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Pulse speed on a plucked wire

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This paper serves to update an elegant experiment published in *The Physics Teacher* to measure the speed of a pulse on a taut metal wire.[1] Unfortunately, commercially available units[2] that serve the same purpose are priced outside the range of most high school or college physics teaching laboratories. Wakeland et al. show how an affordable adaptation of the traditional standing wave apparatus using taut metal wire and horseshoe magnets can be used to measure the speed of a pulse by using an oscilloscope to measure an induced voltage in the wire as the pulse transverses the middle of the magnets, which are a known distance apart.

We use a modified version of Wakeland et al.'s setup (see Fig. 1) that consists of a single horseshoe magnet and a laptop running a free oscilloscope software program[3] that uses the laptop's soundcard for data acquisition. The oscilloscope software is easy to use to set trigger levels and to move cursors to measure the time between when the pulse from the plucked wire first enters the middle of the horseshoe magnet and when the reflection from the tensioning pulley is received a known distance away. The speed of the pulse is calculated from the distance over time. We found this setup to be a much more affordable alternative to using expensive software and/or hardware. In our lab the connection between the soundcard's 1/8-in microphone jack and the stretched wire is facilitated by using a standard "F" jack to 1/8-in adapter coupled to a BNC to "F" jack adapter.[4] Finally, from the BNC jack we used inhouse BNC to minigrabber leads that clipped to the taut wire. We did not find that the weight of the electric contacts affected the results. Our horseshoe magnet has an average magnetic field of 0.34 mT at the location of the wire. We used plain steel guitar strings (GHS and D'Addario brand) obtained from a local music shop.

Results from the setup are displayed in Fig. 2 and Table I. Each data point in the graph represents an average of five plucks of the wire. Uncertainties in the tension and velocity are smaller than the symbols used to represent the data points. As noted by Wakeland et al., a too vigorous pluck increases the tension in the wire, thereby skewing the results. The theoretical speed for a wave or pulse on a taut wire is given by

$$v = \sqrt{T/\mu}\ , \qquad (1)$$

where T is the tension and μ is the mass per unit length of the wire.[5] We display and fit the data for each wire to the equation $T = \mu v^2$ for ease of display and analysis. Each wire-diameter is fitted to a straight line to determine the mass per unit length for each wire. This fitted value is then compared to a separately determined mass per unit length with uncertainty from measurements of the mass and length of each wire (see Table I). As can be seen the fitted mass per unit length falls within the uncertainty of the measured value. An additional check is to compute the mass of a 1-m long cylinder having the stated diameter and the density of steel, $\rho = 7850\ \text{kg/m}^3$. Excellent agreement with the fitted mass per unit length is achieved with this check.

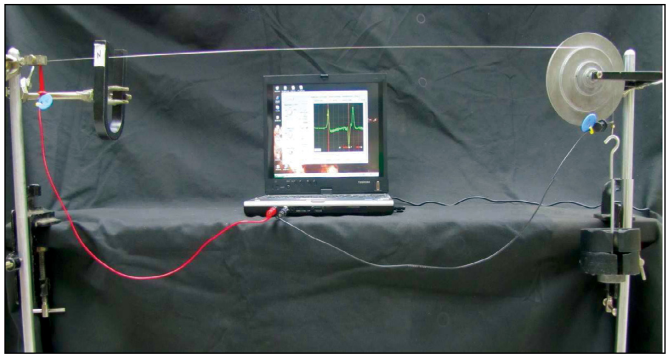

Fig. 1. Photograph of the experimental setup. The PC laptop is running a free oscilloscope software program[3] that utilizes the laptop's soundcard. Students can easily vary the distance between the horseshoe magnet and the tensioning pulley to note the effect on the time between received pulses.

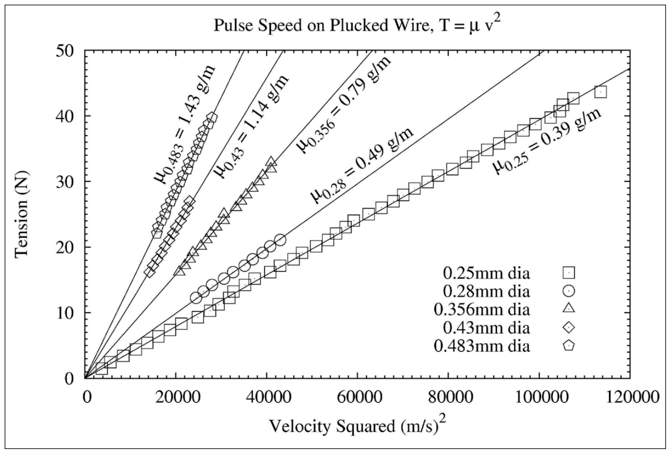

Fig. 2. This graph represents the experimental results obtained with the setup illustrated in Fig. 1. Each displayed data point represents an average of five plucks of the wire. The fitted lines through the data for each wire allowed a determination of the mass per unit length — noted for each wire diameter. These fitted values are compared to a static measurement of the same quantity in Table I.

References

1. Ray Scott Wakeland and Bennet Brabson, "Wave speed on a string revisited," *Phys. Teach.* **28**, 57–58 (Jan. 1990).
2. The PASCO sonometer model number WA-9611 and WA-

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Table I. This table lists the steel guitar wires we tested using the device illustrated in Fig. 1. Measured values of the wire mass and length were used to determine a mass per unit length for the wire with uncertainty. The speed of a pulse along a known length of the wire was measured for different wire diameters and tensions. These data were fitted in Fig. 2 to also determine the mass per unit length, which compares well with the static measurement.

Wire Diameter (mm)	Wire Mass ±0.005 (g)	Wire Length ±0.0005 (m)	Calculated μ (g/m)	Fitted μ (g/m)
0.25	0.400	1.030	0.39±0.05	0.39
0.28	0.500	1.030	0.49±0.05	0.49
0.356	0.785	1.000	0.79±0.05	0.79
0.43	1.200	1.075	1.12±0.05	1.14
0.483	1.415	1.000	1.42±0.05	1.43

9613; www.pasco.com. However, this device does have a clever tensioning apparatus.

3. www.zeitnitz.de/Christian/scope_en. This is a PC-based soundcard oscilloscope software program. Audacity (audacity.sourceforge.net/) could also be used to record the induced voltages along the wire.
4. We obtained the adapters at Radio Shack; www.radioshack.com. However, a 1/8-in mono plug soldered to wires terminating in mini alligator clips would also work. These parts are also available at Radio Shack or a similar electronics parts supply store.
5. R.D. Knight, *Physics for Scientists and Engineers,* 2nd ed. (Pearson Addison-Wesley, San Francisco, 2008), p. 613.

Fermi Questions

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Question 1: Google and Pac-Man

On the 30th anniversary of the introduction of the video game Pac-Man, Google created a miniature version of the game and placed it as its logo on its home page. How much total time was wasted in the United States playing this game?

(Thanks to Daniel Brill of Old Dominion University for suggesting the question.)

Question 2: Magnetic levitation

Animal tissue is diamagnetic. How large a magnetic field gradient is needed to levitate frogs or people?

Look for the answers online at tpt.aapt.org. Question suggestions are always welcome! For more Fermi questions and answers, see *Guesstimation: Solving the World's Problems on the Back of a Cocktail Napkin,* by Lawrence Weinstein and John Adam (Princeton University Press, 2008), available from AAPT.

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