The Beats Go On

Norman Brickman, MPT
Washington, D.C., Chapter of MPTA

I. Introduction

The last issue of the MPTA Journal published my article on ***The Aural Tuning Of Pianos,*** with a start-to-finish description and walk-through of what is involved. In this article we step back and focus on a key underlying part of an aural tuning, hearing the beats. Hearing beats is fundamental for several reasons:

1) They are foundational for setting each and every string;
2) They introduce accuracy;
3) They are used by all piano tuners, both aural and those who use Electronic Tuning Devices, (ETD), for tuning unisons and for a final overall quality check; and
4) They are effective in evaluating the condition of a piano. By just playing a few notes or chords, one can draw conclusions on the:

- Unisons,
- Tuning consistency across multiple octaves,
- The quality of the temperament octave, and
- The current overall level / quality of the tuning.

Finally, a piano is a musical instrument. Final judgment of a tuning and other quality-related decisions rest with the human ear, not with an electronic device.

II. What Are Beats?

Beats are also referred to as pulsations, or waves. Whenever two musical notes are played together, one will hear not only the fundamental tones but also a pulsation at the mathematical difference of the two frequencies. As William Braid White, the famous pianocology and musicology expert noted,

> *"The cycle of operations, comprising the periodic swelling up of the sound, followed by its dying away, . . . is called a beat. It constitutes one of the most important of all the phenomena we encounter in the process of tuning. It will be observed that the number of beats occurring between two simultaneous sounds must always be equal to the arithmetic difference between their frequencies"*[1]

As Dr. White goes on to point out, as piano tuners, our use of beats is of most interest for those cases where the frequency differences between the two notes are small. For example, for two strings supposed to be in unison, or for musical intervals where coincident (or near-coincident) fundamentals and partials are in close proximity to each

1. Dr. William Braid White, "Piano Tuning and Allied Arts," Fifth Edition, 1946, Tuners Supply Company. Page 54.

other – there will be beats, as will be discussed in the next section.

III. Hearing Beats While Tuning

For piano tuning purposes, there are three environments that we address during our tunings where we hear beats: (a) unisons; (c) octaves; and (c) musical intervals. As has long been observed, the beats or pulsations are most readily observed in unisons. *"They are more easily perceived in the unison than in the octave, and more easily in the octave than in the fifth [and fourth, major third, more][2]"*. We will now briefly discuss the three environments in this same order, ranging from easiest to hardest to hear, but with the assurance that with a little practice every reader will have no difficulty hearing all three. While inharmonicity of a vibrating string is also important within a piano tuning, its intricacies within a tuning will only be introduced in this article on hearing beats.

III.A Unisons

Most everyone reading this article is already familiar with tuning unisons, but that also means that you already understand how to hear beats! We explained earlier that beats occur when two musical notes are played together, and in the case of tuning unisons that is exactly what is happening. Each piano note usually involves two or three strings that are tuned to the same frequency. When one string is off from the other(s), a low-frequeny beat (or waver or pulse) will be heard.

So for a tri-chord unison, assume you have already tuned one string to the proper frequency with the other two strings being muted. When you go to tune the second of the three strings, if there is any difference momentarily existing between the frequency of the two strings you will hear that as a beat, or as a mismatched (non-singular) pair of strings. If you are tuning A49 to 440 Hz, if the second string is at 441 Hz the note doesn't sound "right" due to the 1 cycle per second (cps) beat or pulsation when A49 is played.

Arthur Reblitz pulls together the concepts of beats and tuning unisons in the following description. *"If you tune one string to 440 hz and the other to 442 hz, the vibration of the faster string will catch up to and overtake the slower string twice per second. Likewise, the tone will grow louder and then softer twice per second. Each time the tone gets louder and softer is called one* ***beat****. Two strings vibrating at 440 produce no beats. Strings tuned to 440 and 441 beat once per second; strings tuned to 440 and 445 beat five times per second."*[3]

There are recent indications that ETDs based on newer technology of the past couple years have adequate power and resolution to enable piano technicians to avoid using

---

2. J. Cree Fischer, "Piano Tuning," Dover Publications Inc., 1975. Page 73.
3. Arthur A. Reblitz, "Piano Servicing, Tuning, and Rebuilding," Vestal Press, Second Edition, 1993. Page 205.

their ears in tuning unisons[4], but for the most part it appears that tuners who use an ETD will still tune the unisons aurally[5],[6]. At the least all tuners will aurally check the final results, which for unisons means that we learn to hear beats!

III.B Octaves

Beats are used in the aural tuning of octaves based on principles that are similar to their use with unisons. The main foundation for octaves is that a vibrating string not only produces its fundamental frequency (or first harmonic), it also produces higher harmonics, aka partials. Beyond the fundamental frequency (1x), the harmonics produced by the vibrating string are: 2x (2-times) the fundamental (octave); 3x (octave + fifth / 3:2 interval); 4x (double octave); 5x (double octave + major third / 5:4 interval); etc. Figure 1 shows this harmonic frequency effect[7] for a vibrating guitar string, with the general physical principles being the same as for a vibrating piano string.

In tuning octaves, it is also important to say again that beats are produced from two tones regardless of whether the tones are fundamentals or partials of the vibrating strings that produce them.

Assume that A4 (440 Hz) has been tuned, and now A3 (220 Hz) is being tuned to A4. Tuning consists of matching the second harmonic of A3 with the fundamental tone of A4. But – there is more! The two notes will have additional coincident partials that will need to be taken into consideration in setting the frequency of A3, such as the 4th harmonic of A3 with the 2nd harmonic of A4 (aka a 4-to-2, or 4:2, octave), the 6th harmonic of A3 with the 3rd harmonic of A4 (a 6:3 octave), and so on.

The higher harmonics are mentioned in the preceding paragraph on the octave because besides having coincident partials to think about, another consideration for tuning octaves is the inharmonicity of a vibrating string due mainly to its stiffness. The string's partials tend to be stretched out going to the higher numbers, rather than uniformly or precisely being 2x, 3x, 4x, etc.

---

4. Ken Deloria, "Piano Tuning Tactics: Harmonics, Temperament, and Electronic Tuners", Keyboard Magazine, November 29, 2017. *https://www.keyboardmag.com/gear/piano-tuning-tactics-harmonics-temperament-and-electronic-tuners*
5. Richard's Piano Tuning Blog, "Tuning Fork or Electronic Tuning Device", December 29, 2015. *http://www.richardspianoservice.com/blog/2015/10/29/tuning-fork-or-electronic-tuning-device-etd-why-do-people-often-not-trust-machine-tuners-2/*
6. Andy Chase, "Aural vs Electronic Tuning . . .," February 13, 2016. *https://pianotuninginyork.blogspot.com/2016/02/aural-vs-electronic-tuning-which-is.html*
7. Music Theory: Frequencies Related to Playing A Note On Guitar, *https://music.stackexchange.com/questions/6942/music-theory-frequencies-related-to-playing-a-note-on-guitar*

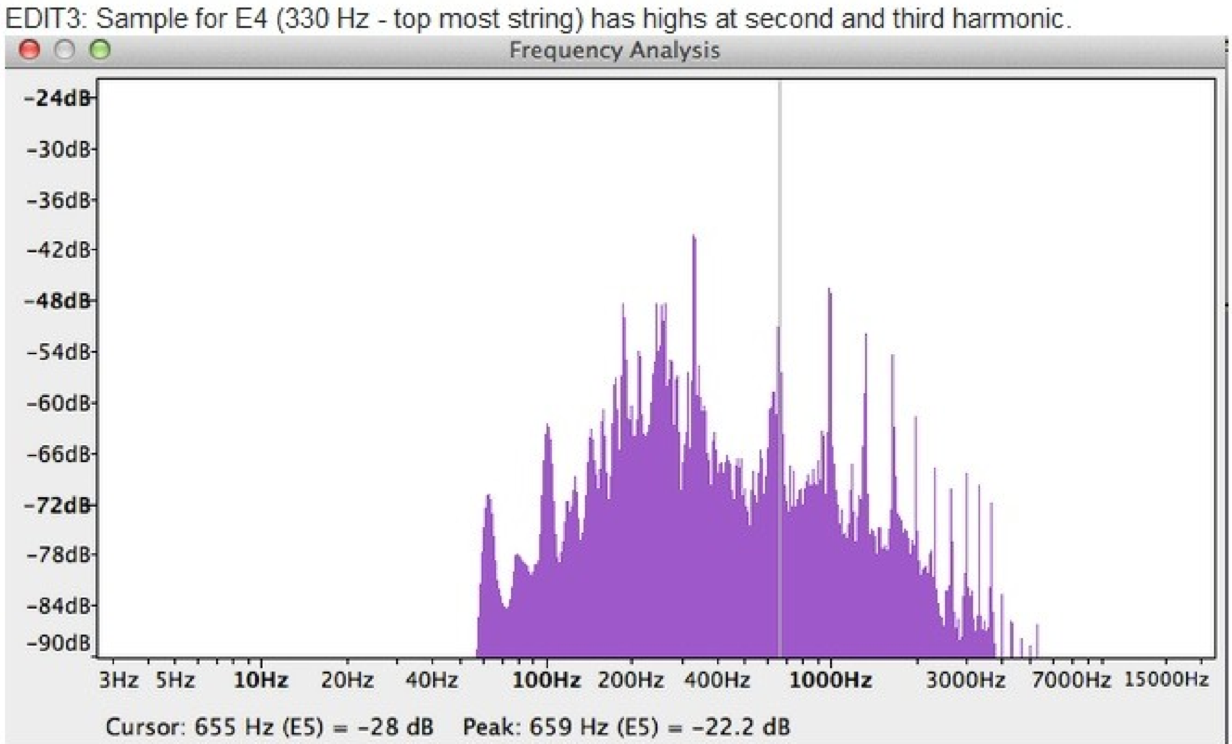

Figure 1 – Harmonic Spectrum of a Vibrating String

So regardless of the octave nominally being considered a “pure” (non-tempered) interval, you will still learn when to emphasize a “4:2 octave”, or perhaps a 2:1 or a 6:3 octave. The type of octave you select will also be related to the intervals that you use to check the octave. As introduced in the next section on Musical Intervals, for lower octaves you might set 6:3 octaves if you test the octave with a minor third - major sixth (6:5 and 5:3), and for upper octaves tuning you might prefer 4:2 and 4:1 octaves and you would then favor major thirds, tenths, and octave-tenths in your testing of octaves.

The net result is that the octave is stretched by the aural tuner, but the process is implicitly integrated note by note. As Arthur Reblitz describes it,

> *“When you tune an octave, you compare the entire partial series of both strings, with the second partial of the lower note, the fundamental of the upper note predominating. If you tune these coincident partials to be beatless, the octave is stretched to whatever extent the second partial of the lower note is sharp of its fundamental.”*[8]

III.C Musical intervals

Besides unisons and octaves, an aural piano tuner uses a set of other musical intervals in the process of tuning a piano. The intervals provide direction and validity checking on the tuning of notes. Considering that we tune in equal temperament, I find that describing the intervals by their numeric relationships is appropriate and natural and quite adequate, but at least for music conversational purposes you should also be

8. Arthur A. Reblitz, “Piano Servicing, Tuning, and Rebuilding,” 1993. Page 214.

prepared to recognize their musical analogies. The following table lists the musical intervals most commonly used by an aural tuner to hear beats[9]. The intervals that are smaller than an octave are repeated for convenience from the table presented in the aural piano tuning article contained in the last issue of the MPT Journal[10]. The intervals shown in the first column are the important information that leads to the information in the third column on where the coincident partials will be heard. The last column, with the musical names of the intervals, particularly those above an octave, could be of interest to those with a musical inclination or background, but will not be key to understanding beats or learning aural tuning techniques. Calling an interval a double octave, or 4:1, will have a literal meaning for us versus calling it a fifteenth!

Table of Intervals

Interval	**Number of half-steps in the interval**	**Where to listen for the beats from coincident partials**	**Alternate Description [and if widened vs narrowed]**	**Musically known as**
1:1	0	At fundamental + higher coincident frequencies		Unison
6:5	3	Two octaves above the “4” in 6:5:4	[narrow]	Minor Third
5:4	4	Two octaves above the upper note	[wide]	Major Third
4:3	5	Two octaves above the low note	[slightly wide]	Fourth
3:2	7	One octave above the high note	[slightly narrow]	Fifth
8:5	8	Three octaves above the low note	[narrow]	Minor Sixth
5:3	9	Two octaves above the “4: in 5:4:3	[wide]	Major Sixth
16:9	10	Four octaves above the low note	[wide]	Minor Seventh
2:1	12	At high note + its octave + more		Octave
5:2	16	One octave above the high note	Octave + Major Third	Tenth
3:1	19	At high note + higher coincident frequencies	Perfect 12th / Octave + Fifth	Twelfth
4:1	24	At high note + its octave + more	Double Octave	Fifteenth
5:1	28	At high note + higher coincident frequencies	Double Octave + Major Third	Seventeenth
6:1	31	At high note + higher coincident frequencies	Double Octave + Perfect Fifth	Nineteenth

9. Look in wikipedia.com at “Interval (music)” in its section on “Compound intervals.”
10. Norman Brickman, “The Aural Tuning of Pianos,” Master Piano Technicians Journal, Vol,. 40 No. 1, Spring 2020.

8:1	36	At high note + its octave	Triple Octave	Twenty-Second

Hearing beats produced in playing a musical interval involves the same principles for each and every musical interval that we use in tuning pianos, so for a first example let's concentrate on the 5:4 interval since it is in such common use in aural tunings. From earlier explanation we understand that beats are produced only when two tones are close to each other. The 5:4 (major third) meets that criteria at relatively low-numbered partials, which is also the reason that musically we consider a major third to be pleasant.

Assume that the 5:4 interval we are discussing is C3 and E3. Figure 2 shows the fundamental notes (C3 and E3) along with harmonics (labeled in parenthesis). Being a 5:4 ratio, the 5th harmonic (or partial) of C3 and the 4th harmonic of E3 are almost coincident. *Almost* but not precisely coincident, because in a modern equal temperament piano tuning we purposely widen the C3-E3 interval and hence will hear beats at E5 as shown in Figure 2 with the dotted line. So without elaborating on the multiple uses of a 5:4 ratio in piano tuning, an aural tuner will also be listening for its beats at two octaves above its higher note (in this case E3).

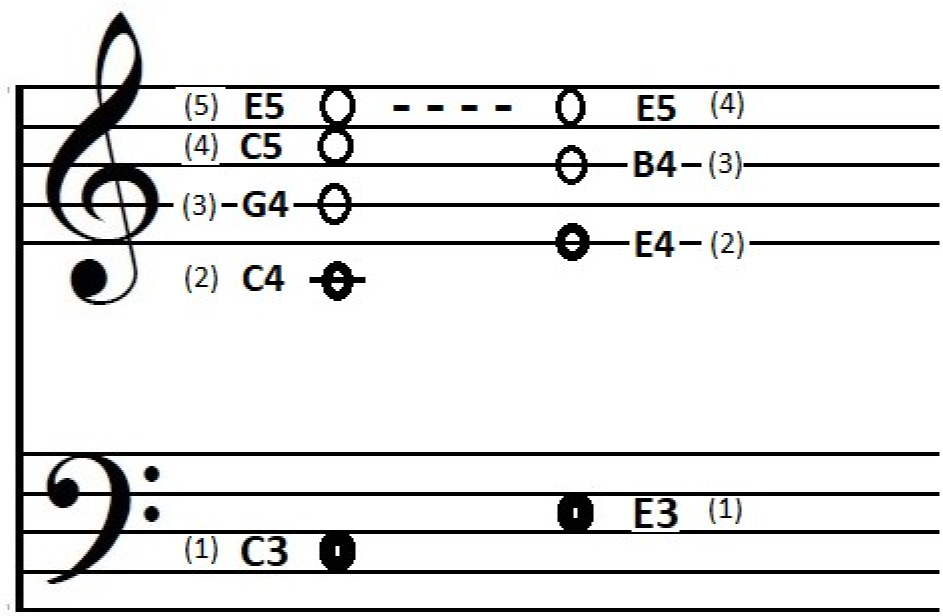

Figure 2 – Harmonics and Near-Coincident Partials of a Major Third

For our second example, an extension of the first, consider using the 5:2 interval and the 5:1 interval, both being very commonly used in tunings. 5:2 could be C3 and E4, and 5:1 could be C3 and E5, and in both cases you would listen for the beats at E5. Assume that E3 has been set, and you are now using these two intervals to set its octave E4 and its double octave E5. By setting E4 to C3 with the same beat rate as E3 to C3, you have a check on the octave. (Not by counting beats, just by setting equal beat rates!) Similarly, by setting E5 to C3 with the same beat rate as E3 to C3, you have tuned the double octave. Notice that the inharmonicity of the octave and double octave has implicitly been considered in setting E4 and E5 without having to explicitly think about inharmonicity. (See the earlier quote from Arthur Reblitz.) This is not to exclude a technician from purposely adjusting the octaves and double octaves to differ from what has been described here (and out of scope for this paper), but keep in mind that one good (and common) practice, after a tuning, is to aurally check it using a run of 60 chromatic major seventeenths (double octave + major third) across the whole keyboard[11].

IV. Summary

This article has described the beats that a tuner listens for while tuning a piano. With experience the hearing of beats becomes rote, an automatic process that does not require one to constantly think about which beats to listen to and where to listen. When integrated into an aural piano tuning regimen, the beats provide the aural “meter” to guide an accurate setting of the tuning pins. Piano tunings performed using an Electronic Tuning Device usually are compared against aural tunings and usually use oral means to check unisons and to overall check the piano when done. I have tried to describe the ease (and enjoyment) of using beats to facilitate and enable high-quality aural tunings, and hope others will increasingly consider endorsing and encompassing comprehensive use of aural means to do their piano tunings.

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 an MA 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 12 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

11. Carl Lieberman, RPT. Online Piano Convention, April 4, 2020. *https://www.youtube.com/watch?v=GPslNZCizOM&feature=youtu.be*