Dayton C. Miller's Acoustics Apparatus and Research

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Abstract

The CWRU Physics Department has a rich history of research in acoustics, which peaked during the early 20th century. In particular, the department head, Dayton Miller, invented the phonodeik - the predecessor to the oscilloscope - which could photographically record sound waves. The department still has much of the original equipment purchased and by Miller, including pieces designed by noted German acoustician Rudolph Koenig. This project explored the history of acoustics research in the department. Key pieces of equipment were identified; their use and function were investigated; and a website was created to present this information, including video and audio clips of several of the instruments in use.

Background

Research in acoustics was an important area of physics in the late 19th to early 20th century, in part due to the work of Hermann von Helmholtz, who published *On the Sensations of Tone as a Physiological Basis for the Theory of Music* in 1863. Rudolph Koenig worked directly with Helmholtz and others to design and build state-of-the-art instruments for the qualitative and semi-quantitative analysis of sound. Koenig's *Catalog of Acoustics Apparatus,* published throughout the mid to late 19th century, offered to the world a wide variety of instruments for acoustics research, including those first described in Helmholtz's book.

Beginning in the 1890s, Dayton C. Miller, chair of the Physics Department at Case School of Applied Sciences, purchased an extensive assortment of apparatus from Koenig, and later from Max Kohl of Chemnitz, Germany, for the analysis of sound. Miller was interested in determining, for example, what made one flute sound better than another flute. Miller amassed a collection of nearly 1700 flutes and over 3,000 books regarding the instrument, all of which he subsequently donated to the Library of Congress. His early work was qualitative, due to the limitations of the available equipment--primarily the flame manometer and Fourier analyzer. With his invention of the phonodeik in 1908, Miller was able to produce photographic traces of complex sounds produced by musical instruments. This allowed him to quantitatively determine - through use of Olaus Henrici's harmonic analyzer - the fundamental and harmonic components of the sound produced by a given musical instrument, and compare this data with that obtained from other instruments. As an example of this method of analysis,

consider the saw-tooth wave, which was the first to be examined by Miller. The following table lists the theoretical and measured coefficients for the first five components of a saw-tooth wave, illustrating the level of accuracy attainable by mechanical analysis.

Calculated	**Measured**
127.32	127.30
63.66	63.55
42.44	42.47
31.83	31.85
25.46	25.50

Table 1. Comparison of calculated and measured coefficients for the first five components of a saw-tooth wave. (Fickinger 41)

Miller used this method to record and analyze thousands of sound waves from numerous musical instruments, such as flutes, violins, clarinets, oboes, saxophones, and organ pipes. He made hundreds of glass lantern slides detailing his work in acoustics, including photographs of equipment, dozens of phonodeik traces, diagrams, and experimental setups. Over a period of thirty years, he published over a dozen papers on acoustics and the science of sound; he also published books on the subject, particularly *The Science of Musical Sounds* (1916) and *Sound Waves: Their Shape and Speed* (1937), both of which thoroughly detailed his work and the instruments used in mechanical harmonic analysis.

Description

The project consisted of two parts: researching key instruments in the acoustics collection, including understanding their function and use by Dayton Miller in his research; and creating a website (http://www.phys.cwru.edu/ccpi/) to document this information, and provide photographs and video clips of the instruments and their use. Regarding the first goal, several references were used in determining how these century-old instruments functioned, and how they were utilized by Miller (see Bibliography for a full list). Key sources of knowledge included the following: the acoustics catalogs of Rudolph Koenig and Max Kohl - the two acousticians on which Miller relied for his equipment - provided online by the libraries of the Smithsonian Institution; the collected papers and books of Dayton C. Miller; discussions with the department historian, Professor William Fickinger; and hands-on interaction with the instruments.

Through discussions and examinations of the collection, it became clear that the project should focus on about sixteen instruments, which can generally be categorized as either “sound-makers” or “sound-analyzers”. The sound-makers include instruments that produced specific tones (Helmholtz resonator, organ pipe in conjunction with the wind chest, tone bars, tuning fork, tonometer, tone variator) and interference phenomena (double siren). These instruments were primarily used in lecture demonstrations for teaching acoustics, and in the case of the tonometer, also as a high-frequency standard. The sound-analyzers include apparatus used as frequency standards (vibration microscope, fork clock, Régnault chronograph), or used in mechanical harmonic analysis

of sound waves (flame manometer, Fourier analyzer, phonodeik, harmonic analyzer, harmonic synthesizer).

Almost all of these instruments are still in the department's collection – with the exception of the harmonic analyzer and synthesizer – allowing for hands-on examination. Photographs were taken of the available instruments. Select images from Miller's large collection of glass lantern slides were digitally scanned for presentation, including photographs of the harmonic analyzer and synthesizer originally used by the department, and various photographs and diagrams of other equipment and experimental setups.

It was decided that the best way to understand the instruments, and pass on this understanding, would be to bring them into working condition, and record demonstrations of their use for presentation on the website. In particular, the phonodeik was restored to proper working order with the rediscovery and implementation of its original diaphragm. The original experimental setup, as described on the website, was modified to use a laser light source, and an electric rotating mirror was used to spread out the beam reflected from the phonodeik's mirror. In a dark room, the structure of a sound wave produced by an organ pipe and tuning fork could easily be seen; video clips of this demonstration were recorded. Other instruments that were demonstrated and recorded include the Helmholtz resonator, organ pipes and wind chest, tone bars, tonometer, tone variator, double siren, flame manometer, and the Fourier analyzer. The University of Northern Iowa provided numerous video clips demonstrating proper use of Henrici's harmonic analyzer. Most of the video clips were originally over a minute in length, but were trimmed down to a few seconds to reduce their file sizes.

The layout chosen for the website revolves around one main page, which features a thumbnail gallery of the sixteen highlighted instruments. The images chosen for the gallery came primarily from the catalogs of Koenig and Kohl; diagrams were used if such illustrations were not available. Brief descriptions are attached to each gallery item, allowing users to quickly find objects of interest. Each instrument has a separate article detailing its function and use; the content of these articles generally follows the same outline:

- Photographs of instruments used by the department;
- Description of the instrument's use in acoustics research and demonstrations;
- Description of its function, with explanatory diagrams where necessary, and;
- Links to video or audio clips that demonstrate its use.

At the conclusion of this project, the website contained articles for sixteen instruments, with a few dozen photographs and illustrations, a total of 21 video clips demonstrating ten of the instruments, and five audio clips of various Helmholtz resonators. See the appendix for a complete printout of the website.

Follow-through

Future work on this or a similar project would primarily involve the following: restoring and/or demonstrating use of the vibration microscope, fork clock, and Régnault chronograph in conjunction with the smoked-paper lamp; recording video clips for the previously-mentioned instruments, as well as clearer, higher-resolution footage of manometric flames and phonodeik traces for various musical instruments and tones; demonstrating use of both double sirens in producing interference phenomena, cancellations, etc.; acquiring footage of an harmonic synthesizer in action; and recording any other demonstrational video clips that would better highlight use of apparatus in the collection. Further research and expansion of content would include thorough investigations and documentations of the various sets of tuning forks and organ pipes in the collection to determine the purpose and proper use of each. In addition, as the physics department's history website is expanded further, content from other webpages would be highlighted on appropriate acoustics webpages to better immerse the reader in the history of the department.

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