval (major sixth) is enlarged and the 8:5 (minor sixth) is narrowed. The 5:3 is often used in conjunction with use of the 6:5 to measure octaves in a 6:3 manner. Similarly, the 5:4 beat rate can be compared with a 5:2 interval to establish the octave in a 4:2 (or slightly less-stretched) manner.

The 3:2 (fifth) and the 4:3 (fourth) intervals have much less beating to them, with the 3:2 being very slightly narrowed in the tuning process, while 4:3 is very slightly widened.

Setting a Temperament Octave

The piano tuner first tunes/tempers one (equal temperament) octave in the middle of the piano scale, and then progresses outward from that octave using various

interval tests. The temperament octave is set from C3 to C4. The following nine steps describe setting the notes of the temperament octave in the sequence labeled in Figure 1.

1) Set **C4** to the 261.63 Hz tuning fork as described in "Setting a Starting Note for Tuning."

2) Set **C3**. Use G#2 (or G#1), and adjust its frequency as required to hear the interval beats, such that an equal beat comparison can be made between 5:4 G#4-C3 and 5:2 G#2-C4. This establishes, and inherently might very slightly stretch, the octave based on the 4th and 2nd partials of C3. An alternative, using 6th and 3rd partials of C3 with its possible slightly increased stretch, would be to first adjust the frequency of C3 and use an equal beat comparison between 6:5 C3-D#3 and 5:3 D#3-C4.

3) Set **E3** and **G#3** such that the 5:4 ratios between C3-E3, E3-G#3, and G#3-C4 show an evenly increasing beat rate going up the scale.

4) Set **C#3** based on a 3:2 drop down from G#3 that is slightly narrowed. Since this narrowing will be difficult to hear the beats, another option is to compare the 6:5 interval between C#3 and E3 to be slightly faster beating than the 5:4 between E3 and G#3. (Some practice and experience help here and elsewhere in setting the temperament octave. Don't worry if your first attempts result in errors – you will hear the errors in the testing that takes place at the end of the nine steps. That's where practice comes in to make it perfect.)

5) Set **F3** and **A3** using the 5:4 ratios between C#3-F33 and F3-A3. Each should beat only very slightly faster than the same intervals one semitone lower that were set in step 3.

6) Set **D3** based on a 3:2 drop down from A3. Same process as in step 4.

7) Set **F#3** and A#3 using the 5:4 ratios between D3-F#3 and F#3-A#3. Same process as in steps 3 and 5.

8) Set **D#3** based on a 3:2 drop down from A#3. Same process as in steps 4 and 6.

9) Set **G3** and **B3** using the 5:4 ratios between D#3-G3 and G3-B3. Same process as in steps 3, 5, and 7.

Test the temperament octave and make adjustments as appropriate. A progression of 5:4 (major thirds) is one test, a progression of 6:5 (minor third) intervals is another, and a progression of 5:3 (major sixths) are also of use. As you follow the steps in the next section to expand the tuning up and down the scale, the first few additional notes added provide additional tests for an expanded temperament octave. Note that some piano tuners, rather than use a single temperament octave as described here, explicitly create an initial one and one-half or two octaves, which is also fine.

In summarizing this section, again note that in setting the temperament octave as described above you were not asked to set or listen for a particular rate of beats per second, only to perform comparisons among beat rates. Additionally, the correct scale for the piano, including any inherent inharmonicity for that piano, was automatically accounted for in the process described. The same automatic adjustment for inharmonicity applies in the next section as well.

Moving Up and Down the Entire Scale

After setting a temperament octave, the task is to fill in the rest of the scale while maintaining or replicating the settings used in this first octave.

Moving up the scale. In going up from the temperament octave, proceed in consecutive half-tones while doing the following for each new note:

1. Use the octave and, as you progress, double-octave and triple-octave tests. An octave (2:1) does not give the most accuracy in the upper notes as one can get with other intervals, but it provides an initial setting and leads to the following subsections below.

2. Test for a progression of beat rates. Using the approximate settings within the upper octave that you achieved in the preceding step, now find an interval with appropriate beat rate and ensure that the beat rate continually increases as you go up the scale. The 5:4 (major third) can start beating too fast for your use rather soon, but then you can start using a 5:2 and 5:1 for the same purpose, as well as the 5:3 interval (major sixth).

3. Further test for octave accuracy by comparing two intervals per higher note. In a piano without too much inharmonicity, the beat rate of a 5:4 compared with the beat rate of the 5:2 (for notes one octave above) and 5:1 (for notes two octaves above) will be identical. The use of octaves and multiples of octaves becomes increasingly important as you move up to the highest notes on the scale.

Going down the scale. In descending from the temperament octave, I tend to put more reliance on the 6th and 3rd partials, as opposed to usually favoring the 4th and 2nd partials when going up the scale.

1. As in going up from the temperament octave, you proceed by consecutive half-tones going down. Use an octave test to initially set the notes, and come back to the octave test (to check again) after considering use of subsections below.

2. After setting, say, one octave going down, I will usually check for a progression of beats just like in going up the scale. The 5:4 and 5:2 intervals are still available and usually do a good job here.

3. I get a lot of use out of doing an octave test using a 6:5 interval (minor third) for the low part, and a 5:3 (major sixth) for the upper part. The beat rate of the two intervals will be equal if the octave is pure (pure from a 6:3 partials sense).

4. For the lower notes I often make use of the progression of the 7:4 interval (minor seventh).

Once you have completed the whole scale of the piano, you will want to go over the whole range again while checking for the usual increase / decrease in beat rate for particular intervals. Another good overall test is an octave test, such as using double octaves across the whole scale to spot any anomalies.

One Last Note

Congratulations for reading through to the end! Understanding these essentials and gaining experience listening to the beats will send you on your way to successful aural tuning.

***Norman Brickman, MPT**, was formally educated in piano tuning and technology with Mr. John Travis at Montgomery College, Gaithersburg, Maryland, 1975-76. Additional training in piano technology includes an apprenticeship under Mr. William Hupfer, chief tuner-technician of the Concert Department of Steinway & Sons, New York City; and an apprenticeship under Mr. Fred Hemry, a registered Piano Technician in Bethesda, Maryland. Other higher education includes a master's degree in computer science and a Ph.D. in Physics.*

Norman has been involved with the Master Piano Technicians of America for many years. He served as the editor of the MPT Journal for twelve years, treasurer of the national MPTA for many years, and various other activities involving both the national MPTA and the Washington, D.C., area local chapter. He may be reached at PotomacPiano@verizon.net, or though his website: www.potomacpiano.com

[1]*The most current version of Wikipedia's article on Equal Temperament may be found here: https://en.wikipedia.org/wiki/Equal_temperament*

[2]*Inharmonicity of the vibrating string was explained in the section under the same title. For an environment where the resultant A4 note must be precisely 440.00 Hz, having a second tuning fork available for 440 Hz can be used to slightly adjust the initial C settings within the temperament octave.*

Answers to the Test Your Knowledge Questions on Page 7

1. Bartolemeo Cristofori
2. Polish Pianist Romuald Koperski
3. Steinway & Sons
4. "The Indestructible"
5. Mason & Hamlin
6. Thirty-Six