Intentional Non-consonant Tuning — Why and How?

By Gerald E. Leob, M.D.

About the author: Dr. Leob is not a full-time practicing technician, but has taught himself to tune as an avocation. Professionally, he is a neurophysiologist working on developing an understanding of the brain's mechanisms for hearing pitch and ways of restoring this capability in the deaf through a functional artificial ear. He is with the National Institutes of Health in Bethesda, Maryland.
—Jack Krefting

Introduction

The development of the even temperament early in the history of keyboard instruments established controlled dissonance as a major sourf their distinctive voice quality, and was an almost necessary consequence of the physical existence of a keyboard. Much of the art and science of piano tuning relates to producing this even distribution of the dissonance. However, the modern piano incorporates three other physical features besides the fixed scale which also produce dissonances requiring control by the tuner.

First, the great dynamic range available to a hammer strike mechanism implies that strings will often be vibrating in non-ideal modes with non-integral overtone ratios. Second, the extension of the range into the upper and lower registers generates a range of relative pitch sensations not related to the frequency of the fundamental alone. Third, and less generally recognized, the doubling and tripling of strings struck simultaneously generates subtle but pervasive voicing effects dependent on small inequalities among "consonant" strings.

It is interesting to note that even as electronic devices are lessening the need for a subjectively well-trained ear for the setting of scales, we have little systematic understanding of the objective physics responsible for these other important subjective effects. While every good tuner eventually devises subjective personal strategies to cope with them, this lack of understanding can only hamper both the training of new tuners and the design of aids to improve speed and accuracy. Tuning textbooks stress elegant methods for the setting of scales, then dismiss the remainder of the job as the establishment of mere consonances, with grudging mention of the desirability of sharpening-up the two treble octaves a beat or so. I would like to explore methods by which an ear well-trained to hear beats can discover these effects and then systematically optimize them for each instrument and its environment.

The usual "textbook" string is shown as a standing wave with a fixed, even number of cycles ending at fixed nodes at either end. In a string struck off center, as in the piano, multiple patterns are simultaneously superimposed on the string, each pattern corresponding to a different integral number of such cycles present on the string. The audible perception is of multiple, independent sources of pure (sinusoidal) tones starting at a lowest frequency present (fundamental) and including, with various amplitudes, all integral multiples of that frequency (overtones). The frequency of the fundamental (and hence the overtones) is determined by the string's mass, tension, and length, all assumed to be fixed by the construction of the piano and the last visit of the tuner. In fact, the latter two vary continuously with each hammer blow.

The Dynamics of String Tension

The change in the tension of each string when struck is fairly easy to understand. The impact of the hammer stretches and stresses the string by a factor of perhaps 10 to 20% of its resting tension. Since the shortest distance between two points (e.g. bridge and agraffe) is a straight line, and since a vibrating string is actually describing a complex serpentine course between those points, the tension in a loudly vibrating string will be considerably higher than it was at rest. This increased tension drives the resonant frequency of the whole harmonic series of vibrations perceptibly higher, much as a violinist anticipates sharpening of a hard-bowed string.

The effect is best appreciated in the bass, since the relative amplitude of the vibrations is greater and the higher overtones where the effect is most noticeable are more audible. When tuning the octave CCC to CC, you may have noticed that the beats never disappear completely and that they tend to change in character as the notes are held. Strike a single undamped CC string lightly and listen to the beats at that fundamental during the decay of a sharply struck

CCC string. If you adjust the tension of the CCC string so that no beats are audible as both strings fade to inaudibility, you will note perhaps one beat per second of sharpening when the string is sharply struck. If you listen to the higher harmonics shared by the strings, they will be beating much faster, although not necessarily at even multiples of the CC fundamental beat rate. If both strings are sharply struck together, the waxing and waning of all these beats can become quite complex, as the decay of the various modes of vibration in each string proceeds independently and contributes less "added tension" to each.

Rather than throwing up one's hands at the impossibility of properly tuning such an unstable system, we can adopt two useful strategies from the invention of even temperament. First, make it even, and second, make it sound pleasant in the context in which it is actually used. To make it even, one simply follows the usual practice of making the final tension adjustment on the bass strings when they have decayed to near imperceptibility. At this point, the "added tension" effect is minimal. For the lowest bass notes, however, it is never absent, and the tuner should pay some attention to making sure that the particular set of beats to which he is listening and which he is eliminating are always the same (usually the first) overtone.

Making it sound pleasant is a more complex task. The voice of the piano is the product of the complex resonances of all the undamped strings, struck or unstruck, at any instant. The tone of any note derives from the distribution of its harmonics, and this is strongly influenced by the resonances which the higher harmonics evoke in the undamped strings of the treble octaves plus simultaneously struck or held notes resonating with the lower harmonics. If the amplitude of vibration of this string has driven its fundamental even a half beat sharp, its tenth harmonic will be five beats sharp, perhaps more so because of the stiffness of the string for short wavelength vibrations. These higher overtones, which contain as much or more energy than the fundamental, are located three to four octaves above the fundamental, namely, right where those undamped strings we so cautiously sharpen upwards reside. It seems likely that sharpening the treble could have at least as much to do with some of the tenor and bass ranges as it has to do with the "brilliance" of the treble. Certainly, this explains why an unsharpened treble sounds flat against a fortissimo base - it is!

At this point, I solicit the experience of the readers. How much do you really sharpen up and where in the scale do you start? Do you sharpen the same for a piano to be used for quiet chamber music as for one to be assaulted by a virtuoso performing a concerto? Do you "flatten" the far bass to compensate for its sharpening at louder levels or do you adjust the bass during such loud keystrikes, thus accomplishing the same thing? The above discussion suggests that a rather graduated sharpening upwards might be ideal, with an accelerating number of beats per second as one proceeds upward in the treble (and more than the usual textbooks advise) and perhaps an accelerating flattening in the far bass to compensate for the greater "added tension" effect in strings which are not increasing in length at the same rate at which their fundamental frequency is decreasing.

The Dynamics of String Length

At first glance, it would seem impossible for the length of the freely vibrating string to change. However, the length which governs the resonant frequency of a vibrating string is not the measured length between its points of tethering, but the distance between the nodes, the points where the string is motionless. If the string is tethered between rigid objects, these ends define the nodes of the fundamental, but this is not the case in a piano. In fact, the whole idea of vibrating a string is to get one of its tethering points - the bridge on the soundboard - vibrating as well. If the bridge moves up and down out of phase with the string, the point on the string which is actually standing still is some distance in from the end, and the string "thinks" it's shorter. When the vibrations are in phase, the node point moves past the bridge and the string acts longer (the node is actually a virtual one, having only theoretical existence). A struck string gradually imparts its motion to the bridge, and the bridge imparts motion to the struck string and to all other undamped strings attached to it. This is the basis for one of the most distinctive characteristics of the piano, its attack and decay curve of loudness. When this is interfered with (e.g. loose bridge or lack of bearing), the instrument ceases to sing. The interested reader is directed to an excellent discussion of the interactions among strings and the bridge by Gabriel Weinreich ("The Coupled Motions of Piano Strings," *Scientific American,* January, 1979, pp. 118-127).

How can the tuner have any effect on this physical process? Consider what happens when tuning two strings of a unison. If the tuning hammer is brought slowly and smoothly through the point of consonance, one would expect to hear a gradual decrease followed by a gradual increase in the beat rate. If you perform the experiment, you will discover that the beating disappears abruptly at about one beat per second flat and reappears as abruptly at one beat per second sharp. No matter how smoothly you adjust the tuning hammer, it is always the same. However, if you estimate about where you would have expected a 0.5 beat per second rate and restrike the strings, you will hear such a rate, but only for about two cycles (four seconds), whereupon it dies out even though the loudness of the strings should still be perfectly adequate to hear these beats. What is happening? The two strings are trying to move the same bridge, but they do not agree about the rate. It takes 4-6 seconds for the bridge movement to come to equilibrium, during which time the "prompt sound" brilliance of the attack gives way to the "after sound" sustained singing. If the strings are individually tuned to pitches differing by less than about one cycle per second, the induced movement of the bridge will be such as to "lengthen" the string which is too sharp and "shorten" the string which is too flat, and they will both then be vibrating at precisely the same frequency.

The fact that they are both somewhat out of phase with the bridge motion causes a constructive interaction which sustains the after-sound period much longer than would occur if their motion was in phase. The quality of the tone changes significantly if the two strings are tuned perfectly consonantly, which can be done only by repeatedly striking the note to listen to the very low beat rates which appear only during the prompt sound phase (highter harmonics will, of course, beat faster). Many tuners will repeatedly strike a note after tuning it "consonant" during the after sound period. Small adjustments of the hammer (on the order of setting the pin) give rise to quite noticeable changes in the timbre of the prompt sound tone, particularly in the treble, even though the note continues to be "in tune." In fact, if one very carefully tunes a piano so that there is complete beatless consonance in each unison during both attack and sustained tone phases, the effect is very lifeless indeed. Of course, the piano is unlikely to stay this precisely in tune for long, particularly if played loudly as we are wont to do after finishing a job to "show it off." Still, there may be more than untutored criticism at work when a client tells you that his newly tuned piano sounds "dull."

I have devised a method to systematically exploit dissonance in the trichords, which I find can have remarkable effects on the "voice" of a piano, an aspect more usually associated with hammer felt. First, complete the tuning of all the center strings of each trichord, including octaves around the pattern scale and their sharpening up as previously discussed. Then tune the left strings (the una corda string in the grand) just under one beat per second sharp. The precise amount is more easily determined than one might think, since you can pull the string sharp to the point where after sound beats reappear, and then "set the pin" to the point where these beats disappear and only the prompt sound beats are present. (The una corda string is selected for this treatment since, with this pedal depressed, it normally vibrates sympathetically with the two struck strings, which are likely to be somewhat sharpened by the force of the blow.) The right string of the trichord presents an interesting dilemma which I prefer to think of as an opportunity. I have found that by adjusting it within the range defined by the first two strings, one can significantly influence the tone quality of both the prompt and after sound phases. This is probably because slight inequalities always exist in the string bearing, hammer contact, and even elasticity through the effects of time, wear, and corrosion. With careful listening during those repeated key strikes while you're setting the pin, you can even out the harsh notes and enliven the dull ones considerably.

At this point, I again solicit the readers' experience. What are you listening for when you make these final adjustments to each string? What order do you tune in and why? What distinguishes the tuning job of a master from an apprentice? Do you take any special pains when tuning a piano prior to voicing the hammers?

The ability of even the untrained human ear to detect effects as subtle as the above puts a great burden on the ears and hands of the master tuner. The physical origins of these effects are second and third order processes which we can barely measure, much less model and fully understand. On the one hand, the tuner can hope that years of training and subjective experience will, by trial and error, lead him to a strategy for tuning which satisfies his most discerning clients. On the other, he can try to use available physical theory to devise strategies which guarantee that his appreciation of the state of tuning of an instrument is at least better than his clients'. The evolution of the beat systems for setting the pattern scale and the advent of succesful electronic instruments to aid tuners are testimony to the power of objectively understanding the basis of the subjective experience we seek.□

In Memory

HENRY F. MacCONAGHY died June 3, 1981 in San Diego of a lung infection. Born in Philadelphia, he went to San Diego in 1920 and trained with the well-known craftsman, Rene Pupois. He joined the Guild as a craftsman member in 1959.

He served the San Diego chapter as president and came to the executive board in 1965. He was also local chairman of the annual convention held in San Diego. His many awards include Man of Note and the Hall of Fame (1977). In writing for the Hall of Fame book in 1976, past president Erwin Otto said, "Henry MacConaghy, a never failing, devoted Piano Technicians Guild member and friend, office holder, teacher and champion of the blind. Henry, your efforts for the sightless will always be an example and be remembered by all members . . ."

(Information contributed by Jess C. Cunningham)