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DETERMINING TOP PLATE PROFILES IN ASSEMBLED GUITARS VIA MEASUREMENTS OF MAGNETIC FIELD

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ABSTRACT

The thickness of wooden top plates is of considerable importance to luthiers. However, the geometry of an assembled instrument makes thickness measurements difficult using standard techniques. Here we describe a device that measures the thickness of a top plate by measuring the magnetic field produced by a small rare-earth magnet located on the inside of the instrument. The magnetic field is measured using a Hall device in conjunction with an analogue-to-digital converter. The instrument is based around a micro-controller that provides several advantages including the following:
(i) a simple calibration procedure for different magnets and sensors; (ii) an LCD display that can show sample thickness in microns or 'thou'; (iii) automatic determination of thickness at the magnet location when the probe is swept over the surface; and (iv) the recording of thickness at multiple locations for subsequent analysis.
KEYWORDS: lutherie tools, hall effect, thickness measurement, guitar top-plates

INTRODUCTION

The thickness of the top-plate on a stringed musical instrument and its variation with position are crucial in determining the instrument's acoustic performance [1]. Many guitar-makers alter the thickness of the soundboard after it is glued onto the back and sides, in order to reduce the mass and stiffness of particular areas and thereby change the vibration properties. It is often difficult to thin evenly over the entire top. The vibration of the thinned soundboard is often examined afterwards by studying the resonant (Chladni) modes of the plate, and further thinning undertaken to obtain the desired symmetry. This is usually a time-consuming process.

It is important to be able to determine how evenly or unevenly the soundboard is thinned. This would be a simple measurement exercise if it were not for the awkward geometry of the internal guitar cavity. Measurement devices may be inserted through the sound-hole, which is about 95 mm in diameter, but the lower end of the soundboard extends over 300 mm from the sound-hole and is reinforced with a series of internal braces of much greater thickness. These restrictions prohibit the use of a typical set of callipers/micrometers over most of the soundboard area. A Hall effect probe is used here to measure the decrease in magnetic field strength with distance from the surface of a permanent magnet. A device was constructed that processed the signal using a small programmable micro-controller. Unlike ultrasonic test methods, this technique is unhindered by variations in temperature, humidity or grain layer boundaries. It is capable of higher precision than extendable calliper jaws. Although the device will only perform well on surfaces that are nearly flat and parallel, this condition is often met in the areas where higher precision is required including this application to guitar sound boards.

The concept of studying changes in magnetic field as a non-destructive test method for determining distances is not new [2-4], yet this device has a number of flexible options, owing mainly to the calibration procedure and use of a micro-controller.

Beyond the application to guitars, the device may be used with most materials whose relative magnetic permeability is close to 1, including air, wood, most polymers, rubbers: indeed most gases and non-magnetic condensed phases. It would be possible to use this principle in ferromagnetic materials [3], with a more complicated calibration method. Sensitivity of the device is not linear (Fig.3) and, consequently, when distances are very close to zero, a small motion in the probe results in relatively large fluctuations in output.

DEVICE CALIBRATION AND OPERATION

The device consists of a Linear Hall Effect IC (Honeywell SS2) embedded in a Perspex cylinder so that the sensing element is parallel to the base and facing outwards. A rare-earth magnet is selected according to the needs of the particular project (here we use Nd-Fe-B cylinders available from Australian Magnet Technologies, Newcastle), also embedded into a Perspex cylinder. The embedded elements are set as level and as close to the surface of the cylindrical face as possible. The IC output voltage is inversely proportional to the measured magnetic flux density and thus varies monotonically with the distance between the probe element and the source magnet.

Calibration of each particular probe/magnet system is required, as there are noticeable differences between each Hall effect IC and magnet selected. However, the field variation with position is smooth and is well approximated by a fifth order polynomial (Fig.2). Such a fit can then be interpolated to determine distance from IC output. Originally the Hall probe output voltage was processed manually, but a more convenient solution was to construct our own device (Fig.1) around a small programmable micro-controller (ATOM28 - Basic Micro Inc., Farmington Hills, MI.). A push-button switch on the probe and five buttons are displayed on the device, allowing the user to navigate a simple, menu-oriented, operating system. Output consists of a liquid crystal display screen and/or a loudspeaker connected to a tone generator.

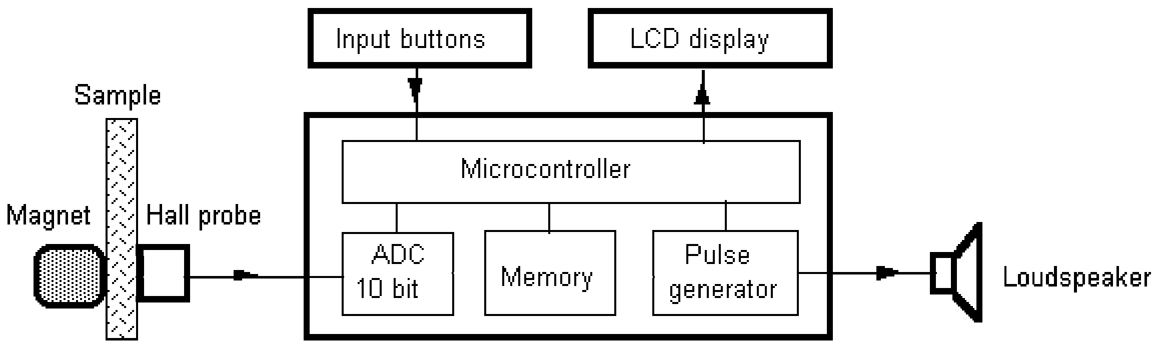

Fig.1 Schematic of Hall probe device set-up. The memory unit consists of 256 bytes of EEPROM, 384 bytes RAM, and 8 kbytes of Flash memory.

The user then has the ability to execute the following routines on the device:

Calibration The user can perform and/or store a new calibration (using a standard set of shims), and access previously stored calibrations.

Measurement This consists of the following modes of operation:
Continuous – the thickness is continually measured and displayed.
Single – thickness is measured/displayed each time the probe button is pressed.
Scan – thickness is continually measured while the probe button is depressed, after which the minimum value is displayed.
Record – thickness is measured, displayed and stored in sequence in memory each time the probe button is pressed, for involved studies.

Sound Output Feedback is available in the form of an audible tone. The pitch of the tone is proportional to the thickness, giving an indication of thickness variations without having to look at the LCD display. The user can determine the pitch range accordingly.

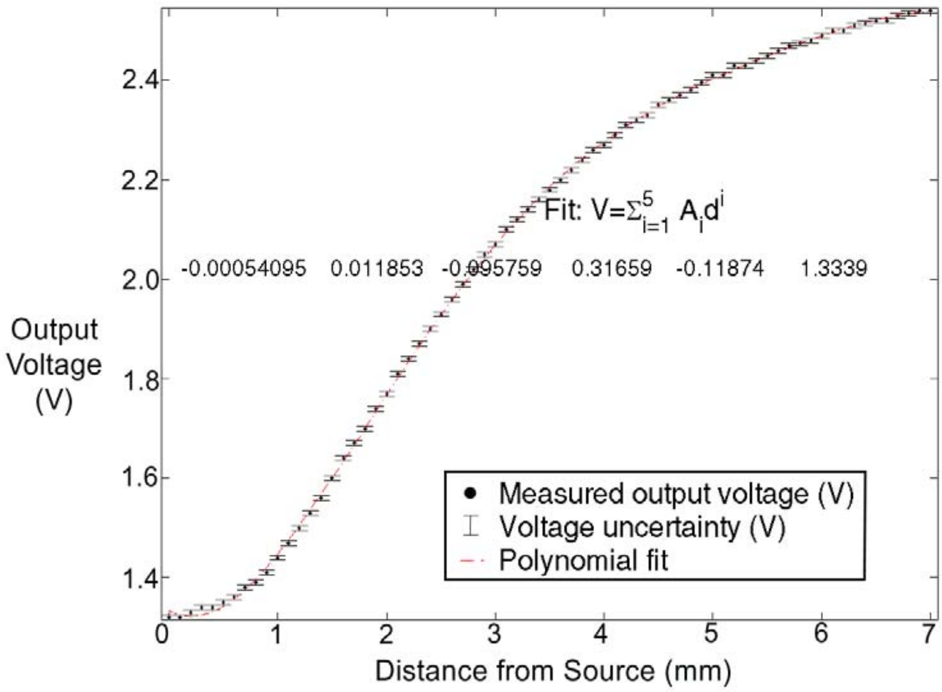

Fig.2 Calibration curve indicating voltage response of Hall effect IC as a function of distance from a permanent magnet. The polynomial coefficients, from highest to lowest order, are displayed. The uncertainties in voltage and distance indicate the resolution of the instruments. (Distance uncertainties are too small to be visible.)

Once the device is calibrated, the magnet and probe are placed on opposite sides of the material so that both faces lie flat and firmly touching the surface, directly opposite each other. A local minimum in the apparent thickness signal indicates that the magnet and probe are aligned and that the reading thus represents the thickness. This local minimum can be found manually, applying small perturbations.

ACCURACY

The device was tested by measuring simply shaped samples of wood whose thickness could be independently measured using vernier callipers. Some results are shown in Fig. 3:

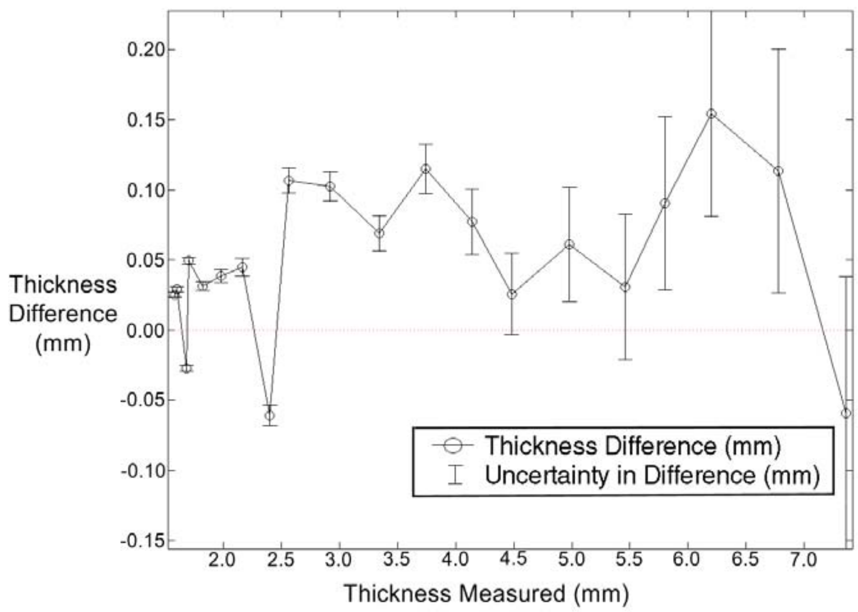

Fig.3 Difference in thickness of wood measured using the Hall probe device and vernier callipers. The uncertainties in thickness differences represent the limits of reading of the voltage output and vernier callipers.

CASE STUDY: THREE GUITAR SOUNDBOARDS

This Hall probe device was used successfully in a project in which three acoustic steel-string guitars were constructed specially for a scientific study. They were made as similarly as possible, with the exception of the soundboard materials (which were Engelmann spruce, Sitka spruce and Western Red cedar.) After attachment and preliminary shaping, the thickness of the soundboards was not well known, and variations were as great as ±0.5 mm in the least controlled areas (halfway between the bridge area and the bottom of the guitar). Utilising the device described here, we were able to measure absolute thickness with an uncertainty of ±0.05 mm, over the range of 0.0 to 7.0 mm. The results were used to modify each soundboard. The measurements were performed using a cylindrical Nd-Fe-B magnet 6.0 mm high and 6.0 mm in diameter, with a surface strength of 309 mT.

CONCLUSION

It is possible to obtain a precision of ±0.05 mm, over thicknesses ranging from 0.0 mm to 7.0 mm, using a device employing the Hall effect and a micro-controller, with a rare-earth magnet placed on the other side of the material. The device was successfully applied in a comparison to conventional vernier calliper measurements, and a case study that required identical thickness distributions among three acoustic guitar soundboards, thinned *after* attachment to the back and sides. This research was made possible through the Australian Research Council and Gilet Guitars.

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