free electrons, since $\mathbf{F} = q\mathbf{E} = q\mathbf{v} \times \mathbf{B}$. Thus, in our situation here, the electric field in the metal is given by

$$\mathbf{E}(x,y,z,t) = \mathbf{F}(x,y,z,t)/q = \mathbf{u_y}\,(x,\,t) \times \mathbf{B}(x,y,z)$$

Note that the electric field, **E** is anti-parallel to the Lorentz force, **F** for $q = -e$. The current density, **J** is

$$\mathbf{J}(x,y,z,t) = \sigma\mathbf{E}(x,y,z,t) = \sigma\mathbf{F}(x,y,z,t)/q = \sigma\{\mathbf{u_y}\,(x,\,t) \times \mathbf{B}(x,y,z)\}$$

The macroscopic current $I = \mathbf{J} \cdot \mathbf{A_{string}}$, where $\mathbf{A_{string}} = \pi r^2_{\text{string}}\,\mathbf{n}$ = cross sectional area of the string, and **n** is a unit vector perpendicular to the cross sectional area of the string. This motionally-induced macroscopic current, arising from the Lorentz force acting on the free electrons in the metal of the vibrating strings of the guitar near the poles of the magnetic pickups of the guitar is in fact a type of Eddy current, I_{Eddy}!

Note that because of the nature of the cross product $\mathbf{v} \times \mathbf{B}$, in the Lorentz force equation, when **v** is *perpendicular* to **B**, this force is maximal. However, the Lorentz force *vanishes* when **v** and **B** are *parallel* (or anti-parallel) to each other. Thus, the magnitude of the Lorentz force $F = |\mathbf{F}| = q|\mathbf{v} \times \mathbf{B}| = qvB\sin\varphi$ where φ is the opening angle between **v** and **B**.

The amplitude of the Eddy current, $|I_{\text{Eddy}}|$ induced in the vibrating string of a guitar, for a pickup located at x_{pu}, is

$$|I_{Eddy}| = \sigma\omega\,|y_o|\,|\sin(kx)|\,B(z=h)A_{string} = 4\sigma\pi^2 r^2_{string}\,f\,|y_o|\,|\sin(kx_{pu})|\,B(z=h)$$

In the figure below, we show the magnitude of the Eddy current, $|I_{\text{Eddy}}|$ induced in each of the vibrating strings of a guitar, for open strings vibrating transversely in the plane of the strings, parallel to the body of the guitar, and perpendicular to the magnetic field(s) of the permanent magnets in the guitar pickups. As we have discussed in the 4th set of lecture notes on Fourier analysis, the neck pickup of an electric guitar is typically located at the *anti-node* of the 2nd harmonic, thus $x_{\text{pu}} = {}^5\!/_8 L_{\text{scale}}$. For steel strings on an electric guitar, steel has a conductivity, $\sigma = 1.1 \times 10^7\ \text{Ohm}^{-1}\ \text{m}^{-1}$. A typical magnetic field strength at the strings of a guitar, located ~ 4-5 mm above the poles of a guitar pickup is B(z = 4-5 mm) ~ 200 Gauss = 0.2 kilo-Gauss = 0.02 Tesla.