Journal of Physics Special Topics
An undergraduate physics journal

A1_4 The Sustain of a Chambered Electric Guitar

Y. Davis, N. Drewes, T. Lomax, S. Norman

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 8, 2020

Abstract

In this paper we expand our model for the sustain of a solid body electric guitar to include the effect of chambering of the body. Here, we consider the energy loss due to the air vibrations in the chambers and find that for the high E string, the sustain decreases from 0.64 s to 0.54 s as the body is chambered. However, this is mainly due to the reduction of the body mass.

Introduction

In our last paper we considered the impact of the body vibration on the sustain of a guitar [1]. However, a large number of solid body guitars are not truly solid — they have chambers inside of them to reduce the weight of the guitar. Therefore, we want to investigate the impact of the energy loss due to the air movement inside these chambers on the sustain. Here, we will examine an idealised rectangular shaped version of the Gretsch Jet Firebird, as played by AC/DC's late Malcolm Young.

Theory

Following from the solid body guitar, we will now consider the movement of air inside the closed chambered body. Here, we consider the air moving in a singular direction, driven by the wooden top face of the guitar body, such that the resonant frequency of the air chamber will be $\omega_{0,air} = c_s/2d$ where d is the depth of the body and c_s is the speed of sound in air. Ignoring the damping of the air, the equation of motion for the chamber is

$$\ddot{s} + \omega_{0,air}^2 s = (F_0/\rho_{air}V_{air})\cos\omega_0 t \qquad (1)$$

where s is the displacement of the air, F_0 is the driving force exerted by the body, and V_{air} is the volume of the chamber. As energy is simply force times distance, the driving force by the guitar body may be expressed as $F_0 = E_G/A_G$, where A_G is the amplitude of the body oscillations [1]. Using a solution of the form $s = A\cos\omega_0 t$, Eq. 1 can be solved as

$$s = s_0\cos\omega_0 t,\; s_0 = \frac{E_G/A_G}{\rho_{air}V_{air}(\omega_{0,air}^2 - \omega_0^2)}. \qquad (2)$$

The energy density η for a sound wave in air is

$$\eta = \frac{1}{2}\rho_{air}\omega_0^2 s_0^2. \qquad (3)$$

For the air chamber in the body, with a volume of V, the total energy E_{air} contained in the air oscillation is

$$E_{air} = \frac{E_G^2\omega_0^2}{2\rho_{air}V_{air}(\omega_{0,air}^2 - \omega_0^2)^2}A_G^{-2}. \qquad (4)$$

Results

To examine the impact of the air movement, we compile the model from our previous paper and the energy in the air vibration and compare the solid and chambered bodies [1]. As before, our algorithm is set up such that in each successive cycle the energy lost due to the body E_G and air movement E_{air} is subtracted, and the new amplitude is found. The sustain is 2τ, the time over which the amplitude drops by e^{-1}.

We again consider the high and low E strings, for which all constants can be found in our previous paper, except that we now use a scale length of 24.6” [1, 2]. For simplicity, we keep the same body resonant frequency ω_{0G} and damping constant b. The body dimensions have changed to a rectangular body of width $w = 28\,\mathrm{cm}$, height $h = 40\,\mathrm{cm}$, and depth $d = 5\,\mathrm{cm}$ [2]. The thickness of the walls in the chambered body are assumed to be $2\,\mathrm{cm}$ at the sides (Δh and Δw), and $0.5\,\mathrm{cm}$ for the plates (Δd). Jets have traditionally been made of mahogany with density $\rho_G = 600\,\mathrm{kg\,m^{-3}}$ [2, 3]. Therefore, the mass of the solid body model is simply $m_g = \rho_G wld$, while the mass of the chambered body is $m_g = \rho_G(wld - V_{air})$. The chamber volume is $V_{air} = (w - 2\Delta w)(h - 2\Delta h)(d - 2\Delta d)$. In air, $c_s = 343\,\mathrm{m\,s^{-1}}$, so $\omega_{0,air}/2\pi = 3430\,\mathrm{Hz}$ and $\rho_{air} = 1.23\,\mathrm{kg\,m^{-3}}$.

Fig. 1 shows the amplitude of the string oscillation as a function of time for the high and low E strings on the solid and chambered guitar respectively, with the black dashed line at e^{-1}. Since the low E vibrates at energies far removed from the the resonant frequency of the body, there is little difference, so we focus on the high E. Here, the sustain decreased from $2\tau = 0.64\,\mathrm{s}$ for the solid body to $2\tau = 0.54\,\mathrm{s}$ for the chambered build.

Conclusion

Chambering, a common practice in the building of solid body guitars, does have an effect of the sustain of the string. As seen in Fig. 1, there is just a difference of $0.1\,\mathrm{s}$ between the sustain of the two builds. The average person would probably not pick up on this since it is so small. Therefore, chambered guitars have the advantage of reduced weight without losing out on other typical characteristics. In fact, the de-

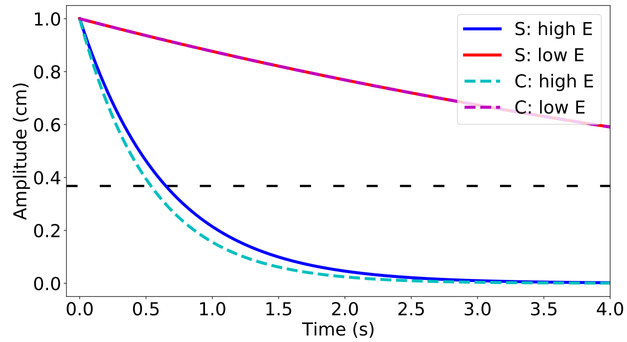

Figure 1: The amplitude of the high E (blue) and low E (red) strings as a function of time, for a solid (solid) and chambered (dashed) guitar. The black dashed line is at e^{-1}, where $A = A(2\tau)$.

crease in sustain is most likely not driven by the air movement but by the decrease in the mass of the guitar due to the existence of the air chamber. With a lower mass, the guitar body can vibrate more easily, and increase the energy lost from the string. In addition, we made a very basic assumption — that both models have the same resonant frequency. However, just due to the existence of the chambering in the body this will not be the case. In a more realistic situation, the two builds will have less sustain at different frequencies closer to their respective resonances. We have increased the complexity of our model of the sustain in electric guitars by adding the chambering typically found in ‘solid’ body guitars, and have shown that this decreases the sustain slightly.

References

[1] Y. Davis, N. Drewes, T. Lomax and S. Norman, *A1_3 Modelling the Sustain of an Electric Guitar*, PST 19, (2020).

[2] `https://www.andertons.co.uk/guitar-dept/electric-guitars/alternative-body-guitars-old/gretsch-g6131t-62-vintage-select-jet-firebird-with-case` [Accessed 17 November 2020].

[3] `https://www.engineeringtoolbox.com/wood-density-d_40.html` [Accessed 17 November 2020].