Modelling of Chirping Sound on Steel Ball Collision

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1. Introduction

In many games and computer generated motion films, the collisions of hard materials are quite usual. At the moment of every collision the software should generate sounds to improve the sense of realism. To synthesize the sound on computer simulated environments, we need a theoretical model with variable parameters.

Research on the vibration and sound of collision is not new. Nishimura and Takahashi investigated the mechanism of how the colliding sound is produced, then carried out experiments with balls of diverse diameters[1]. Endo, et al. analysed sound radiation on collision of cylindrical objects[2]. Mascarenhas, et al. investigated the collision of rods with square and circular cross sections[3]. Mehraby, et al. found that when the hard steel balls collide, 1.1 percent of the impact energy is stored in the spheres as vibrational energy and the vibrations do not have any role in creation of audible sound[4].

While most of the previous researches have focused on the usual impact sound of collision, this paper looks into the unusual "chirping" sound. The chirping sound is generated when two hard steel balls, or similar, are brought into contact with each other. In this paper we understand and define the chirping by first building a simple theoretical model of collision then conducting experiments to better understand the model. These two steps would demonstrate that our research can explain the mechanism and nature of the chirping sound.

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2. The Chirping Sound

To define the chirping sound, basic experiments were conducted. Through them, it was possible to examine the mechanism of how the chirping sound is produced. After various collision experiments, we found that the vertical collision, where the lower steel ball is on an elastic surface or spring, always produces the chirping sound. Though, the chirping sound is clearly different from the normal impact sound to human ears, we recorded the collision sound for later analysis. Figure 1 shows the sound wave with chirping sound. As shown in Figure 1, the chirping sound can be defined as the sound generated by repeated collision of two steel balls or any hard materials, where the interval of the collision is steadily decreasing.
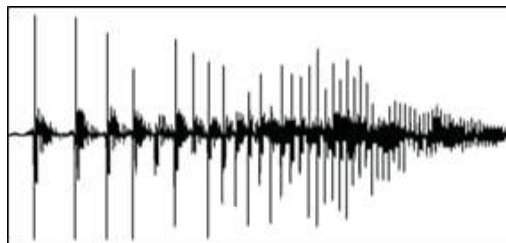

Figure 1. The chirping sound wave

3. Theoretical Model of Chirping Sound

A chirping is a series of the same collision wave pattern. Thus, we decided to focus on the intervals of the pattern, not the individual collisions. Figure 2 describes our model of vertical collision. We assumed a lower ball is on a spring with infinite spring constant, i.e., $k = \infty$. And the upper ball is falling down to the lower ball from the initial height of H. After colliding

at the speed of V, it bounds up at speed of v up to h, where e is coefficient of restitution. In the lower box in Figure 2, the three vertical bars describe simplified sound waves generated by three collisions.
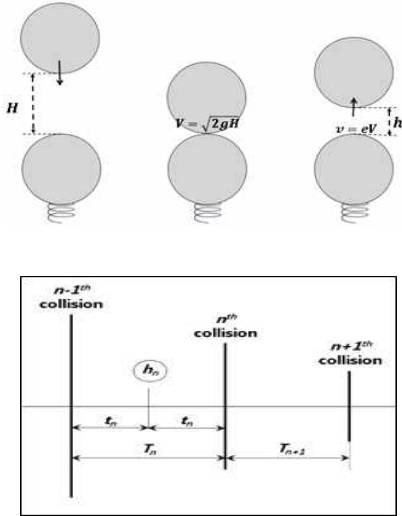

Figure 2. Vertical Collision Model

The interval of nth chirping collision, T_n equals $2t_n$, where t_n is an one-way travel time to the highest position h_n of upper ball before nth chirping collision. Because the ball speed v_n at n^{th} collision is,

$$v_n = e \cdot v_{n-1} = e^n \cdot v_0 = e^n \cdot \sqrt{2gH},$$

and $v_n = gt_n$, the interval T_n is defined as

$$T_n = \frac{2 \cdot e^n \sqrt{2gH}}{g} \qquad (1)$$

Our theoretical model, equation (1), defining the chirping interval only depends on the coefficient of restitution of the colliding objects and the initial height, but has no relation with other factors, such as the mass of colliding objects. We verified the model with experiments with different parameters.

4. Conclusion

The chirping sound is an unusual audible sound when two steel balls are brought into collision. Chirping sound is generated by series of collision. In this paper, through various experiments, we defined the chirping sound and build a theoretical model for it. To verify our model, we conducted colliding experiment with different parameters. The larger coefficient of restitution of the colliding material has, and the higher the initial colliding velocity is, the longer chirping is. Long chirping is more audible to human ears. The mass of colliding objects does not affect the intervals of repeated collision.

Our model and experiments have some limitation. We assumed the spring constant of the base material as an infinite value. In real vertical colliding situation, lower ball moves up and down, and this phenomenon would complicate the theoretical model. We leave it as a further research to model more realistic collision.

Reference

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