Measurements and analyses on the driving point characteristics of the piano bridge and the two-dimensional vibration of single strings

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Abstract

The typical decay of a piano tone has two different rates corresponding to prompt– and after–sound. One reason in case of single strings is energy exchange between vertical and horizontal vibration. It is clarified here by measuring that this energy exchange happens mainly at hitch pin on the piano bridge.

1. Introduction

It is well known, that the typical decay of a piano tone has two different rates corresponding to prompt– and after–sound. It is mainly related to the coupling vibration between strings in the same choir[1], where the influence of soundboard impedance have to be taken into consideration. Nakamura had reported, how the soundboard impedance influences on the string vibration[2][3]. On the other hand, one reason in case of single strings is energy exchange between vertical and horizontal vibration[1]. Iwaoka and Nakamura had simulated this energy exchange at hitch pin and indicated, that it can cause the prompt- and after-sound [4]. Tanaka, et al. had reported that the single string starts rotate as a result of two-dimensional vibration [5]. It is clarified here by measuring, that this energy exchange between both directions happens mainly at hitch pin on the piano bridge. It is also discussed here, how this energy exchange happens.

The vertical vibration is excited by a hammer attack, and the traveling wave front arrives at the hitch pin, where the horizontal vibration occurs. This mechanism can be observed by measuring the string displacement and velocities in both directions. The bridge velocity and the mechanical impedance were simultaneously also investigated at the position corresponding to the struck string.

2. Experiment

The experiment was carried out through two equipments. They are complementary to each other. The former experiment clarifies the qualitative mechanism. A photonic displacement sensor (MTI KD-245) was set toward the E1 string of a concert grand piano, while an accelerometer (B&K 4500A) and a mechanical impedance head (B&K 8001) were installed on the bridge corresponding to the note. The photonic probe was used for observing the vertical and horizontal vibration separately, and the accelerometer was used for investigating the influence of soundboard on the vibration, and also for synchronizing. The impedance head shows the soundboard characteristics. The E1 string has the speaking length of 1910 mm, and the observing point by the photonic sensor is in 247 mm distance from the bridge. This measuring point was chosen according to the hammer location, i.e., the hammer strikes the string at the symmetrical point from the other end. This experiment shows, how the energy exchange of string vibration occurs between vertical and horizontal directions. The installed photonic sensor has a very narrow substantial dynamic range, where the signal keeps its linearity. In spite of this weakness, it is completely able to clarify the qualitative mechanism, namely when and how the energy exchange occurs between both directions at the hitch pin, and how the mechanical impedance influences simultaneously on the vibration.

On the other hand, the latter experiment shows the quantitative relation. Two accelerometers (B&K 4374) were mutually stuck with each other, as shown in the Figure 1, and set on the thin sheet phosphor bronze, which is fixed on the string, while another accelerometer was set on the bridge corresponding to the struck string. The observing point is the same as that of the former experiment. The outputs of two accelerometers on the string are subtracted, so that the vibration of a fixed direction can be observed; It shows the vibration of the direction shown by the arrow, where any other noises are canceled. This small trick is absolutely necessary, because the accelerometers are so sensitive, that they record otherwise excessive information such as that of the rotation movement of themselves. These signals are integrated and recorded as velocity. This experiment shows the quantitative result, namely when and how much energy is transferred from the vertical vibration to the horizontal. It is true that these small accelerometers (0.65g each) may influence the physical behavior of the string, but this experiment can show the ratio of the energy exchange.

Figure 2(a) shows the bridge velocity corresponding to the former experiment, where the vertical wave of a string and its reflected wave are superimposed, and this...
doubled force drives the soundboard [2][3]. This forced vibration as input and the free vibration of soundboard, which is influenced by the driving point impedance, are seen in Figure 2(a): The first resonance of the soundboard, which has been estimated by the driving point characteristics, is about 76 Hz, while that of the string is about 41 Hz. Corresponding to these frequencies, we can see the small wave in Figure 2(a), whose wavelength is about a half of the main pulse cycle. This mechanism was explained in ref. [2][3] and this curve is similar enough to that simulation. Figure 2 (b) and (c) show the vertical and horizontal vibration of a piano tone as illustrated by displacement versus time, respectively. The wave front of vertical direction arrives at the measuring point about t=0.02s. This main impulse is not seen in the horizontal vibration, because the string is excited only toward the vertical direction. This traveling wave front reflects at the hitch pin and arrives at the measuring point about t=0.026s. The influence of the soundboard resonance by 76 Hz is not clearly seen in the waveform of the string, that is also well in agreement with the simulation of Nakamura[2]. At the same time the reflected wave front is also seen in the horizontal direction. This means, the horizontal vibration is mainly caused by the reflection at the hitch pin. It is worthy of notice, that the reflected impulse is one-sided; it is only seen in the positive area. As a result the string must start to rotate, that is agreed with reports of Tanaka et al. [5]. Figure 2(d) and (e) show the vertical and horizontal vibration of a piano tone as illustrated by velocity versus time, respectively. They are the results from the latter experiment and show the quantitative relation. Before the arrival of major impulse, we can see some small wavelets, which are caused by the dispersion due to the elasticity of the string. The amplitude of the horizontal reflected wave is approximately 1/10 of the vertical input amplitude. From this result, it can be considered that the transform ratio of reflection is 5:1, because the observed wave consists of the direct component and the component reflected by the bridge; The ratio of input impulse, the vertical reflection and the horizontal reflection is 5:4:1. This is well in agreement with the simulation in ref. [4].

4. Conclusions

It is clarified here by measuring, that the energy exchange between vertical and horizontal vibration mainly occurs at the hitch pin. The vertical vibration is excited by a hammer attack, and the traveling wave front reflects at the hitch pin, where the horizontal vibration occurs. It is also clarified that the reflection ratio is approximately 5:1. The influence of the soundboard impedance was also observed in bridge vibration.

Figure 2. The string and bridge vibration
(a) bridge velocity, (b) vertical string displacement, (c) horizontal string displacement, (d) vertical string velocity, and (e) horizontal string velocity.

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5. References