The Physics of the Piano

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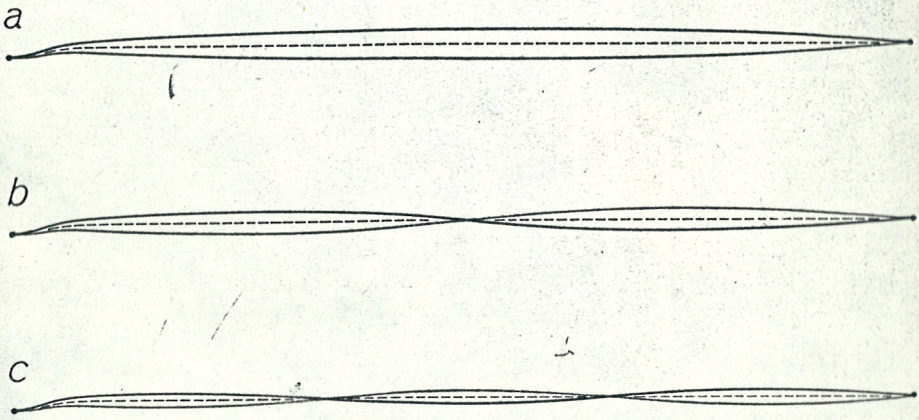
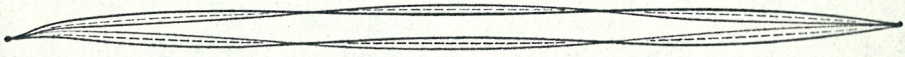
Vail 1965 Scientific American 216/6, Dec. S. 88-96+99 (XEROX)

Almost every musical tone, whether it is produced by a vibrating string, a vibrating column of air or any other vibrating system, consists of a fundamental tone and a number of the higher-pitched but generally fainter tones known as partial tones or overtones. The complex sound produced by this combination of separate tones has a timbre, or characteristic quality, that is determined largely by the number of partial tones and their relative loudness. It is timbre that enables one to distinguish between two musical tones that have the same pitch and the same loudness but are produced by two different musical instruments. A pure tone—one that consists solely of the fundamental tone—is rarely heard in music.

It is widely believed that the partial tones produced by all musical instruments are harmonic—that their frequencies are exact whole-number multiples of the frequency of a fundamental tone. This certainly holds true for all the woodwinds and under certain conditions for many of the stringed instruments, including the violin. It is only approximately true, however, in the most familiar stringed instrument: the piano. The higher the frequency of the partial tones of any note on the piano, the more they depart from a simple harmonic series. In our laboratory at Brig-



IDEAL STRING, that is, one without any stiffness, can be made to vibrate at many different frequencies: the fundamental frequency (*a*) produces a pure tone, rarely heard in music, whereas higher-pitched partial tones, or overtones, are produced by harmonic vibrations (*"b" and "c"*), whose frequencies are whole-number multiples of the fundamental frequency.



SIMULTANEOUS VIBRATION of a string at two or more different frequencies is normal for stringed instruments. Here the string vibrates at the fundamental frequency and the second partial frequency (*"a" and "c" in upper illustration*). In the piano the stiffness of the strings causes higher partials of a complex tone to depart from the simple harmonic series.

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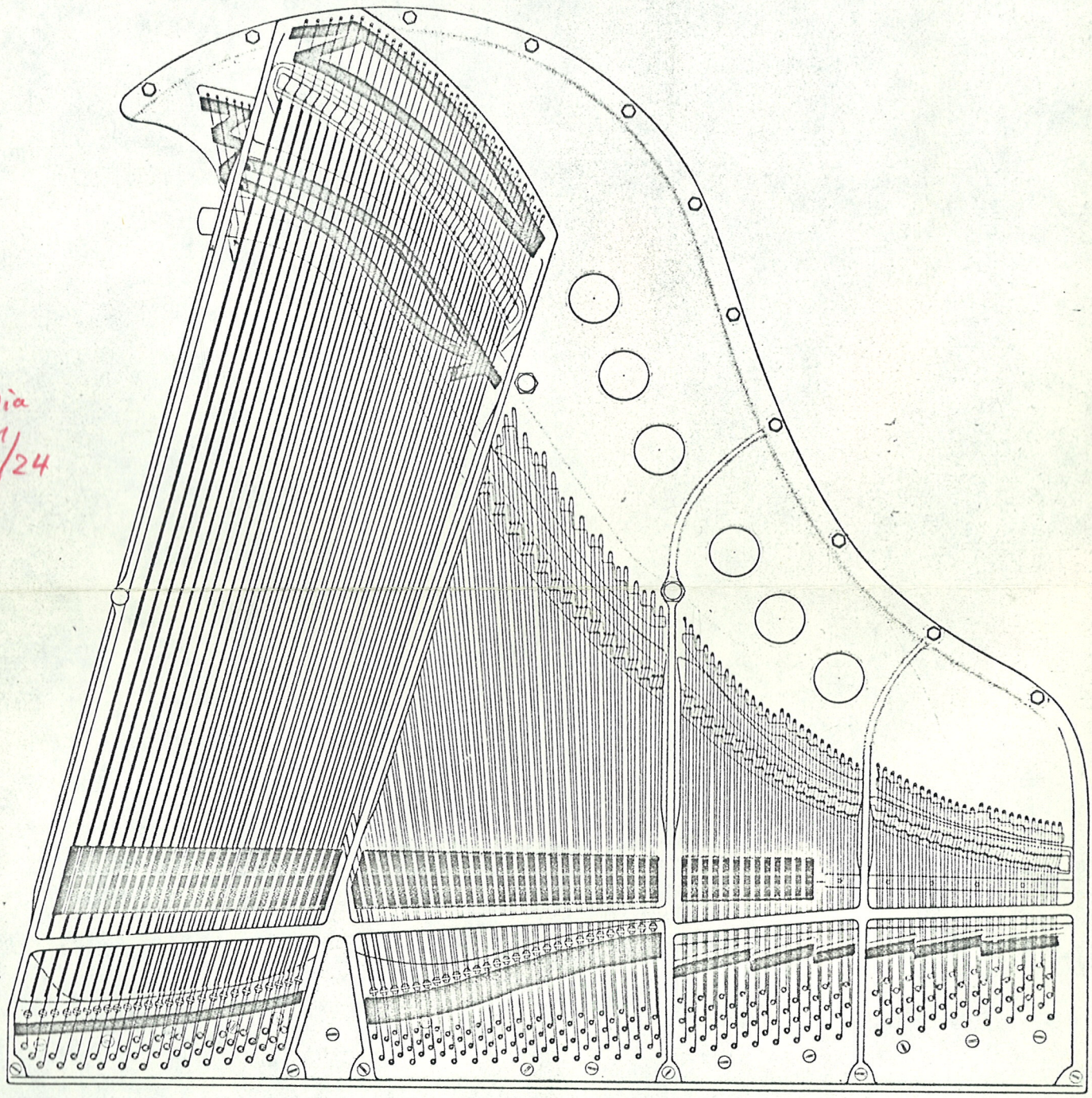
in which the valves admitting air to the pipes were controlled by pivoted keys that were returned to their original position by springs.

We do not know who first conceived the idea of adding keys to a stringed instrument. From this obscure beginning there eventually evolved in the 15th century the clavichord. In the early clavichords a piece of metal mounted vertically at the end of the key acted both as a bridge for determining the pitch of the string and as a percussive device for producing the tone [*see upper illustration on page 92*]. Since one string could be used to produce more than one tone, there were usually more keys than strings. A strip of cloth was interlaced among the strings at one end in order to damp the unwanted tone from the shorter part of the string.



TOP VIEW of the interior of a modern "baby grand" piano shows the powerful construction of the full cast-iron frame, which sustains the tremendous tension exerted by the strings. In this particular piano the frame, which is cast in one piece, weighs about 250 pounds and sustains an average tension of some 50,000 pounds; in a larger concert-grand piano the frame weighs as much as 400 pounds and sustains an average tension of 60,000 pounds. The strings are made of steel wire with an ultimate tensile strength of from 300,000 to 400,000 pounds per square inch. In order to make the bass strings (*left*) vibrate slower and thus produce a lower pitch, they are wrapped in copper or iron wire; two such wrappings are often used in the extreme bass. In all modern pianos the bass strings are "overstrung" in order to conserve space and to bring them more nearly over the center of the soundboard. Starting from the treble, or right-hand, end of the keyboard there are 60 notes with three strings each, then 18 notes with two strings each and finally, in the extreme bass, 10 notes with only one string each. Larger pianos have more strings but the same total number of notes: 88. Rectangular black objects in a row near the bottom are the heads of the dampers. Parts made of felt are in color. Strips of cloth interlaced among the strings at top damp unwanted tones from the short parts of the strings beyond the bridge (*see illustration on next page*).