First steps toward a drum-tuning device

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Abstract

Two designs for a drum tuner and a prototype of the first design are presented. Both designs were modeled after a commercial device called the DrumDial. Also, both devices rely upon the sensitivity of a UGN3503U Hall probe to transduce minute, difficult to measure deflection into easily measureable voltage. Though both designs were conceived, only the first design was physically realized as a working prototype. This prototype incorporates a stainless steel beam, which deflects when the device is placed on a drumhead. Magnets sit on top of the beam and changes in their position are noticed by the Hall sensor. During the course of research, deflection experiments revealed that a cantilevered beam supported a linear relationship between applied mass and deflection. Total displacement of the beam midpoint in these experiments varied from 1.33 mm to 9.96 mm. Other measurements and parameters obtained included the spring constant (889.315 $\frac{\mathrm{N}}{\mathrm{m}}$) and Volt-to-millimeter conversion factor ($\frac{8\mathrm{V}}{\mathrm{mm}}$) of the prototype. Though crude, the prototype proved effective and easy-to-use as a drum-tuning device.

Introduction & Background

The primary goal of this work was to design and then build two devices that measure local tension in a drumhead and identify musical notes associated with particular tensions. Such a device could allay the drum tuning[1] process and provide drummers with a means of producing audible pitch in their instruments.

Detecting pitch in one-dimensional (1-D)[2] instruments has been heavily studied and techniques for determining pitch are numerous [11]. However, pitch detection can be difficult—even sophisticated techniques will introduce transient and octave errors[3] [11, 12]. An octave error is one in which a detector measures one or two octaves above or below the actual pitch [12]. A transient error occurs when transient noise and distortions between consecutive notes muddle a measurement [11].

Typical detection algorithms rely primarily on some sort of autocorrelation technique [11, 13]. Autocorrelation involves estimating a signal's period by comparing the signal with itself at a different time [11]. The autocorrelation function is written as:

$$\rho(n) = \sum_{m=1}^{M} x(m)x(m+n), \qquad \text{(Eq. } \mathbf{1}\text{)}$$

where M is the period associated with the lowest expected fundamental frequency, $x(m)$ is a sampled signal, and n is the discrete time-lag variable (i.e., number of samples) [11]. A time-lag of zero yields the highest value and corresponds to the signal energy. The second peak corresponds to the signal period [11].

Unlike many 1-D instruments, the modes of a drum are significantly inharmonic. That is, they are *not* integer multiples of a fundamental [1, 5]. Each mode vibrates at a different frequency, making the process of detecting a drum's overall pitch rather complicated [1]. The spectrum must be decomposed into its component modes and the dominant mode selected out. The dominant mode frequency will contribute most to the drum's overall pitch. Typically, the (x, 1) modes are the largest contributors [5].

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[1] Tuning in the realm of drumming usually means creating uniform tension in the drumhead. Efforts will be made throughout this work in order to distinguish between tuning and tuning to pitch.

[2] For a discussion of 1-D systems, see Reference 14.

[3] Transient and octave errors are the two main causes of inaccuracy in pitch recognition [11].

Drum modes are calculated by solving the wave equation in two dimensions [3]. Solutions to the equation are Bessel functions of the first kind in the radial direction [3, 4]. Modes are described by two integers—m and n, which are written as (m, n). They give the number of nodal diameters and nodal concentric circles, respectively [4]. The general solution to the wave equation is:

$$u_n(r,\theta,t) = J_m(\kappa_{mn} r)[A_{mn}\sin(m\theta) + B_{mn}\cos(m\theta)]\,[\alpha_{mn}\sin(c\kappa_{mn}t) + \beta_{mn}\cos(c\kappa_{mn}t)], \quad m,n = 1,2,\ldots \qquad \text{(Eq. 2)}$$

or, written more compactly using the identity $\alpha\cos\varphi + \beta\sin\varphi = \sqrt{\alpha^2+\beta^2}\cos(\varphi+\varphi_0)$,

$$v_n(r,\theta,t) = J_m(\kappa_{mn} r)[\cos(m\theta)]\,[\cos(c\kappa_{mn}t)]. \qquad \text{(Eq. 3)}$$

Note that the angular and temporal phase shifts (i.e., the φ_0's) have been ignored [7]. The constant c is $\sqrt{T/\sigma}$, where T is tension per unit length in the membrane and σ is the mass density of the membrane [3, 7]. As can be seen, c has units of length per unit time (a.k.a speed). Each κ_{mn} is $\frac{z_{mn}}{a}$, where z_{mn} is the n^{th} positive zero of the m^{th} Bessel function $J_m(\kappa_{mn}r)$ and a is the radius of the membrane [3, 8[4]]. The polar angle is, of course, given by θ and the ordinary frequency is given by $c\frac{z_{mn}}{2\pi a}$. Simplified solutions[5] [6] are of the form:

$$u_n(r,t) = J_m(\kappa_{mn} r)\,\alpha_{mn}\sin(c\kappa_{mn}t), \quad m,n = 1,2,\ldots \qquad \text{(Eq. 4)}$$
$$v_n(r,t) = J_m(\kappa_{mn} r)\,\beta_{mn}\cos(c\kappa_{mn}t), \quad m,n = 1,2,\ldots \qquad \text{(Eq. 5)}$$

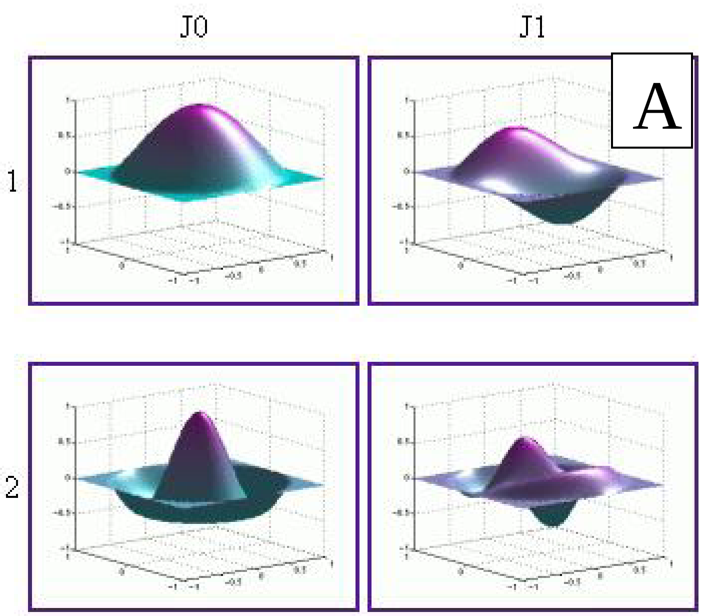


Figure 1: *Vibrational Modes.* The (1,1) mode 3D plot (**A**), for example, can be obtained by taking the J_1 curve from 0 to z_{11} and traversing θ through $\cos(\theta)$. Photo Source: [14].

All modes apart from the (0, 1) mode (fundamental) are doubly degenerate. Each set of indices, (m, n), has two orthogonal modes (spatial sine and cosine in Eq. **2** above), both of which have the same (angular) frequency $c\kappa_{mn}$. When the system is perturbed (e.g., when a lug is tightened), the degeneracy in the modes is lifted [4]. If the perturbation is significant enough, audible frequency splitting can be heard [4].

To prevent audible frequency splitting, drummers "tune" or "clear" their drumheads. This involves tightening the tension screws at each lug such that tapping the drumhead near these lugs produces a single pitch [4, 9, 10]. Drum manufacturers Pearl and dw suggest similar tuning methods, both of which involve tightening the tension rods in pairs [9, 10].

First, one rod is selected as the starting point and tightened using a drum key. Then, the rod diametrically

[4] There is a huge error in this source. The ordinary frequency is written as $2\pi\frac{a}{z_{mn}c}$. But this is the period!

[5] Assumptions were made in order to obtain these solutions. They are:

1. The membrane is fixed along its circumference (Dirichlet boundary condition).
2. The initial displacement is independent of polar angle θ.
3. Because the initial and boundary conditions have circular symmetry, the functions $u_n(r,t)$ and $v_n(r,t)$ are independent of θ.

opposed is tightened and the process repeats for another rod pair. All tension rods are turned the same number of times (e.g., two turns of the drum key) so as to minimize any difference in tension across the lugs. Once the head has been brought to a particular tension, smaller adjustments are often made. An implement (e.g., stick or finger) is used to strike the head in front of each lug. Then, the tension rods are tweaked in an iterative manner to make each tap at each lug sound the same. This iterative process is often tedious and time consuming. As a result, many drummers turn to tuners.

Prior Work

Numerous drum-tuning devices, such as the DrumDial, are commercially available. However, prices for these devices can cost over $150.00 and not one device was found that measures drumhead tension explicitly.

For the purposes of this work, only the DrumDial (DD) will be examined at length. The simple reason is that it is the basis for the tuner designs presented in the results section. But first, another commercial device—the Tune-Bot—will be briefly discussed since it accomplishes the goal of musical tuning.

There are multiple ways of tuning a drum to pitch using the Tune-Bot. The most basic method mimics the typical tuning procedure discussed previously. First, the device is mounted to the drum hoop and a lug is chosen as the starting point. The head near the lug is tapped and the pitch is displayed by the device. Adjustments are made to the lug until the desired pitch is obtained. Then, the lug diametrically opposed is tuned and the process carries on in the same way for the other lugs [15]. From what can be gathered on the Tune-Bot website, the device utilizes some rather sophisticated signal-processing techniques used in communication systems and sonar [15]. Also, novel algorithms were developed and incorporated using so-called micro-electronic technology [15].

In contrast, the DrumDial works by using a relatively simple spring-linear translation gauge system. When the DD is placed on a drumhead, a probe attached to a spring presses downward, deflecting the head. The probe appears to consist of an ~3.175-mm diameter ball bearing in a conical assembly, which is attached to the end of a linear translation gauge. The gauge sits on top of a weighted cylindrical base. Sticking out from the base center, the probe can be pressed inward such that its tip is flush with the bottom of the base. By some mechanism, the deflection of the probe is translated into a reading and displayed on the analog gauge in mils (thousandths of an inch). Select DD parameters can be found in **Table 1**.

The procedure for tuning a drum with the DD is similar to that of the Tune-Bot. First, the device is placed in front of a lug using a space-off bracket (as can be seen in **Figure 2**). This bracket ensures the probe of the device remains ~4.483 cm from the rim of the drum throughout the tuning process. Second, the tension rod of the selected lug is tuned to some particular reading based on the drummer's preferences. Third the rod diametrically opposed is tuned using the device and the process repeats for the different rod-pairs.

Figure 2: *Using an analog and digital DrumDial.* The DD is placed in front of each lug as shown. Tension rods are adjusted until a single reading is given at each lug. A bracket is used to keep the distance between rim and DD probe constant at ~4.483 cm. Source of photos: www.drumdial.com.

Having reviewed the basis for the tuner designs this work presents, their development can now be discussed.

Methods

Professor Steven Errede and Professor Emeritus Lee Holloway of the University of Illinois (Urbana-Champaign) were heavily consulted for design guidance. Given the limited time allotted to the project, the materials at hand, and the machining capabilities available, only two designs were pursued. However, multiple variations of the two designs were discussed and considered. Below, the investigations and information gathering process relevant to each design are presented.

Design 1 (D1):

A DD was placed on a digital scale and slowly lowered until a reading of "80" was obtained[6], which corresponds to a vertical deflection of 20 mils from the base of the DD. The "effective mass" of the probe was recorded. The tension associated with this deflection was then determined by multiplying the measured effective mass by g. Also, the spring constant of the DD was estimated using Hooke's law and the values obtained for deflection and effective mass.

The width of the contact area (a thin annulus) of the DD base weight was measured using a digital dial caliper. Also, the dimensions of stainless steel beams and a brass scrap were measured and recorded.

A stainless steel beam was situated across a brass scrap and fixed tightly at both ends. This scrap-beam system was clamped to a table using C-clamps and situated beneath the bottom of a digital dial caliper. The caliper, held by a vice, was adjusted until the stick-like part of the device, which extends from the bottom a given amount for different caliper readings, contacted the beam. The caliper reading was recorded. A total of 600 g was then suspended from the center of the beam using an insulated wire. Mass was added in 50-g increments. After each 50-g addition, the caliper was re-adjusted such that it contacted near the midpoint of the stressed beam. Each time the caliper was adjusted, its new reading was recorded. Direct contact with the center of the beam was restricted because of the load-bearing wire.

Other clamping methods were also tested. The two other clamping methods investigated involved fixing one beam end tightly or fixing one end tightly, the other loosely. Beams fixed at one end were adjusted such that the corners of the free end nearly coincided with the inner radius of the brass scrap. For the beam fixed at both ends, one tight, one loose, the brass scrap was arranged such that the beam was supported by the scrap. In the other clamping methods, each beam was supported by the bolts and washers holding the beam to the scrap. In all cases, mass was suspended from the beam such that the load-bearing wire dangled along the axis of the scrap.

The width of a cantilevered beam (one end fixed, the other free) was determined using Hooke's law. First, the force of the DD probe pressing down on the drumhead was calculated. Then this force was set equal to the beam spring constant multiplied by its deflection. In symbols:

$$F_{Hooke} = m_{Eff}(\mathrm{g}) = \frac{Ywt^3}{4d^3}(0.508\,\mathrm{E}-3), \qquad \text{(Eq. 6)}$$

[6] For a surface of "infinite tension" (e.g., a hard countertop) the DD gives a reading of "0."

where m_{Eff} is the effective mass of the probe when it is pressed into the DD 9.652 mm, g is the gravitational constant, Y is Young's modulus for steel, w is the width of the beam, t is the beam thickness (fixed at 0.508 mm), and d is the distance from the fixed end of the beam to the load or force (fixed at 25 mm). The number $0.508\ \mathrm{E}-3$ is simply the desired deflection of the beam and is in units of meters. This particular number was chosen because the tip of the DD probe is only about 20 mils ($0.508\ \mathrm{E}-3\ \mathrm{m}$) from the bottom of the DD base. The length d (distance from bending point to load) was fixed at 25 mm and the thickness t was fixed at 0.5 mm.

Parts for the device were milled by Professor Emeritus Lee Holloway. Once these parts were crafted, the device was assembled and tested. The beam was tested with both ends fixed (one loosely) and one end fixed (the other free). A two-channel digital storage oscilloscope was connected to the leads of a UGN3503U Hall probe[7]. The Hall probe sensitivity curve is provided by **Appendix A**. For device characteristics, the reader is referred to Reference 16.

A mylar head (by Remo) stretched over a tom tom drum (by Phattie) was used for testing. First, the device was placed on granite slab to obtain a reference voltage from the Hall probe. Second, the device was placed on the drumhead and the difference relative to the reference was recorded. Third, the drum was de-tuned by turning a tension rod a quarter turn. Finally, the drum was brought back into tune using the device. This was done by comparing voltage readings in front of the lugs, tweaking them until the voltage was the same.

To determine the voltage change per millimeter of deflection, the brass base of the D1 device was placed on stainless steel beams of three different thicknesses—0.254 mm, 0.508 mm, and 0.762 mm. While the device was supported by the stainless steel beams, the device probe remained in contact with a granite slab. All voltage readings were recorded.

Design 2 (D2):

A cylindrical piece of brass scrap metal was machined (by Holloway) to accommodate a cylindrical race bearing whose races were vertical (i.e., parallel to the axis). To hold the bearing in place, the brass was tapped and a set screw was put in place. A ½-inch thick aluminum rod was whittled down to ensure the rod could slide freely through the bearing.

Results

As stated previously, only two designs for the device were pursued. These designs were settled upon after discussions with Professor Errede and Professor Emeritus Lee Holloway. The first design (Design 1 or D1) consists of a brass disk, stainless steel beam, aluminum blocks and rods, magnets, and a Hall sensor. Design 2 (D2) consists of two brass disks, an aluminum rod, aluminum blocks, a race bearing, magnets, and Hall sensor. Schematics of these designs are provided by **Figures 3—5**, and **Figure 13**. Also, dimensions and other parameters of the DD and materials used for the tuner are provided by **Table 1**. Note that the "Prototype Tuner" is the prototype presented at the end of the Results section (**Figure 11**).

[7] Hall sensor and Hall probe are used interchangeably throughout this work.

Design 1:

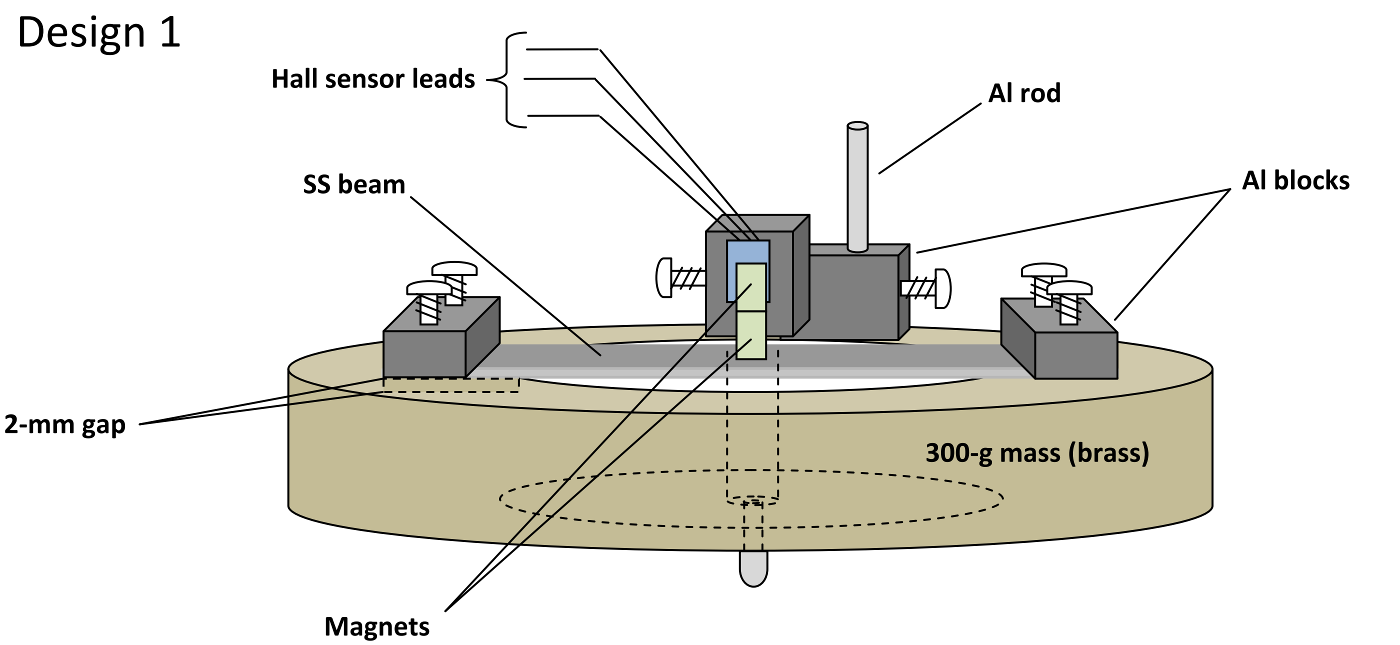
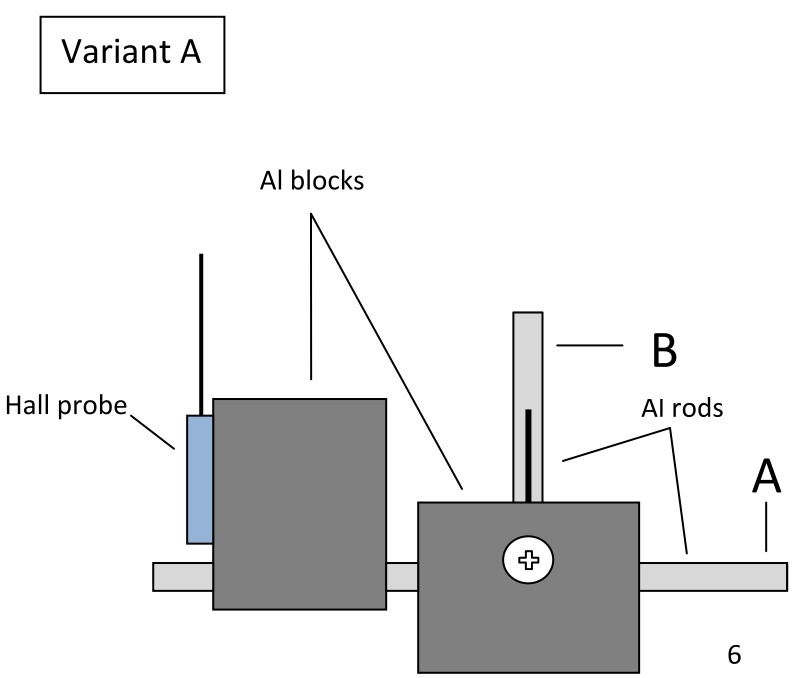


Figure 3: *Drum tuner, Design 1.* The stainless steel (SS) beam is flush with the bottom surface of the Al blocks and supported by the disc at one end. This end is held tight while the other end is free to move within a 2-mm gap. The idea is that when the device is placed on a surface, the beam is supported by the Al blocks but allowed to pivot on the block edge at one end. Since one end is not held flush with one of the Al blocks, the overall stiffness in the beam is reduced. The primary goal of this design was to minimize friction.



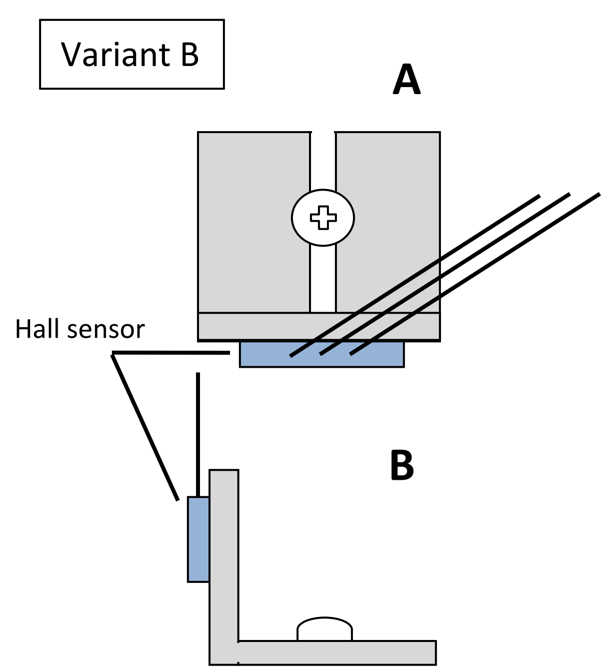


Figure 4: *Profile of Hall sensor adjustment mechanism from Design 1.* A horizontal translator (**A**) was implemented in order to vary the sensitivity of the Hall probe. A vertical translator (**B**) allows for

Figure 4: *L iron Hall adjustment mechanism.* This variant offers translation to and away from the magnets. A slit-screw system as seen in **A** can be created to translate the Hall probe

When the D1 device is placed on a drumhead, the probe protruding from the bottom presses downward, distorting the head. The probe is attached to the midpoint of the stainless steel beam fixed at both ends (one end loose, the other tight). Consequently, as the probe is pressed, the beam deflects until the restoring force in the beam equates to the force upward from the drumhead. Atop the beam is a dipole magnet, which is composed of two smaller dipole magnets. This dipole is situated in front of a Hall sensor that is fixed to the non-moving components of the device (i.e., the wall of the cylindrical scrap). Displacing the dipole produces a shift in the magnetic field as measured by the Hall sensor, which outputs a so-called Hall voltage to a voltmeter or circuit. By examining the Hall voltage produced directly in front of each lug, the drumhead can quickly and easily be cleared. This is done by simply adjusting the tension rods until a singular Hall voltage is read at each lug.

Table 1

Prototype Tuner	**DD**	**Brass test scrap**	**Stainless Steel Beams 1 & 2**
Diameter: 5.08 cm	Mass: ~605 g	Outer lip diameter (R1): 57.82 mm	Width: 2.12 mm
Total Mass: ~305 g	Diameter of base: ~5.08 cm	Inner lip diameter (R2): 46.32 mm	Length: 59.16 mm
Mass of brass disc: 300 g	Spring constant: 304.6 $\frac{N}{m}$	(R1 – R2): 5.81 mm	Thickness: 0.52 mm
Distance from disc bottom to probe tip: ~1.07 mm	Diameter as measured from inner edge of contact area: 4.57 cm	Lip height: 6.54 mm	Calculated width: 3.4 mm
Height of L iron: ~3.5 cm	Diameter as measured from outer edge of contact area: 4.78 cm	Total height: 12.72 mm	Spring constant (with calculated width): 1426.26 $\frac{N}{m}$
Height of brass disc: ~3 cm	Mean contact area diameter: 4.67 cm	Hole diameter: 16.13 mm	Actual spring constant (for width of 2.12 mm): 889.315 $\frac{N}{m}$
Total height of device: ~6.51 cm	Null	Diameter of scrap up to bottom of lip: 46.32 mm	Null

Beam deflection as a function of mass was not linear past 100 g when both ends of the beam were fixed tightly. Deflection “saturated” around 400 g, meaning it varied little between 400 and 600 g. In contrast, the other beam clamping methods produced closely linear results. Data from deflection trials is presented by **Figures 6—10** below.

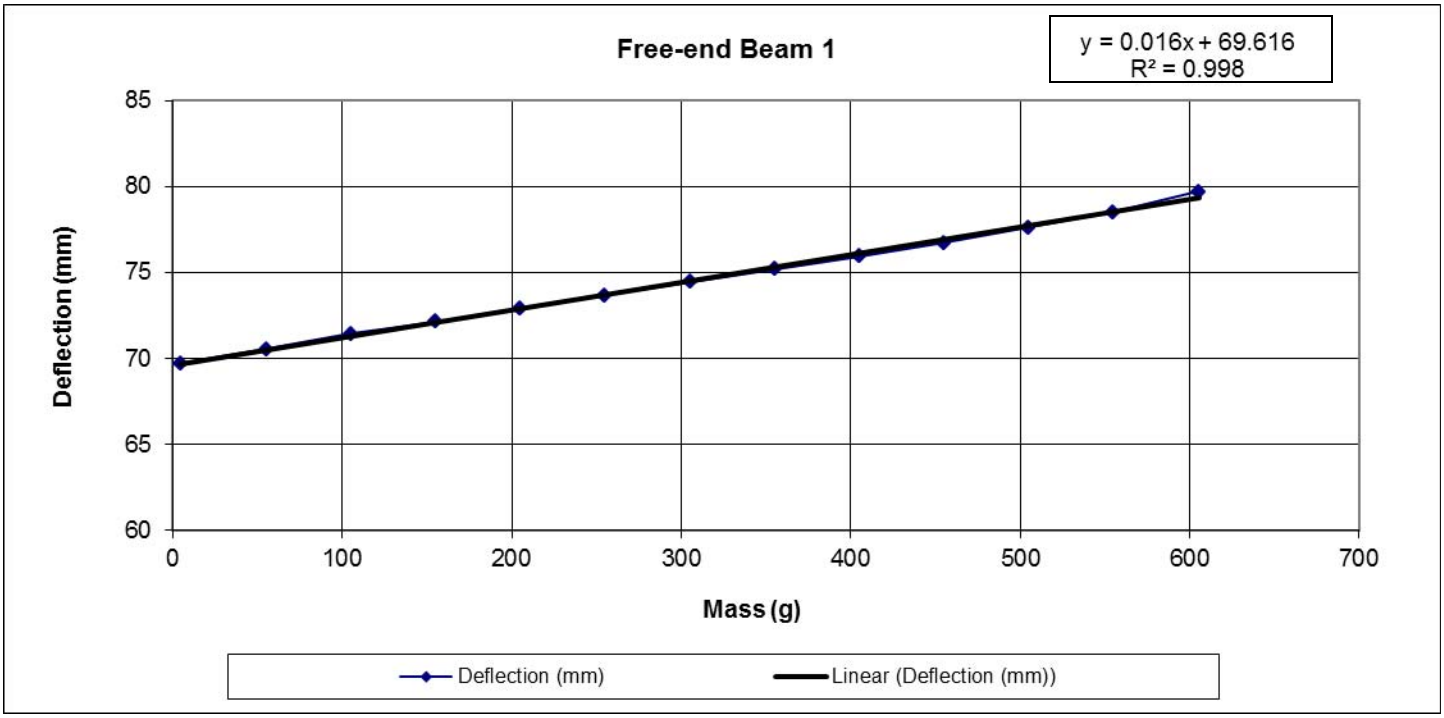


Figure 6: *Beam 1 deflection as a function of applied mass.* Beam 1 (2.12 mm) was fixed at one end such that the corners of the beam rested on the outer perimeter of the brass scrap. Displacement was measured near the midpoint of the scrap. **The total amount of deflection was ~9.96 mm**.

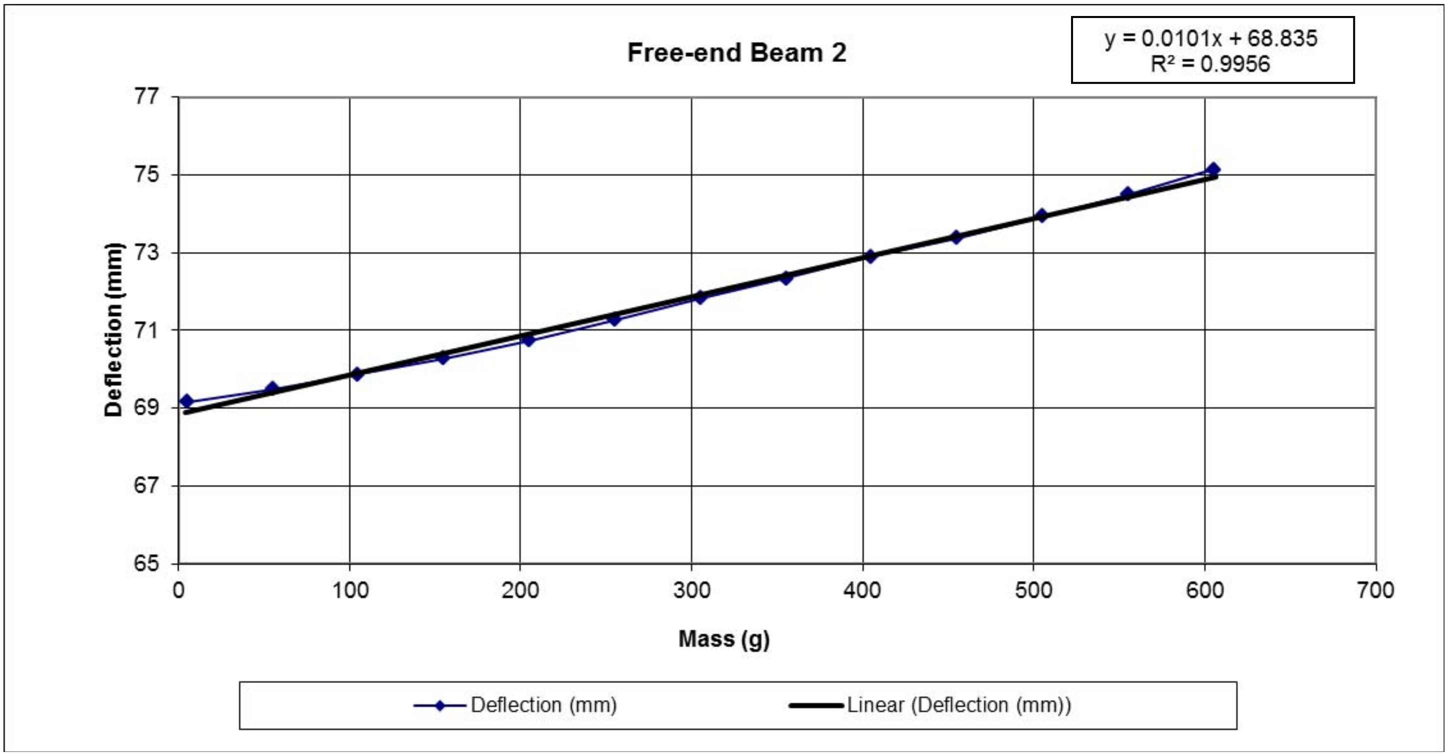


Figure 7: *Beam 2 deflection as a function of applied mass.* Beam 2 was fixed at one end in the same manner as Beam 1. Measurements took place near the midpoint of the scrap and **the total displacement was ~5.97 mm**.

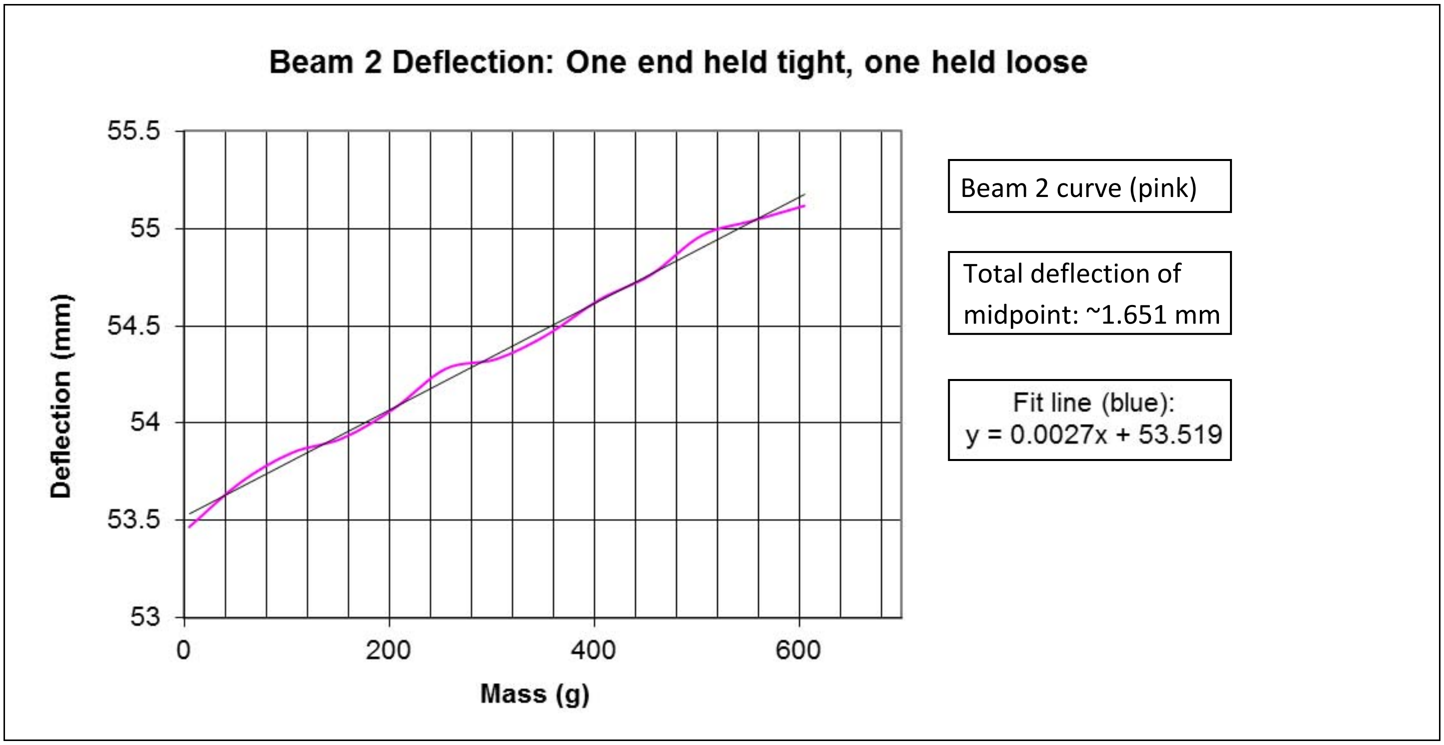


Figure 8: *Beam 2 deflection as a function of applied mass.* For these data, the fixed end of the beam was not held down as tightly as those in **Figure 9** below.

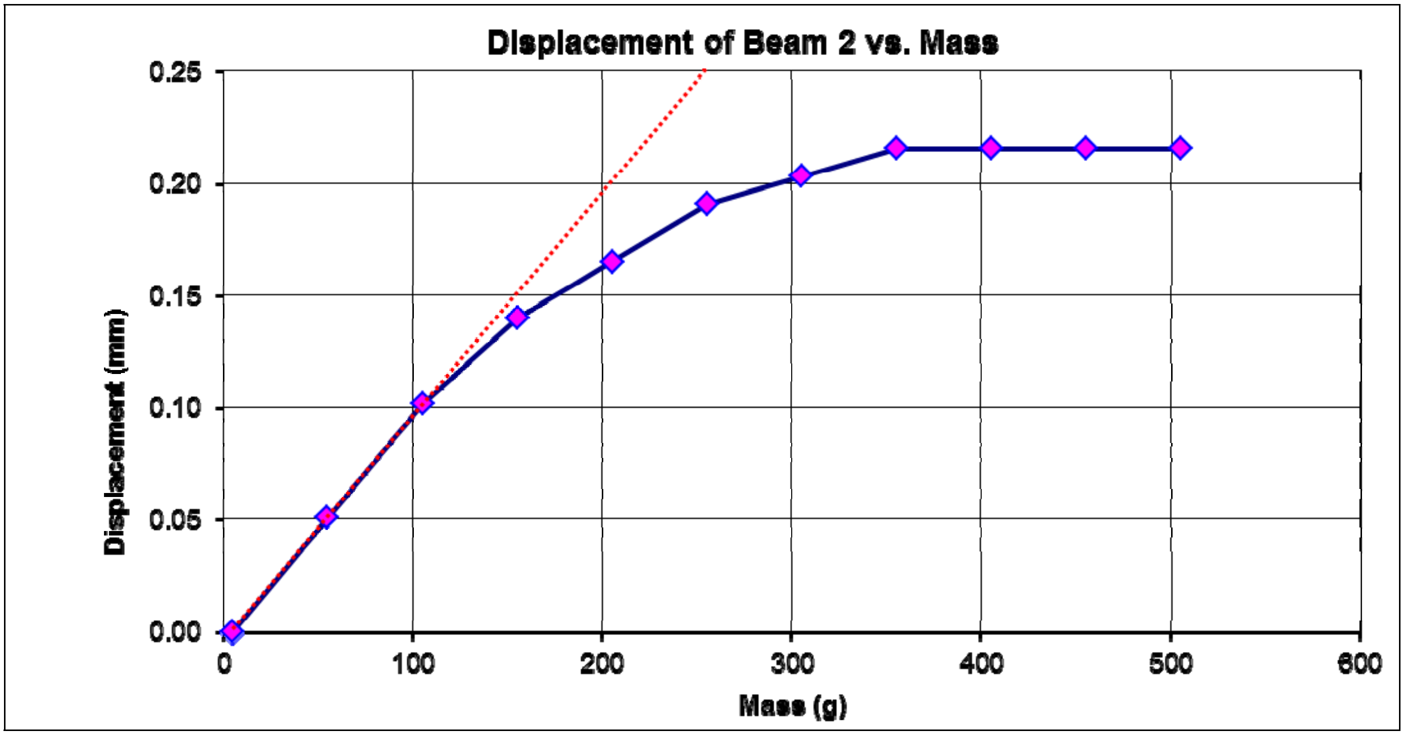


Figure 9: *Beam 2 deflection with both ends held tight.* Measurements of deflection were made near the center of the beam. Deflection was only linear up to 100 g of applied mass. Beam ends were fixed with screws and washers.

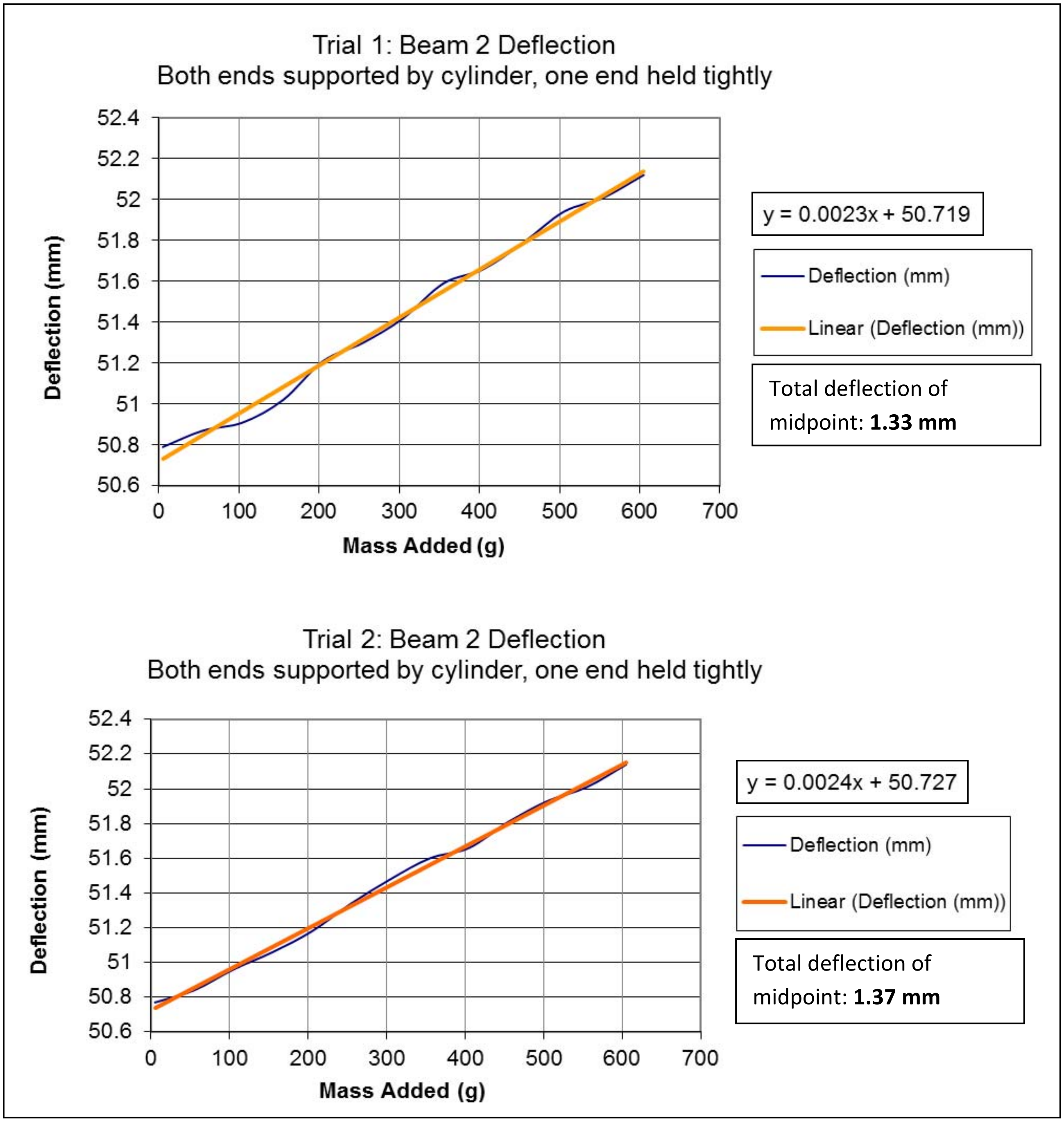


Figure 10: *Beam 2 deflection trials—both ends supported, one end fixed tightly*. These two plots replicate the behavior seen in **Figure 8**. However, the beam used for these plots was more tightly fixed than the beam used in generating **Figure 8**.

Efforts to measure the DD spring constant revealed the DD, exposed to ambient air, had developed a relatively large amount of friction. Here, "large" means that placing a 200-g mass on the probe of the device did not yield a consistent reading for displacement.

The effective mass of the DD probe pressing down on the scale was 302 grams. The drum tension, then, was found to be $T \sim (9.8)(0.3) = 2.94\ N$. Using this force in Hooke's law (Eq. **6**), the associated beam width needed for the prototype was found to be ~3.4 mm.

The constructed device deviated from the planned design. It was built using screws and washers instead of Al blocks and the Hall adjustment mechanism was the Variant B form instead of Variant A. A screw that had been rounded off at the end served as the probe. This probe was attached to the steel beam using two nuts as shown in the photographs below

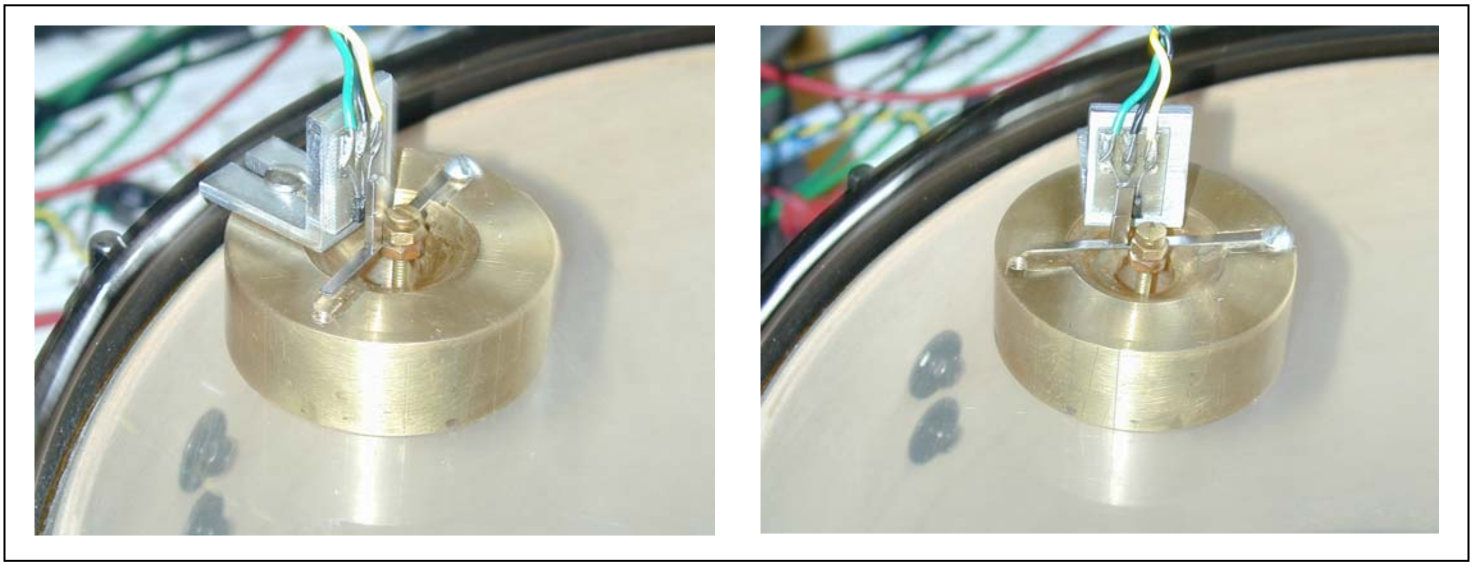


Figure 11: *Photographs of the prototype tuner in use.* Though the magnets and L iron are off center, the device was successful as a drum tuner. The only real constraint on the device is that the plane in which the magnets sit cannot vary relative to the plane of the Hall probe.

When both ends were fixed (one held loosely), the bottom surface of the brass disc did not press flush against a granite slab even when 1 kg was placed on the device. However, when one end of the beam was loosened completely, the device could be used to tune a drum. The process of re-tuning the drumhead when one tension rod had been loosened by a quarter turn took no more than 1 minute.

Voltage differences between the reference plane (the granite slab) and the drumhead were around 320 mV. Lastly, the voltage readings associated with the three steel-beam thicknesses were: ~1.5 V for 0.254 mm, ~2.5 V for 0.508 mm, and ~3.9 V for 0.762 mm. The fit line for these three data points had a slope of 0.127 V per mil or about 5 V per millimeter. A plot of the data was provided by Holloway (**Figure 12**).

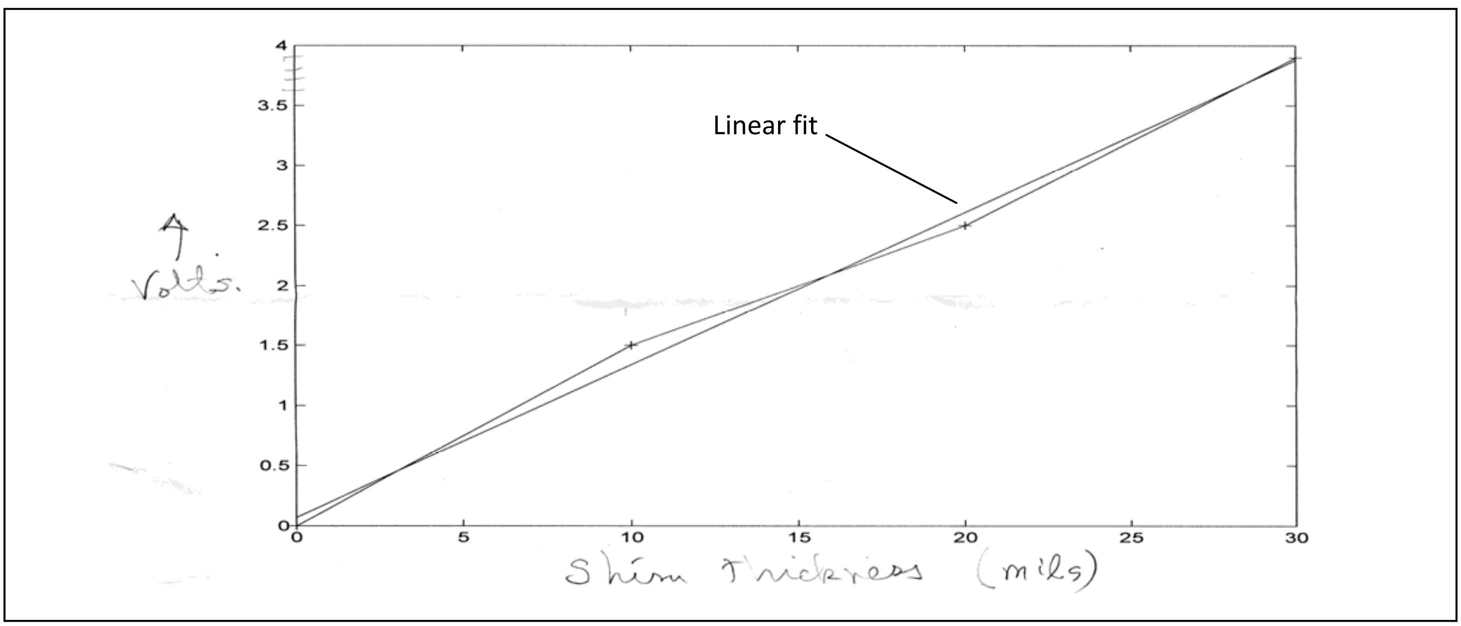


Figure 12: *Hall voltage for prototype on various beam thicknesses.* "Shim" on the bottom axis refers to the stainless steel beams. Data was collected at three points: 10 mils (0.254 mm), 20 mils (0.508 mm), and 30 mils (0.762 mm) [2]

Design 2:

Given time constraints, D2 was not finished. However, the design was completed and can be seen in **Figure 13** below.

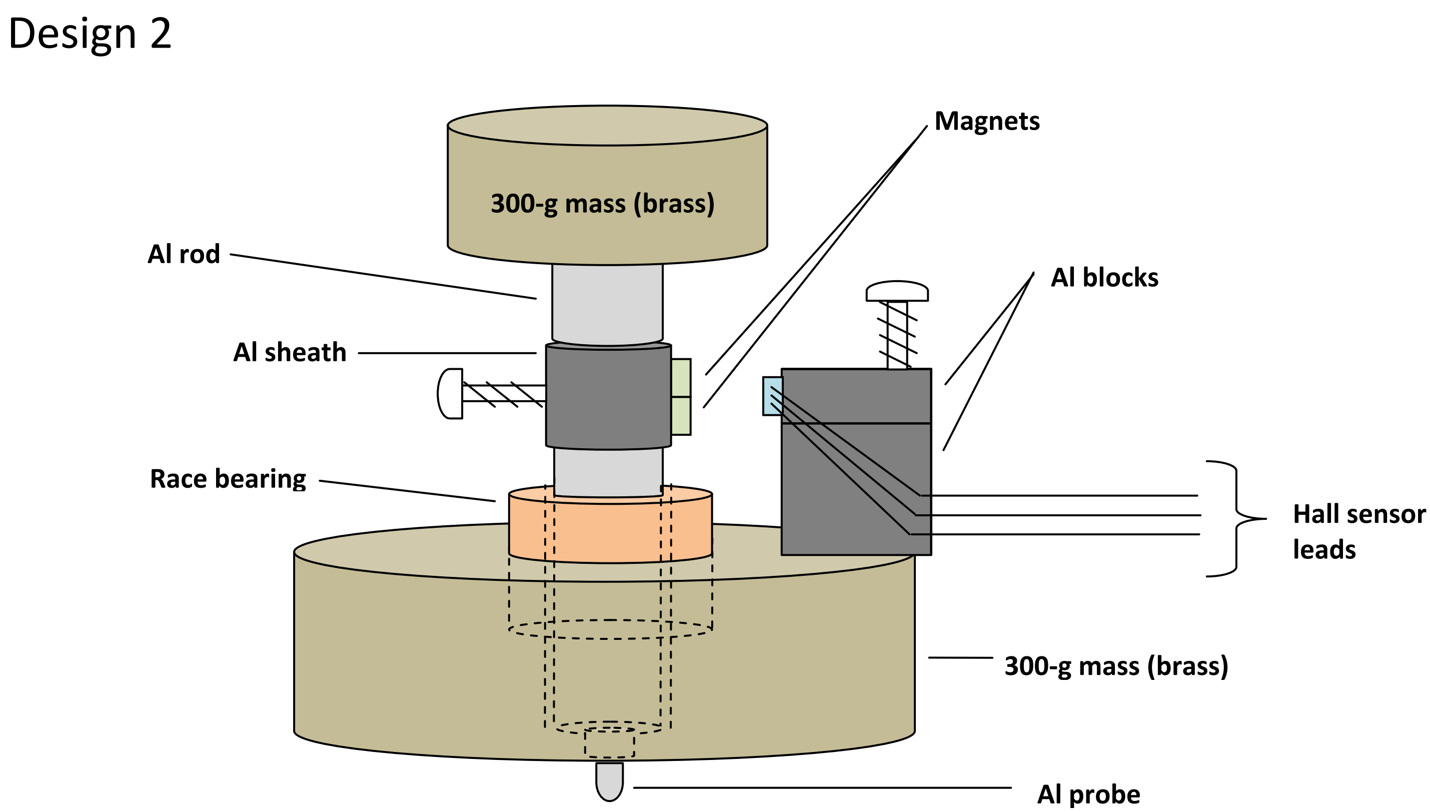


Figure 13: *Drum tuner, Design 2.* In order to keep the Al rod stable, shim stock may be used to prevent wobble but allow vertical displacement. This design requires use of an equation for the tension in the drumhead. This equation is, evidently, not as simple or easy to work with as Hooke's law is [2].

Discussion

The device designs explored were essentially electronic versions of the DD. But while they are similar in design, they may be improvements over the DD's sensitivity and accuracy. With few moving parts, the devices (in particular, D1) should be relatively immune to large amounts of mechanical friction. High friction inhibits the DD's effectiveness as a precision instrument but does not appear to affect its ability to clear a drumhead. In order to compete with the DD, D1 or D2 must be, at the very least, cheaper to manufacture.

Design 1:

There at least three main advantages of D1 over the DD. First, D1 significantly reduces friction since only two parts move relative to each other—the free end of the beam and its Al block support. Any friction is expected to be negligible. In the one free-end configuration (i.e., one end of the beam is free), friction is no problem at all. Second, this device is far lighter than the DD so its perturbative effect on the drumhead is much smaller. Third, it is much simpler than the DD and has significantly fewer moving parts. Lastly, D1 is markedly more sensitive to changes in deflection by virtue of the Hall sensor it uses.

When adjusting the tension rods to tune the drum, care had to be taken in moving the device about the drum. Moving the device back and forth perpendicular to the beam resulted in different readings. This discrepancy was caused by the ability of the beam to rotate slightly. Modifications to the device to minimize or remove beam rotation should not be too difficult to implement [2].

Tension in the drumhead can be estimated by simply invoking Hooke's law using the spring constant of the beam (given in **Table 1**) and the deflection as measured by the device. Note that the changes in head tension caused by placing the device on the head are neglected since they are small compared to the head tension. Ideally, the device should be as light as possible in order to minimize the perturbative effects [1]. At ~300 g, the prototype changes the head tension half as much as the DD (~605 g). And given the results of the investigation, a device of 50 g or less could be made and used as a successful tuner. It appears that making such a lightweight device work would simply require appropriate adjustments of the beam and Hall probe.

In addition to estimates of tension, estimates of the ordinary frequency of the vibrational modes can also be made. This can be done by plugging in the local tension (as measured by the device) into the ordinary frequency equation described in the introduction section [1]. Note that this equation assumes the membrane is perfectly compliant and has no stiffness. Accounting for stiffness is not necessary as it only raises the ordinary frequency by 0.005 % [1].

Though the proper beam width of ~3.4 mm was not used (a 2.12-mm wide beam was used in its place), the usefulness of the device was not compromised. A width was calculated in order that the device would mimic the DD. A device that mimics the DD is likely to work as a tuner (since the DD works) but replicating the DD characteristics, it was found, was not necessary to produce a useful device.

The series of beam deflection measurements was performed in order to determine whether the beam tested would deflect around 1 mm and to determine whether the plot of deflection as a function of applied mass would be linear. A linear relationship would prevent the need for corrections to the Hall sensor output. Results from the beam tightly fixed at both ends agree with theoretical predictions made by Professor Emeritus Lee Holloway [2].

A single-ended cantilever was utilized instead of the intended "diving board" (one end fixed, the other free but supported) cantilever. When attempting to measure deflection, the diving board cantilever was just too stiff. Placing 1 kg on top of the device was not enough mass to push the probe into the device and make the brass disc flush with a flat surface.

While drumhead tension need not be known in order to tune up a drum, a device that measures tension may offer benefits that other devices lack. At the time of this writing, specific examples of benefits are unknown

Design 2:

The development of D2 was limited mostly because of time and greater interest in D1. Time was taken to explore this design in order to determine another way of mimicking the DD. But after some thought, a number of drawbacks were found with this design. First, the multiple components of the D2 device would make it cumbersome and delicate. Care would have to be taken when manipulating it so as not to accidently disassemble it. Second, in order to get the tension out of D2, the tension equation for a membrane would have to be utilized [1, 2]. Such a calculation is difficult and non-ideal [2]. But measuring the tension can be done much more easily and simply using the beam-based device.

Conclusions & Future Work

Overall, the D1 prototype proved to be a success in tuning a drum. Even in its crude form, its sensitivity in measuring changes in deflection could rival the DD. Changes in deflection that were fractions of a millimeter were easily "noticed" by the device. Further, the prototype can be used in calculating local tension in the drumhead. All that is required is a simple calculation.

Despite the success, a great deal of work is still to be done if the device is to function as a reliable, user-friendly, stand-alone instrument (i.e., without the need for a voltmeter or oscilloscope). The goal of using the device to display musical notes associated with tension was not attained.

Increasing the functional breadth of this device will improve its usefulness. At least two modifications can be made to make the device more of a multi-purpose instrument. One modification of particular interest involves associating various tensions to musical notes (dominant mode frequencies) such that the device displays both tension *and* note when placed on a drumhead. However, if the device is to be used on multiple drums, it must be calibrated to account for different shell dimensions. A second modification, then, would be to place a switch on the device that allows the user to cycle through tension-note libraries specific to certain shells.

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Appendix A – Hall probe sensitivity

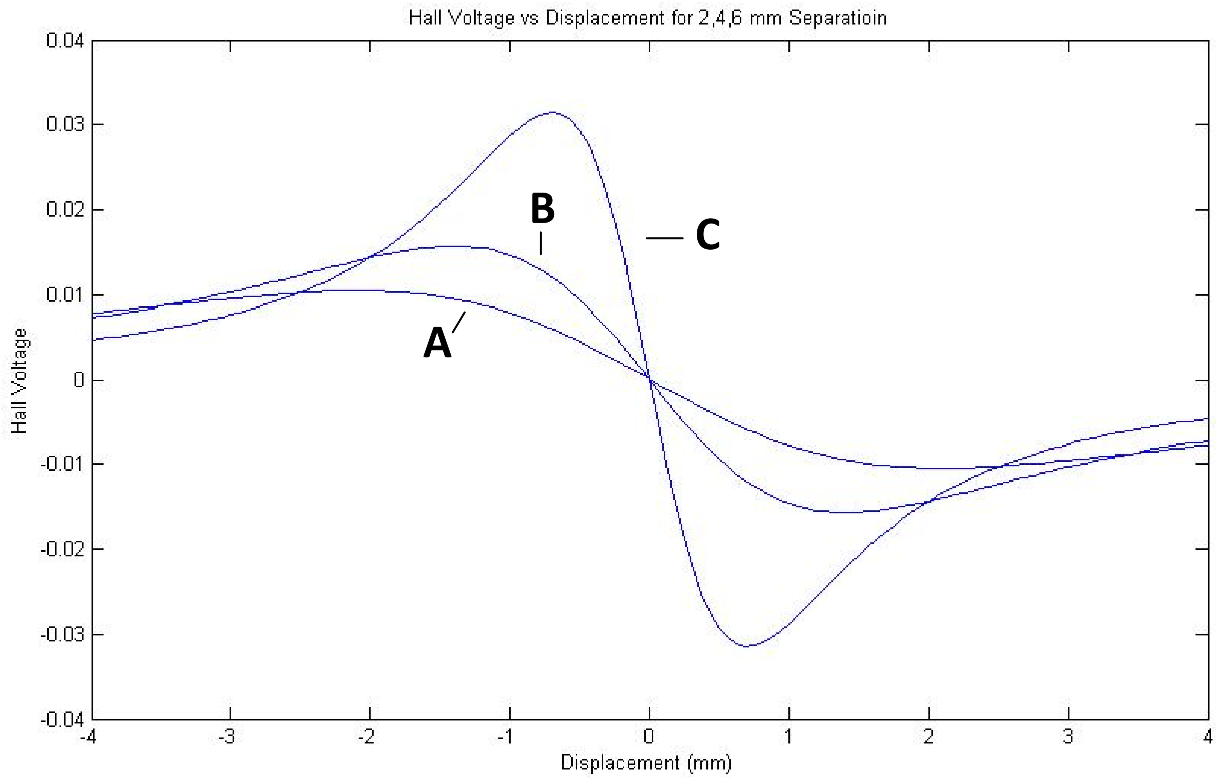

Figure 13: *Hall voltage as a function of distance from magnets.* The sensitivity of the Hall probe can easily be adjusted by moving the probe closer or further from the magnets. Curve A corresponds to a distance of 6 mm, Curve B corresponds to a distance of 4 mm, and Curve C corresponds to a distance of 2 mm.

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