The Robert H Thurston Materials Testing Laboratory Collection at Cornell University

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Abstract. Cornell University has preserved 19th century artifacts of significance to the history of mechanical engineering. They were designed by Robert Henry Thurston [1839–1903] who made contributions to materials engineering related to the technology of steam power. A torsional testing machine invented by Thurston uses a unique cam mechanism to automatically write a stress strain diagram. This machine led to the discovery of work hardening in metals. Another artifact relates to the testing of tribological properties of machine lubricants. This Collection received the ASME designation as a National Heritage Collection in 2019.

Keywords: Materials · Testing · Cam · Mechanism · Tribology · Robert Thurston · ASME

1 Introduction

Robert H Thurston was one of the most famous engineers in the United States in the late 19th century. [1–3] (Fig. 1) Born in Providence Rhode Island in 1839, Thurston was educated at Brown University with a "Certificate" in civil engineering. He served as a naval engineer during the Civil War at the beginning of the steam power era of the Navy. He worked in his father's steam engine manufacturing company for a short time before becoming one of the first faculty at Stevens Institute of Technology in Hoboken NJ [1871–1885]. At Stevens he began implementing his ideas for a more scientific based mechanical engineering curriculum and for developing an engineering testing laboratory. He brought these ideas to Cornell University in 1885 until his untimely death in 1903 [8].

The course of Robert Henry Thurston's career was inevitably linked to the development of steam power in the US. In 1841 his father Robert Lawton Thurston became a partner with Babcock and stared building steam engines, especially suited for marine applications. The company built a version of the Noble T Greene steam engine which was a rival to the famous Corliss engine. The flywheel and piston are a classic slider crank mechanism. In 1855 while enrolled at Brown university, RH Thurston built an operating model of a Greene engine using the facilities of his father's shops. That model is in the Cornell Collection. The Thurston company had Navy contracts at the time. Thus it was no accident that at the outbreak of the Civil War in 1861, young Robert Henry

M. Ceccarelli and R. López-García (Eds.): HMM 2022, HMMS 40, pp. 57–67, 2022.
https://doi.org/10.1007/978-3-030-98499-1_6

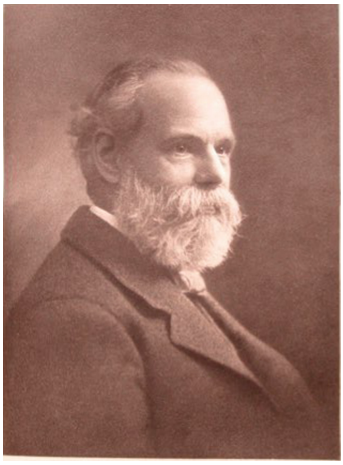

Fig. 1. Photograph of Robert Henry Thurston, Director of the Sibley College of Mechanical Engineering at Cornell University, 1885–1903; First president of American Society of Mechanical Engineers, 1880.

Thurston would become an engineer for the Navy servicing the new steam powered vessels. After the War he taught at Annapolis before teaching at Stevens Institute.

When Thurston was on the faculty of Stevens Tech, he was appointed to a US Board to study steam boiler accidents that were killing more than several hundred people a year. This led him to invent his autographic strength testing machine and to the discovery of work hardening. Thus the technology of steam power brought his genius into both thermodynamics and mechanics of materials. This work of Thurston on boiler safety was a forerunner of the ASME Piping and Pressure Vessel mission.

Thurston began his career in the age of steam power and steam transportation and finished his career in the age of electric power and the gasoline engines. He died a few weeks before his friend Samuel Langley and Cornell graduate Charles Manly failed in their attempt to fly a heavier than air machine and shortly before the Wright Brothers announced they had succeeded in 1903. Yet a decade earlier he had encouraged another friend Octave Chanute to organize an international meeting on flying machines at the Worlds Fair in Chicago in 1893.

One of the areas that Thurston helped change was the creation of the field of mechanical engineering both at the professional and educational levels. In 1880, John Sweet, formerly a professor at Cornell, called for a meeting of engineers in New York to create a new profession related to the technologies of steam power and transportation as well as manufacturing. Forty one year old Thurston of Steven's Tech was elected to head the new American Society of Mechanical Engineers. Beginning at Steven's and continuing at the Sibley College at Cornell University in 1885, he outlined a curriculum that would balance shop knowledge with principles of science. One of the linchpins of this curriculum was the *engineering testing laboratory* where both materials and machines were tested, based on the sciences of mechanics and thermodynamics.

Thurston's work on the thermodynamics of steam is perhaps more widely known because of his popular books on steam power [16]. He had also translated Carnot's famous treatise on entropy from French to English. But Thurston also made important contributions to mechanics of materials. In 1884 he published a three-volume book on engineering materials [14]. In this book he not only summarized the properties of materials but included chapters on how to establish those properties using scientific laboratory measurements. His 1894 book on *The Animal as a Machine,* is one of the early books in bioengineering.

2 Work Hardening of Metals

One of Thurston's major scientific discoveries that impacted mechanical and civil engineering at the time, was the discovery of work hardening of metals in 1873; that is the elastic limit was increased when the metal was initially stressed beyond its elastic limit.

James F Bell of John's Hopkins University in his 1973 scholarly work "*The Experimental Foundations of Solid Mechanics"* wrote [Thurston] "designed and developed an autographic torsion testing machine, measurements from which deeply influenced the thinking of the next forty years." "This apparatus provided the prototype for the present day standardized automated materials testing devices" [4].

This large testing machine is in effect a complaint mechanism in that the test specimen deforms elastically and plastically where the operator is able to apply a torque through a worm gear and a pendulum. [Figs. 2, 3 and 4] The unique aspect of this machine is the automatic measurement of both the torsional deformation of the test specimen as well as the torque applied. [Fig. 5] The torque is proportional to the sine of the angle of the pendulum which is translated into an angle through a cam element in the follower scribe mechanism [14].

In an obituary in the AAAS Science of November 1903, after citing Thurston's work on the US Board to Test Metals in 1972, and devising a machine for torsional tests, they wrote; "the most important [result] being that which established the fact that the elastic strength of wrought iron and steel is increased by stressing the material beyond that limit." [1] Thurston published his early work on this phenomenon in the transactions of the American Society of Civil Engineers in 1874, (pp. 239–240) after having presented his work at a meeting of ASCE in 1873.

3 Invention of a Lubrication Testing Machine

In addition to testing materials strength properties, which helped establish rational structural design, he also believed in testing the efficiency of machines. One of the important but often overlooked components of machine design is the loss of energy due to friction and lubrication. In connection with consulting work for railroad companies, Thurston invented a machine that would measure the viscous properties of lubricants. In Volume III of his tome on engineering materials, Thurston described the construction of his new machine and the mathematical and physical principles on which it works. His machine could measure the temperature of the lubricant, vary the relative speed between moving elements and control the applied normal load between machine elements. Robert

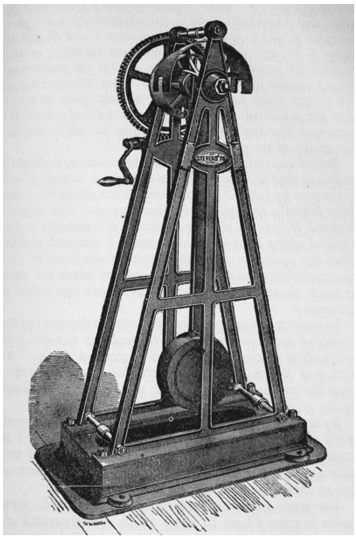

Fig. 2. Lithograph of Thurston's torsion testing machine in his three volume work, Materials of Engineering, [14].

Fig. 3. Photograph of autographic torsional testing machine in the Thurston Collection at Cornell University, Ithaca, NY. USA.

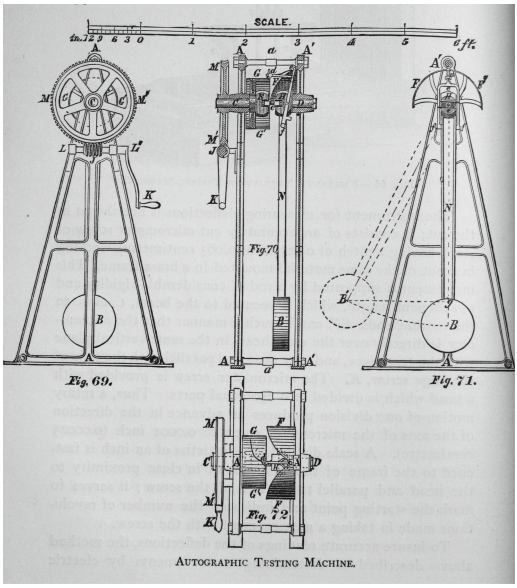

Fig. 4. Drawing of torsion testing machine showing pendulum motion and sine cam mechanism at the bottom [14].

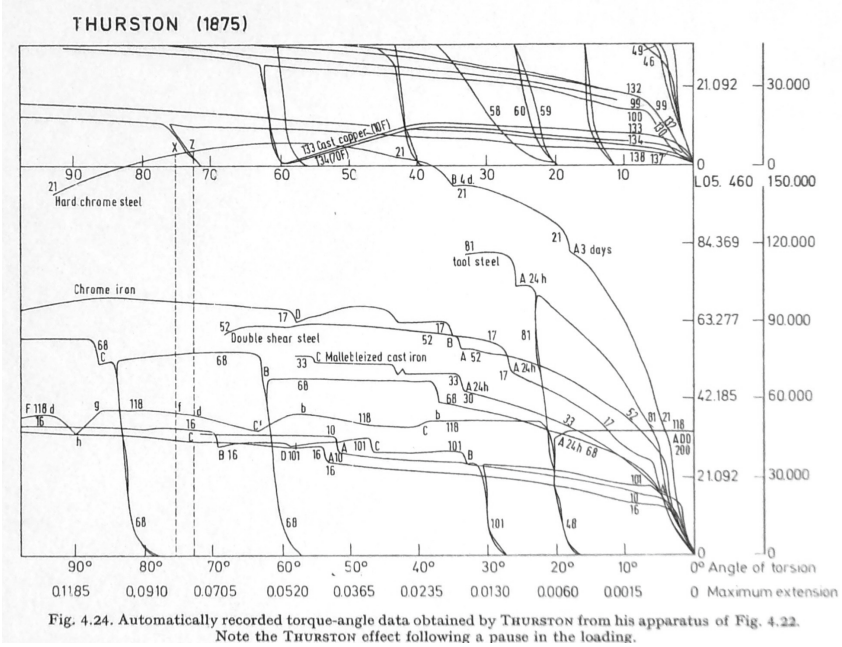

Fig. 4.24. Automatically recorded torque-angle data obtained by THURSTON from his apparatus of Fig. 4.22. Note the THURSTON effect following a pause in the loading.

Fig. 5. Torque- angle (stress vs strain) data from Thurston's Autographic Testing Machine, 1875, [14].

Thurston wrote a unique book on tribology of machines in 1885; *A treatise on Friction and Lost Work in Machinery and Millwork.* This book not only examined the physical aspects of dry and fluid friction, but also discussed the economic impact of friction losses in machinery [15].

Quoting D. Dowson of the University of Leeds; "His major contributions were threefold; he drew attention to the importance of studying tribological concepts; he presented coefficients of friction for a wide range of machine elements and he firmly established empirical testing of lubricants." Dowson also reported;

"He appears to have been the first person to report that the coefficient of friction passed through a minimum as the load was increased." [7].

This machine is in the Thurston Collection at Cornell [Fig. 6].

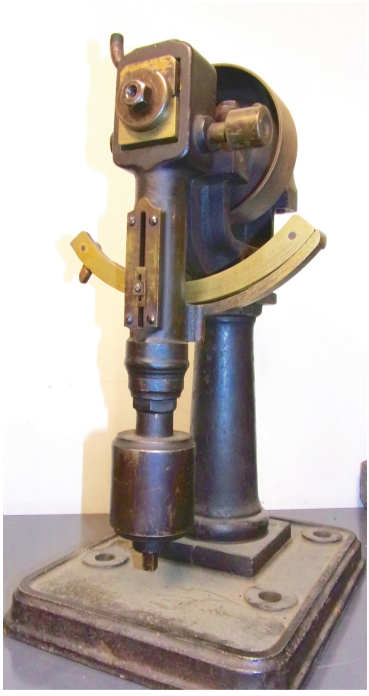

Fig. 6. Thurston's Lubrication Testing Machine. This machine was described in Thurston's 1883 Three Volume book Materials of Engineering [14].

4 Contribution to Engineering Education

When Robert Thurston left Stevens Institute to come to Cornell, each school had less than ten faculty teaching mechanical engineering. When Thurston died at Ithaca in 1903, Cornell's Sibley College of Mechanical Engineering had over forty faculty in seven departments teaching approximately 1000 students. It was perhaps the largest institution of mechanical engineering in the US. AAAS *Science* magazine in their November

1903 obituary for Thurston wrote, "There can be no doubt—, that [the scientific and engineering work of Thurston] was of great benefit to mankind, for he made engineers better scientists, promoted engineering education, and helped to put engineering upon a higher professional plane." [5, 6, 9, 10].

Perhaps because of his working experience in his father's factory Thurston is quoted as writing "Manual training is done not to make [the engineering student] a good mechanic or to teach a trade, but to enable [the engineer] to design intelligently, to criticize good and bad work,"

Thurston wrote numerous articles on the engineering science nature of engineering education, one of which was obtained by the great German engineer Franz Reuleaux of the Berlin Polytechnic Institute who had Thurston's article translated into German. Thurston had visited Berlin during his appointment as US Commissioner to the Vienna World Exhibition in 1873.

5 National and International Statesman for Mechanical Engineering

Thurston was not only president of ASME but was a vice president of the American Association for the Advancement of Science (AAAS) as well as the vice president of the American Institute of Mining Engineers. In addition to his national service on the US Board to Test Metals, in 1873 he was the US Commissioner to the Vienna Exhibition or World's Fair. He sent seventeen letters for publication in Scientific American on the technical exhibits at the Exhibition. He also visited several European countries and reported on the progress of engineering education. He made two other trips to Europe in 1889, 1894. During one of his trips to Europe he visited the laboratory of the famous kinematics engineer, Franz Reuleaux, in Berlin. Cornell University has one of the largest collections of Reuleaux Kinematic Models.

As Director of the Sibley College at Cornell he invited many famous engineers to lecture to the students. The Cornell Collection of Thurston's personal papers in the Rare Manuscripts Division includes correspondence from famous engineers and capitalists at the time, such as, Thomas Edison, Andrew Carnegie, Samuel Langley, Cyrus McCormick, Alexander G Bell and Nikola Tesla, to mention the more familiar names [10].

Thurston also edited a technical publication at Cornell called the *Sibley Journal of Engineering* [1885–1919]. Up until his death in 1903, this Journal contained many articles by Thurston on the nature of engineering education and technology. In addition to all of his books, the Cornell Library has the complete collection of the *Sibley Journal of Engineering*. This Journal has articles by famous engineers at the time such as Steinmetz on advances in electrical power and the lectures of aviation engineer Octave Chanute who in 1891 lectured on the progress in flying machines a decade before the Wright Brothers flights.

6 The Uniqueness of the Collection

In 1885, the year that Robert Thurston came to Cornell to assume the directorship of the Sibley College of Mechanical Engineering and Mechanic Arts, *Scientific American* published a cover story on the Sibley College at Cornell. The article describes;

"A 'mechanical laboratory' — in which are placed a variety of testing machines for determining the strength, elasticity, ductility and 'resilience' or shock resisting power of iron and steel or other materials of construction. **Thurston's 'autographic' and lubricant testing machines,** meters, indicators, scales, dynamometers and all forms of apparatus for determining the quality of materials used by engineers and the power given by machines of all kinds and their efficiency. This department forms a very prominent part of the establishment and the course of instruction includes a considerable amount of work of this kind. This laboratory is one of the most interesting—in this great college."

Fig. 7. Bar-relief bronze sculpture of Robert H Thurston by the artist Herman Atkins McNeil in 1910. This commemorative work of art sits in the entry way to Thurston Hall, home to the teaching of mechanics and materials at Cornell University

Thurston came to Ithaca in 1885, and this article suggests that he brought with him from Stevens Tech the autographic torsion testing machine built by Pratt & Whitney around 1880. However in a query to the Archivist at Stevens' Tech they have one of his autographic testing machines built around 1871–2 at Stevens by students. This machine is on exhibit in their library. According to the historian James Bell, Thurston published his initial work on work-hardening at a ASCE meeting in 1873. So it is likely that his earliest results were performed on the Stevens built machine. However in his three-volume tome on the *Materials of Engineering* 1883–4, he presents strength data on many examples of metals and it is likely that the later machine built by Pratt & Whitney and now at Cornell was used in these experiments.

As mentioned above the Greene steam engine model was made by Thurston himself and was modeled after a full sized machine manufactured by his father's company. It is not likely that another one exactly like the Cornell model exists. Other artifacts include kinematic planimeters and devices to measure strain in metals during load tests. A list of major items in the Collection is given in the Table in this paper.

In addition to the mechanical artifacts, the Thurston Collection also contains his original annotated books and papers, [11–16].

Dedication plaque accompanying the Cornell Thurston Collection.

Mechanical Engineering Heritage Collection
Robert H. Thurston Collection – Cornell University
Early Engineering Laboratory Devices and Testing Machines

The devices in this collection, used at Cornell between 1885 and 1903, exemplify Thurston's vision of the central role of the engineering laboratory in training mechanical engineers.

Building on his work at Stevens Institute of Technology, Thurston fully implemented his pedagogical vision at Cornell's Sibley College of Mechanical Engineering and Mechanic Arts, which under his leadership became the largest and most influential mechanical engineering school in the U.S. Thurston's program achieved national and international recognition as the key to moving engineering training from shop to university.

American Society of Mechanical Engineers, 2019

Table
List of major Artifacts in the Robert H Thurston Collection

1. Autographic Testing Machine, US Patents 1874, 1880 of Robert H Thurston, Manufactured by Pratt and Whitney, Hartford Conn

2. Lubrication Testing Machine, designed by Robert H Thurston circa 1875-1880

3. Working Model of Greene Steam Engine built by R H Thurston while at Brown University c. 1855,

4. Working Model of Steam Engine used in teaching in the Sibley College, Cornell c. 1890

5. Swiss and English kinematic planimeters used to measure efficiency of steam engines, Sibley College 1890 - 1900.

6. Pressure - Displacement indicators with straight-line kinematic mechanism used to measure efficiency of steam engines in Laboratory of Sibley College c. 1890-1900.

7. Mechanical Strain measuring instruments used in metals testing laboratory, Sibley College c. 1900.

8. Bronze topographic plaque showing the effect of alloys of Copper, Lead and Zinc based on torsional strength tests with Thurston's autographic testing machine [14]

9. Personal books of Robert H Thurston [Thurston Bookplates]

a) Report on Machinery and Manufactures at the Vienna International Exhibition 1873 with an account of European Manufacturing Districts by Robert H Thurston, Member of the Scientific Commission of the United States. Washington Printing Office 1875 [includes original photographs]
b) Materials of Engineering in three Parts: Part I Non-Metalic Materials, Part II Iron and Steel 1883, J Wiley & Sons.
c) Memoirs and Professional Reports, 38 Pamphlets 1861-1903.

Acknowledgement. The author would like to recognize Professor Elizabeth M Fisher, former Associate Director of the Sibley School for organizing both material and student resources in creating the Cornell exhibit for the ASME dedication in 1919. The Cornell student section of ASME also contributed design and fabrication help.

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