The Science of the Piano Tone

A Paper on Gabriel Weinreich's Coupled Piano Strings (1977)

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Introductions to the Piano and its Tone

During the 18th century, Bartolomeo Cristofori invented the "*Arpicembalo del piano e forte*", which is roughly translated as harp-harpsichord with soft and loud [1]. This new musical instrument, unlike the harpsichord and similar instruments at the time, allows for the variance in the loudness of the tone. Despite the coupling of piano strings, where a group of strings can be hit by a single hammer, being a feature since the earliest piano, its effect on the quality of the piano tone has not been studied much. Only until a few years before the publication of Weinreich's research in 1977 was there an observed relationship between the two [2].

To study the relationship between the coupling of piano strings and the quality of the piano tone, Weinreich [2][3] divided the piano tone into two parts: the initial attack, or the prompt sound, with a higher rate of decay, and the sustained part, or the aftersound, with a slower rate of decay (Figure 1). The decay of the prompt sound, which provides the loudness of the piano tone, is related to the theoretical decay rate that is computed through the strings' coupling to the soundboard. The aftersound, which provides the piano tone its sustaining sound, represents the mystery that is the subject of Weinreich's research. The research aimed to understand where the sustaining sound came from to be able to suggest improvements that can improve the piano tone.

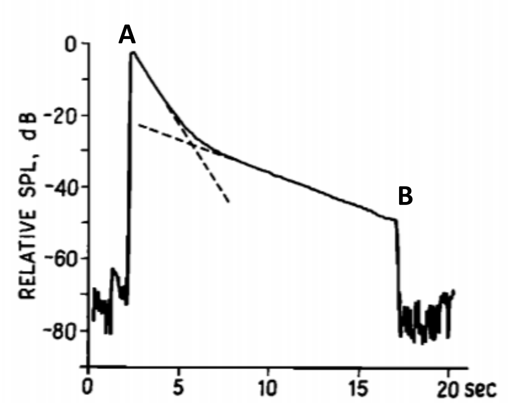

Figure 1. The decay rate of the piano tone. Each line in the vertical scale, representing sound pressure level, measures 10 decibels. The steeper part of the graph between A and B is the prompt sound while the less steep part between A and B is the aftersound. Figure reproduced and adapted without permission from [2]

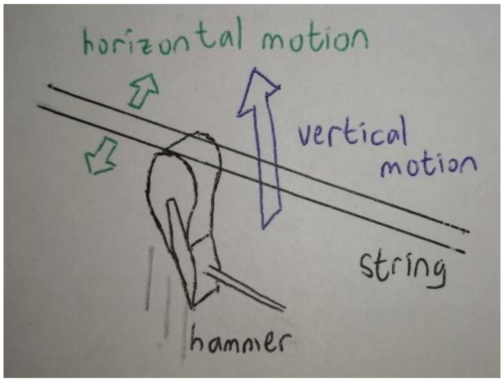

Figure 2. The hammer strikes the strings vertically. The horizontal motion could be caused by the positioning of the strings or the imperfections in the hammer's face. Figure adapted from [3].

Aftersounds in a Single String (First Mechanism)

In a single string, the sudden change of the rate of decay in the piano tone can be attributed to the existence of both vertical (perpendicular to the soundboard) and horizontal (parallel to the soundboard) motions in the string (Figure 2). Although the hammer strikes the string vertically, irregularities in the hammer's face or the position of the string cause the string to have some horizontal motions as well. The vertical motion that resulted from the hammer's hit decays faster compared to the horizontal motion, so at some time the horizontal motion will dominate over the vertical motion [3].

This difference in the rate of decay for the horizontal and vertical motions occur because of the ways in which energy is lost, through heat inside the string, to the motion of the air or through the string's supports. Energy is more commonly lost through the supports [3]. One end of the string is attached to a rigid frame, while the other end is attached to the wooden bridge that is glued to the soundboard (Figure 3). Unlike the frame, the bridge is not completely rigid as its function is to let the soundboard vibrate together with the string. According to Weinreich [3], it

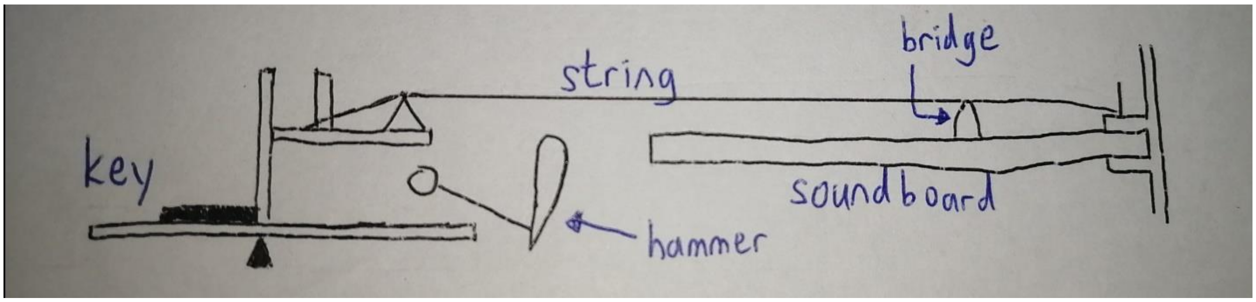

Figure 3. A simplified schematic diagram of the interior of a piano. The parts left unlabeled are unnecessary for the understanding of this paper. Figure adapted from [1].

turns out that the vertical motion of the soundboard has the greater ability to “give,” or accept vertical motion, than horizontal motion [3]. Thus, the vertical motion of the string transfers vibrational energy to the vertical motion of the soundboard more easily than horizontal motion from string to soundboard.

In the above case, vertical motion gives rise to the prompt sound and the horizontal motion gives rise to the aftersound (Figure 2). This means that the aftersound can be heard even if a piano only has a single string per note.

In addition, the tripling and pairing of strings also contributes to the aftersound. When one string vibrates, the bridge also vibrates and transmits the vibrational energy to the other strings. In some prior experiments, it was shown that the rate of decay of the vertical displacement of one of the coupled strings is characteristic of the rate for the aftersound [3]. This showed that uncoupled horizontal motion and coupled vertical motion can both contribute to the aftersound.

The Coupling of Piano Strings (Second Mechanism)

For the second mechanism, consider two strings that are coupled. When the strings are hit, minor imperfections in the hammer will result to different amplitudes, so the motions of the two strings will neither be exactly similar (symmetric) nor exactly opposed (antisymmetric). With imperfections in the face of the hammer, one of the strings will have a higher amplitude than the other at the start. Let the string with higher amplitude be string 1 and the string with less amplitude be string 2. At this point, the amplitudes of the two strings are symmetric to each other (Figure 4).

Eventually, string 2 approaches zero amplitude first. However, the bridge will continue moving because string 1 forces it to move. This is due to string 1 transmitting some of its

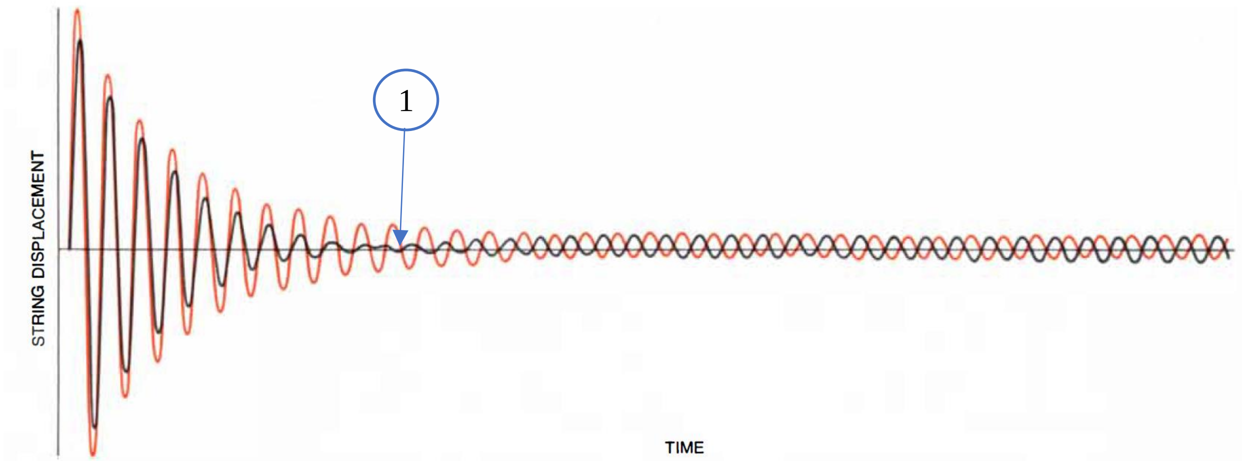

Figure 4. The amplitude of waves from the motions of string 1 (orange) and string two (black). At point 1 the amplitude of string 2 goes to zero but eventually goes beyond zero. Before point 1, the waves were mostly symmetric while after point 1, the waves become antisymmetric. Figure reproduced and adapted without permission from [3].

vibrational energy to the bridge. As the two strings are coupled, this will make string 2 continue moving and go beyond zero amplitude and start vibrations in opposite phase with the first string, resulting in the antisymmetric motion of the strings (Figure 4). If the waves are moving in the opposite phase, the signs of the amplitudes are opposite, so the net forces on the bridge will cancel out, reducing the decay rate. But if the waves are moving in similar phase, the signs of the amplitudes are the same, so the net forces on the bridge increase. The decay rate will also increase. With this, the symmetric waves make up the prompt sound and the antisymmetric waves make up the aftersound.

The better understanding on piano tones made by Weinreich's research through the discovery of the sources of the aftersound will help piano tuners better understand the properties of the piano tone and do necessary improvements to make the quality of the piano tone better. In addition, the research will help acoustical physicists in understanding more about the nature of the piano and allow for more suggestions on the building of a better piano.

References

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