Part II: John C. Hoadley's Engine Trials at the Cincinnati Industrial Exposition in 1881

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Continued from the August/September issue of Engineers & Engines

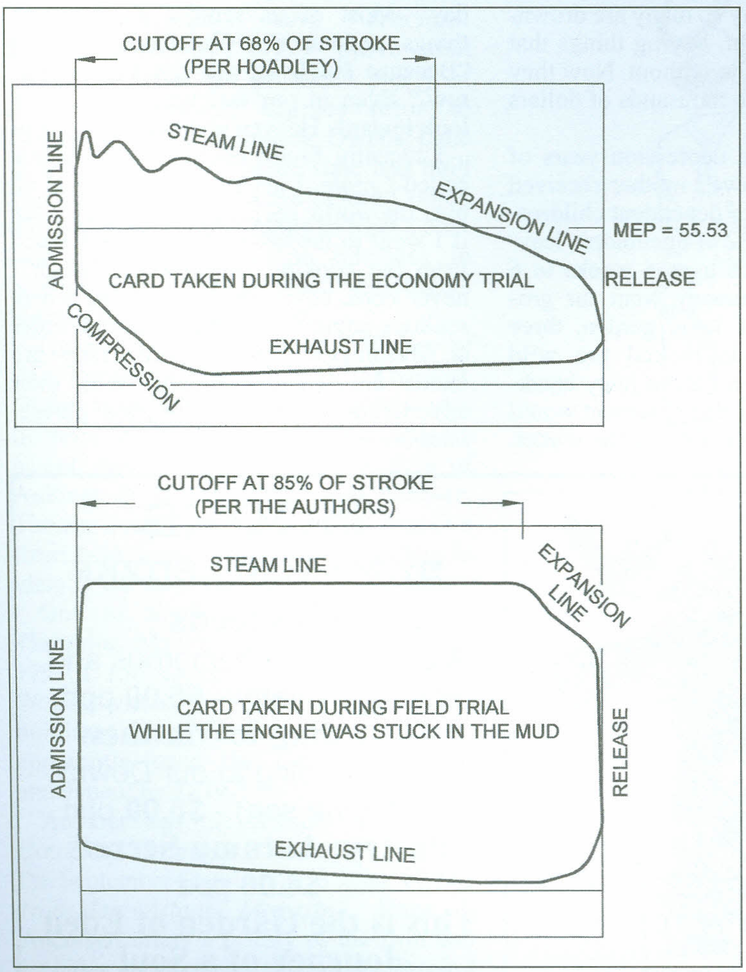
THE INSTRUMENTS USED TO COLLECT THE DATA IN HOADLEY'S REPORT

The Prony Brake

Its Design and Construction

Hoadley provided a detailed description of his brake, which appears to have been assembled specifically for use at these trials. (See the illustration of Hoadley's Prony brake that is based on his description.)

On page 55 Hoadley related, "The whole apparatus being new, neither the concavity in the brake-beam nor the maple blocks in the binding strap fitted perfectly to the pulley, and the surface of the pulley was somewhat rough, so that a little wearing away of both the wood and the iron was constantly going on . . . ." Well-lubricated wooden blocks on a Prony brake do not wear perceptively, even if they do not fit well to the brake drum. Hoadley's description indicates that the Prony brake in the 1881 engine trials had insufficient lubrication, unless the surface of the pulley was extremely rough. Reliance on such a rough pulley does not reflect well on those who allowed its use.



The different points of cutoff that are shown on these two cards offer conclusive proof that, during the economy trials, the Frick was running hooked-up. Courtesy Bruce E. Babcock

This brake was not easy to operate. It was difficult to adjust the load on the brake, and it would occasionally almost instantly arrest the engine. These are likewise telltale signs that the brake was not properly lubricated. A Prony brake will automatically increase the load on an engine when the brake is in need of lubrication, but the likelihood of instantaneous arrest is so rare as to be virtually nonexistent. Hoadley makes no mention of lubrication. The cooling water was discharged onto the top of the brake beam and flowed down through holes to the surface of the drum where it dispersed the heat. The water was expected to serve the double purposes of coolant and lubricant. This arrangement might work for short runs, but the probability of completing a five-hour economy trial without lubrication is less than slim. Another characteristic of the brake that could have contributed to the instantaneous arrests was the narrow width of the brake wheel. It was only four inches wide. Accordingly, each square inch of contact between the wood blocks and the brake drum had to absorb an unusually high horsepower.

The absence of any method of lubrication was not the only unusual feature. On page 55 Hoadley described how "[t]he entire weight of the balanced brake was counterbalanced by an equal weight, acting by means of a rope over suitable pulleys." Hoadley's trapeze arrangement consisting of ropes, pulleys, and weights is reminiscent of one of Rube Goldberg's wondrous creations. The difference is that Rube's devices always accomplished a desirable function. Hoadley's arrangement not only served no useful purpose but also could have introduced errors had the rope not been properly attached to the brake beam. Such arrangements are rare, if they exist at all, and they certainly were not necessary for Hoadley's economy trials.

Another curious attribute of the Prony brake was that the brake beam extended an extra three feet to the left. This was probably the feature that prompted Hoadley to refer to the brake as "balanced." Rather than balancing the brake, this extension made it necessary to add additional weights at the opposite end to overcome the effect of the beam's extra length. Once the additional weight was added at the right, that same amount would then have been needed on the Rube Goldberg trapeze-if it were to counterbalance "[t]he entire weight of the balanced brake." The extension served to limit the counterclockwise rotation of the brake beam, but this could have been accomplished by a simple strap over the top of the beam at the opposite end.

The Operation of the Brake

Hoadley's Prony brake was not only unconventional but also operated unconventionally. The brake was operated throughout the economy trials with a weight of 77.5 pounds located 5 ¼ feet from the center of the brake wheel. This weight and disturn the brake, regardless of the speed. With this arrangement the horsepower required to turn the brake was determined by the sizes of the flywheels and the speeds of the engines, not by the capabilities of the engines.

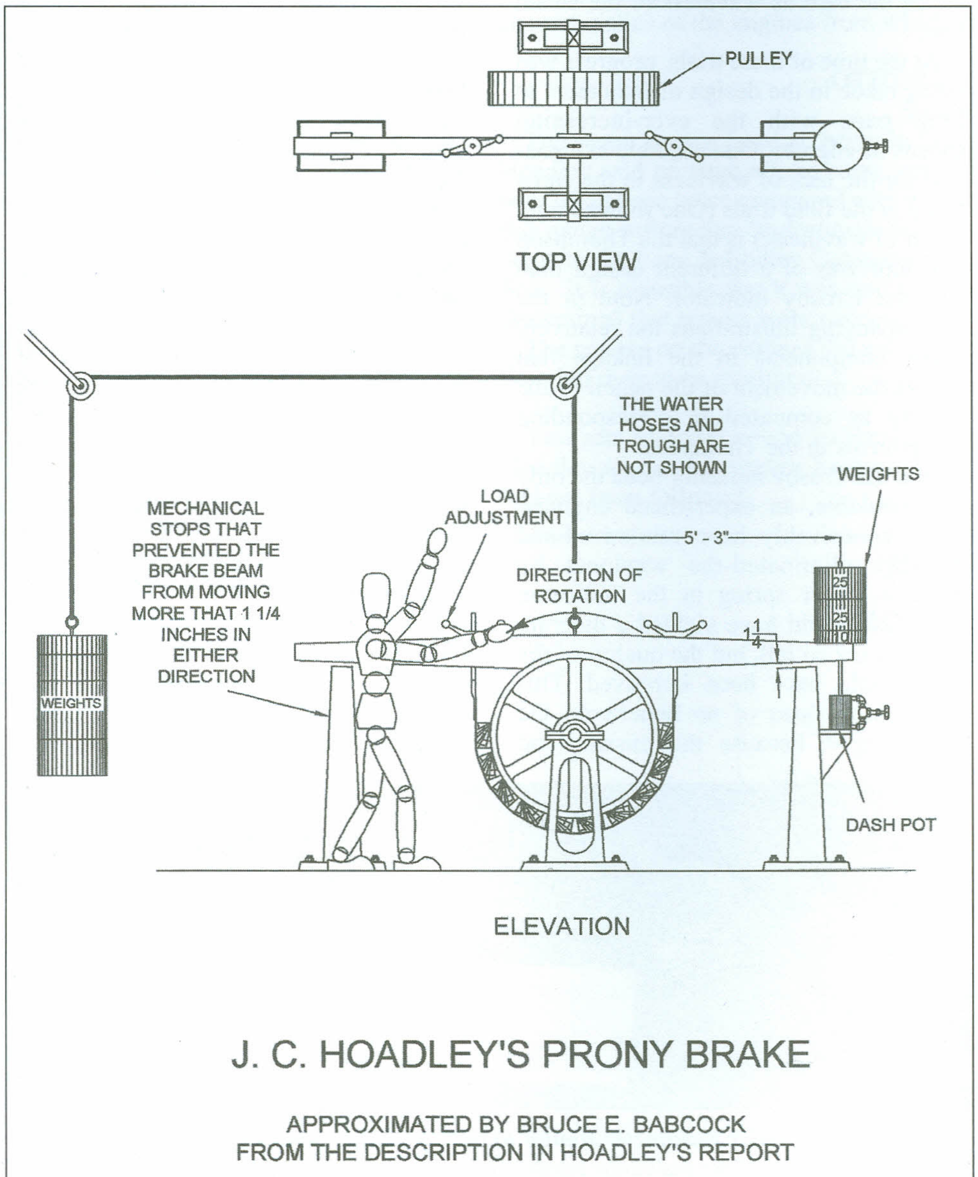
Hoadley reported these horsepower results
(which were unrealistically carried to two decimal places):

Geiser - 21.52 HP with the engine (not the brake) turning 231.65 revolutions per minute
Frick - 19.26 HP with the engine turning 221.65 revolutions per minute
Huber - 16.63 HP with the engine turning 273.53 revolutions per minute

The Huber recorded the least horsepower simply because it turned the brake (not the engine) at 220 RPM. The Geiser recorded the most horsepower because it turned the brake 280 RPM. The Frick turned it 250 RPM. There is no indication that any of the engines were working at their maximum.

In his many pages of data, Hoadley did not mention the rated horsepower of any of the three engines.

Not all of the problems associated with the operation of the Prony brake were entirely the result of its design. On page 56 Hoadley reported that it was necessary to tighten the binding straps from time to time to keep the brake in balance: "If this tightening could have been done regularly, and in just the right degree, the brake-beam might have been kept quite steadily in the true, level position. This desirable result was sometimes very nearly obtained for hours together. Often, however, a little nervousness or indiscretion on the part of the attendant would give rise to considerable vibration, sometimes as rapid as the dash-pot would permit, and occasionally disastrous in their consequences." He related one instance of an engine that was stalled by the brake because the man who was attending to the brake left his post to assist in another area.

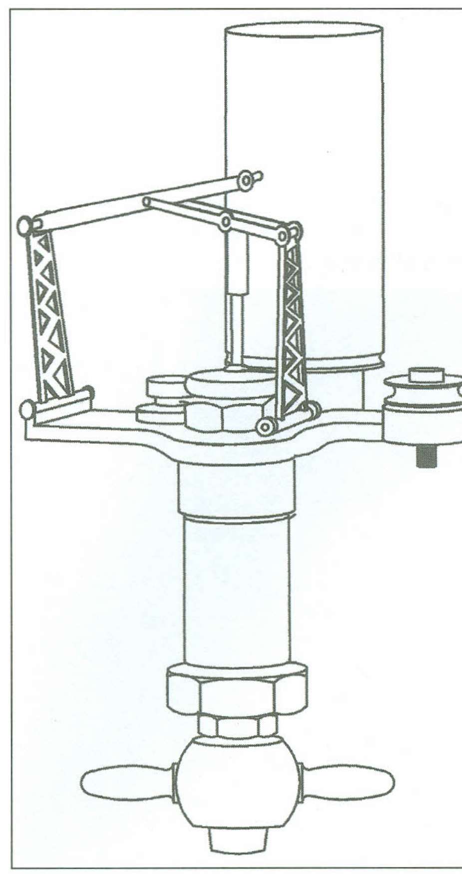


Hoadley's Prony brake might have looked like this. The counterbalance weights at the left, the unusual extension of the brake beam, and the lack of any means of lubrication other than the cooling water are all departures from conventional practices. The design of the brake is not the only quality that was unconventional; the fixed weights at the right indicate that the brake was operated unconventionally. Courtesy Bruce E. Babcock

The Steam Engine Indicators and Indicator Cards

The Indicators

The steam engine indicators used in the trials included a Crosby indicator and a pair of Thompson indicators (introduced in 1875) made by the American Steam Gauge Company. (See the illustrations depicting Crosby and Thompson indica-



This illustration depicts an early Crosby steam engine indicator similar to one that was used in the economy trials. Of note are the heavy lattice links that guide the movement of the pencil and the large diameter of the piston rod. These features could have caused the waves in the steam line on the indicator cards. Courtesy Bruce E. Babcock tors.) The waviness of the lines in the diagrams reveals that the Crosby indicator was not well suited for use at speeds above 200 revolutions per minute or that it was not equipped with the appropriate spring. The waviness is not severe enough to cause serious errors, but it is not what would be expected from a highly skilled engineer.

The Thompson indicator that was installed on the Geiser engine had been used elsewhere at the exposition where, by chance, its barrel spring had been adjusted for use at a speed that was appropriate for the Geiser. The other Thompson indicator, which was installed on the Frick, had not been adjusted accordingly and consequently could be employed only at low speeds. It is obvious that no one prepared the indicators prior to the start of the trials.

No indicator was installed on the Huber during the field trials because the vertical cylinder was located partly behind the driving wheel.

The waviness of steam lines on the cards taken with the Crosby indicator at the economy trials is almost completely absent from the cards taken with the Thompson indicator during the field trials. As the waviness is consistent on the cards from all three engines, it is easy to conclude that it was caused by the indicator and not by the characteristics of the engines. It was easy to obtain precise cards with no waviness from the large Corliss engines that lumbered along gracefully at a hundred revolutions per minute or less. Getting good cards from engines running above 200 RPM was not so easy. During the economy trials, the Geiser ran at 231 RPM; the Frick, at 221 RPM; and the Huber, at 273 RPM. At these speeds the inertia of the linkage that guides the movement of the pencil causes the spring and ultimately the pencil to oscillate instead of following the variations in the pressure of the steam in the cylinder. These oscillations appear at the end of the admission line where the pencil is traveling the fastest and are recorded on the card as waviness in the steam line.

At the time of these trials, progress was being made in the design of indicators to keep pace with the ever-increasing speeds of engines. One possible explanation for the lack of waviness in the cards taken at the field trials (One showed only a hint of waviness.) is that the Thompson indicator was of a different design than was the Crosby indicator. Note in the accompanying illustrations the relatively heavy components in the linkage that guides the movement of the pencil of the Crosby as compared to corresponding components in the Thompson.

Had the Crosby indicator been the only one available, an experienced engineer could conceivably have minimized-and possibly eliminated-the waviness by using a stiffer spring in the indicator. Doing so would have yielded a diagram that was not so tall, but the quality of the card would have been improved. This would have been of no benefit on the Frick engine because the missing rod packing made any card useless.

The Cards

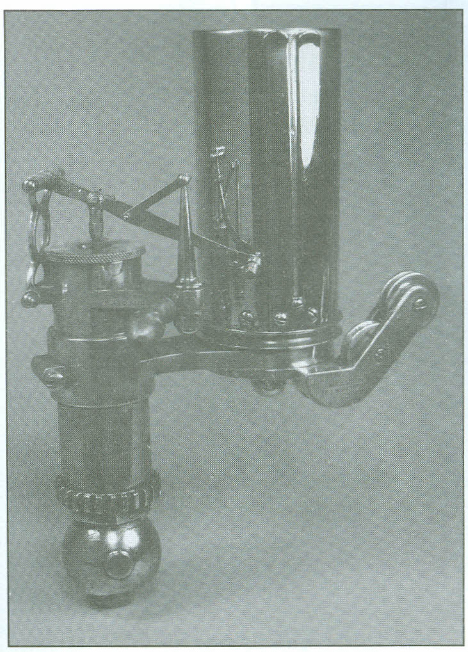
To understand the indicator card from the Frick engine in particular and the cards from all three engines in general, it is illustrative to take a close look at one card.

Working up the card taken from the rod end of the Frick engine leads to a Mean Effective Presure (MEP), or average pressure in the cylinder, of 45.58 pounds per square inch. This compares reasonably with Hoadley's figure of 47.31 pounds per square inch. The difference could be attributed to errors made in tracing.

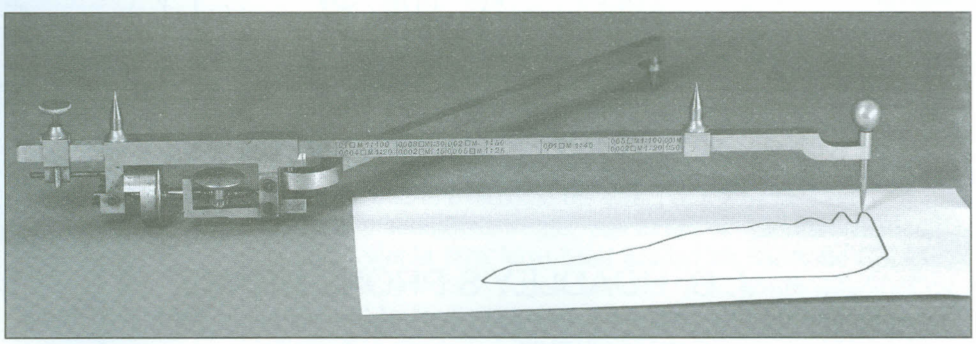
Entries on page 60 show that the cards in Hoadley's report are composites of many cards. His account on page 60 of how he arrived at these mergers is no easier to follow than is Abbot and Costello's classic comedy routine *Who's on First:* "A very considerable number of diagrams were measured . . . . To each line so measured was given a 'weight,' corresponding to the number of perfect lines on the same card which it fairly represented; the resulting mean effective pressure found for this line was multiplied by its assigned weight, and so a mean was obtained fairly representing a considerable number of independent lines. The diagram which best agreed with this mean was selected to represent the mean card, and the normal lines drawn upon it truly represent the mean within the limits of accuracy aimed at."

His explanation does little to explain how the card on page 80 was generated.

Frank Lederle, a graduate of the Stevens Institute of Technology, measured the indicator cards by using an



Shown here is a Thompson steam engine indicator made by the American Steam Gauge Company. This is the type of indicator that was used to take the cards at the field trials. Of special note is the lightweight linkage that guides the movement of the pencil. Courtesy Bruce E. Babcock



Here is an Amsler polar planimeter similar to the one that Frank Lederle might have used to measure the area of the indicator cards. The area of the diagram divided by its length yields the average height. From this simple equation the average pressure in the cylinder (MEP) can be determined. Polar planimeters were widely used in science, engineering, medicine, and surveying. This one was designed specifically for use with cards from steam engine indicators. If the points on top of the long arm are adjusted to the length of the diagram, the reading from the planimeter will be the average height and will eliminate one step in the calculations. Courtesy Bruce E. Babcock

Amsler polar planimeter. Hoadley was limited in the number of cards that could be analyzed because "there was no sufficient corps of assistants at hand . . ."

For the purposes of this article, the card from the rod end of the Frick engine was selected because the pressure at the point of release was significantly lower on that end than on the head end of the cylinder. The difference most likely was from the loss of steam through the stuffing box after the packing blew out.

To determine to what extent the leak affected the shape of the indicator card, an idealized expansion line using the procedure described by William Barrett LeVan in his *Steam Engine and the Indicator* (1889) was drawn. (See the accompanying illustration depicting how an idealized expansion line compares with what Hoadley presented as the actual expansion line.) The almost perfect fit of the idealized expansion line to the actual line is not realistic, especially when it is known that there is a major leak at the rod packing. Idealized expansion lines do not match the actual lines so closely unless there is leakage into the cylinder either through the valve or past the piston. LeVan offers this explanation: "It is not claimed that the theoretical rate of water consumption as deduced from the diagrams can ever be realized in practice. A certain amount will always be lost from condensation, leakage, and unevaporated foam in the steam, which no process of calculation makes allowance for." The close fit between Hoadley's actual expansion line and the theoretical line raises serious doubts about the credibility of what he has drawn as the actual line. The only way that the ideal line could have approached the actual line would have been if there had been enough leakage into the cylinder to offset both the leakage around the piston rod and the condensation that naturally occurs in the cylinder. According to Terrell Croft in *Steam Engine Principles and Practices* (1922), "A leaky exhaust . . . valve may cause the expansion curve to lie exactly on the theoretical [line] or below it... ." It now appears that the cards that showed the effect of the leakage might have been rejected and not included in his composite line because they did not represent what Hoadley considered to be perfect lines.

Another significant factor is that the engine was reported to have consumed 47.94 pounds of water per hour for each indicated horsepower. The steam rate as calculated from the cards showed that it consumed only 30.52 pounds of steam per hour for each indicated horsepower. Here are data for comparison:

	Huber	Frick	Geiser
Water	46.94	47.94	35.40
Useable Steam	40.47	30.52	27.38
Ratio of steam to water	.86	.64	.77

It is important to remember that Hoadley's indicator cards are suspect. The true number for the Frick engine might have been even less, had the cards not been manipulated as described. The description of the leak supports this allegation.

It is not likely that George Frick would have allowed an engine that was leaking badly past the piston to be entered in the trials.

There is ample reason to believe that the cards in Hoadley's report do not represent the characteristics of the engines from which they were supposedly taken.

OTHER INSTRUMENTS

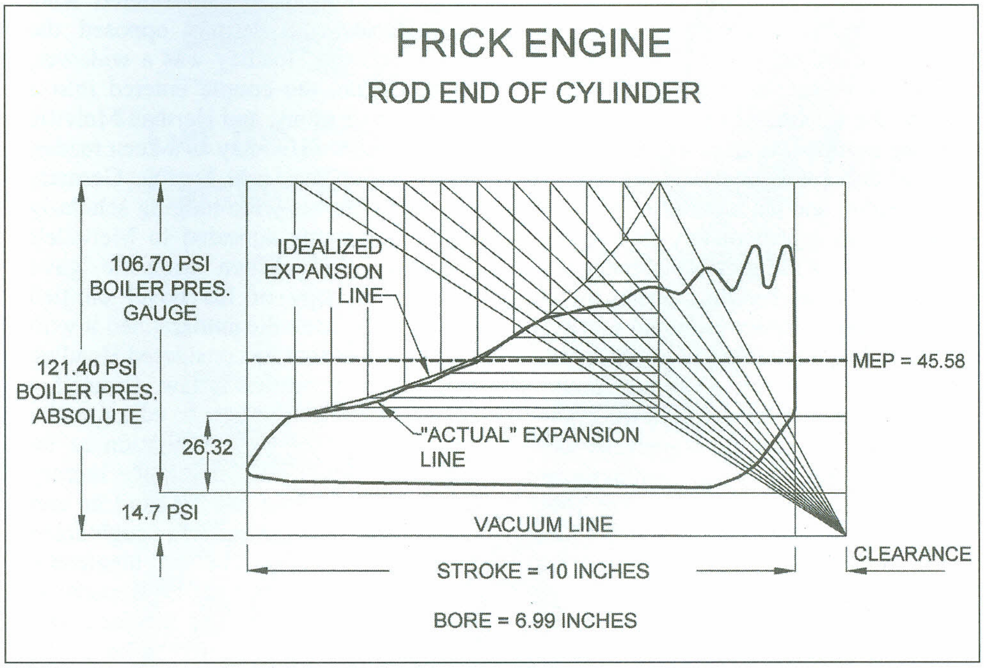
Steam Gauges

The steam gauges fared no better in the trials than did any of the other instruments. As Hoadley said on page 60, he came armed with "a new Crosby gauge of great delicacy, which had been twice compared with a mercury column . . . ." After arriving at Cincinnati, this gauge suffered an "unfortunate fall" and had to be tested again. The gauge was first taken to the Lane & Bodley Company and then to a gauge manufacturer, Wm. Kirkup & Son. It is plausible that it was sent to Wm. Kirkup & Son because Lane & Bodley had determined that repairs were needed.

The gauges on the engines did not agree with the Crosby gauge, but there is no indication that they were recalibrated.

Scales

Two sets of 1,000-pound Fairbanks scales weighed the water for the economy trials. Hoadley expressed concern because his prescribed procedures for measuring the water had not been followed.



This diagram shows the actual expansion line lying nearly on top of the theoretical expansion line. This is a condition that is extremely unlikely because of the major steam leak at the piston rod. The leak would have reduced the pressure in the cylinder causing the actual line to fall well below the theoretical line. This card does not represent the conditions that existed in the cylinder. Courtesy Bruce E. Babcock

A similar pair of scales was used to measure the coal.

Hoadley questioned the accuracy of the measurement of the water for the field trials because of the "doubt that attaches to the suspiciously round numbers given by the city scales, on which the weighing was done."

Revolution Counters

Revolution counters were installed on the engines and on the Prony brake. The total number of revolutions for an entire test was recorded, with averages taken from time to time. On page 59 Hoadley noted, "For fear of accidents to the counters, the speed of both [the engine and the Prony brake] was taken with an ordinary speed counter during one minute, every quarter of an hour."

The readings on the revolution counter on the engine were compared with the readings from the one on the Prony brake to determine the amount of slip. There is no suggestion of what use - if any - was made of the relatively vast amount of information that Hoadley collected; for example, the 2.6 percent slip when the Huber was on the brake as compared to .9 and 1.0 percent for the other two engines may imply that his estimate of the diameter of the Huber's flywheel was in error, but Hoadley remained silent about such important matters.

The revolution counter on the Frick engine broke during the field trials.

Reducing Motion

An important instrument that Hoadley did not mention is the reducing motion: a device to connect the steam engine indicator to the crosshead of the engine. A reducing motion would have reduced the travel of the crosshead from eight inches for the Huber and ten inches for the Frick and Geiser to approximately four or five inches, which is the greatest distance that an indicator can handle. Prior to the advent of the compact reducing motions in the 1880s, reduction in motion was customarily accomplished through homemade devices such as pendulums, brumbo pulleys, and reducing wheels, as well as commercially available pantographs. It is important to know what was used because a simple pendulum can introduce errors into an indicator card. It is not likely that an 1880s compact reducing motion was used at the start of the decade.

Who Was John C. Hoadley?

John Chipman Hoadley was a towering figure in the history of American engineering. Born in 1818 on a farm in Turin, New York, he attended the Utica Academy between the years of 1833 and 1836 and studied algebra, geometry, and surveying. In 1836, Hoadley worked as a surveyor for an engineering party that was enlarging the Erie Canal. From 1837 until 1844, Hoadley served as a draftsman in a Utica machine and pattern shop. Toward the end of 1844, Hoadley journeyed to Clinton, Massachusetts, to work for Horatio and Erastus Bigelow, builders of the vast plant of Lancaster Mills. Hoadley laid out the town's streets, and his exacting plats still exist. Hoadley and the Bigelows organized the Clinton Wire Cloth Company. In 1846 and 1847, Hoadley lectured at the Mechanics' Institute founded by the Bigelows. In 1847, Hoadley married Charlotte Sophia Kimball; she died less than a year later. In 1848, Hoadley and Gordon McKay entered into a business partnership to manufacture textile mill machinery, steam locomotives, and water wheels in Pittsfield, Massachusetts. For approximately four years, the firm of McKay & Hoadley thrived. In 1852, Hoadley, who had a degree in mechanical engineering, and McKay moved to Lawrence, Massachusetts, to superintend the Essex Company's machinery division, which soon became known as the Lawrence Machine Shop.

In 1853, Hoadley married Catherine "Kate" Gansevoort Melville, sister of the renowned author Herman Melville. Kate's mother, Maria, considered Kate incorrigible, and Herman opposed the match because Hoadley was a widower; all the same, the couple entered into a state of matrimony, and Herman Melville came to regard Hoadley as a keen reader. Hoadley had mastered French, German, Greek, Latin; his wide-ranging scholarly accomplishments appealed to Melville's brilliant mind. When Melville gave Hoadley a copy of his novel entitled Moby-Dick, Melville autographed it with the sentiment that he considered Hoadley closer than a brother-in-law. Himself a poet, a nonfiction writer, an editor, and a defender of Melville's reputation as an author, Hoadley made room for literary interests throughout his life, and he and Kate raised their son and two daughters to appreciate literature. In the nineteenth century, there was not yet the separation between the fine arts and the industrial arts that there would come to be in the twentieth century. It is no surprise that Hoadley collected valuable works of art including two rare vases that were commissioned by the Committee of Congress on the Capitol after the Civil War.

In 1857, Hoadley spent one term as a state representative. The Panic of 1857 caused the 1858 demise of the Lawrence Machine Shop. In 1861, the New Bedford (Massachusetts) Copper Company brought in Hoadley to run the firm as a special agent during the Civil War. In 1862, Massachusetts sent Hoadley, a state militia captain and a staunch abolitionist, to England to study harbor ordnance with a view toward improving Union defenses. At the end of the War Between the States, the resourceful Hoadley began to manufacture portable steam engines after his own designs under the name of J. C. Hoadley & Company. About eight hundred engines had been sold by the end of the decade. In 1869, Hoadley's portable engine that was named *Cinderella* received a gold medal, the highest award, at the Fair of the Massachusetts Charitable Mechanic Association. As sole Western agent, Treadwell & Company in San Francisco, California, sold many Hoadley engines. In 1872, Hoadley was a member of the Electoral College. The Panic of 1873 forced Hoadley to close his factory. Beginning in that year, Hoadley served on the state board of health. By 1875, his firm was reorganized, but the manufacture of portable engines continued for only two years. According to *Reports and Awards of the International Exhibition, 1876,* Hoadley's stationary engine at the Centennial Exposition in Philadelphia was subjected to trials and was proved superior to similar engines. The financial downturn in 1873 led to what historians call the Long Depression, which did not begin to dissipate until 1878. By 1877, Hoadley's firm was insolvent. From 1878 through 1879, receivers disposed of the property. The loss of his company did nothing to dim his stellar reputation.

When Hoadley arrived in Cincinnati in 1881, he was a leading light among civil and mechanical engineers. As the engines chuffed up Tower Hill Street during the field trials with Hoadley's carriage in close pursuit, what must Hoadley have thought of the alligator, bears, buffalo, deer, elephant, elk, exotic birds, hyena, monkeys, raccoons, and tiger in the Cincinnati Zoo, which had opened in 1875 and which was separated by only a fence from the dead end of Tower Hill? When the engines popped off, did the monkeys scream? Did the birds shriek? Did the elephant trumpet? Did Hoadley imagine that the hyena was laughing at him? On page 82, Hoadley reported that mounted police accompanied the engines to keep curious crowds at a safe distance and to calm approaching horses, but were they able to quiet the tiger? Walter Laidlaw rode with Hoadley. Born in Scotland in 1847, Laidlaw was a draftsman at the Lane & Bodley Company in Cincinnati. (In 1887, Walter would join his brother Robert and John Wesley Dunn to organize the Laidlaw & Dunn Company, the predecessor to the widely recognized firm of Laidlaw-Dunn-Gordon and to the Laidlaw Works.) Did Laidlaw, who had arrived in America earlier that year, break into a colorful bit of Scottish brogue when the alligator snapped its jaws? The engine trials cost $245. According to measuringworth.com, that amount is equivalent to $5,322.83 today. While the engines stirred the zoo animals to a frenzy, maybe Hoadley shook his head and thought he was not being paid nearly enough! The historical record is silent about what portion of the $245 went to Hoadley, but, in the late 1800s, Geiser published a catalog with this boast on the back cover: "$500 in gold premium at Cincinnati, O, Exposition 1881, the highest ever awarded in the U.S."

A devout Episcopalian, Hoadley's mistrust of Catholicism may have contributed to his disdain for the traction engine built by Edward Huber, who was a Catholic. Hoadley died in Boston in 1886. His extensive library was auctioned in 1887.

Across a lifetime characterized by-yes-far more successes than failures, Hoadley authored *The Portable Steam Engine* (1863), *Description of the Portable Engine Cinderella* (1870), *Memorial of Henry Sanford Gansevoort* (1875), *The Curve of Compression in the Steam Engine* (1878), *The Combustion of Fuel for Generation of Steam* (1881), *The Specific Heat of Platinum* (1882), *Steam Engine Practice in the United States* (delivered before the British Association for the Advancement of Science in Montreal in 1884), and *Warm-Blast Steam-Boiler Furnace* (1886). Hoadley was an early member of the American Society of Mechanical Engineers (ASME), a founder of the Berkshire Athenaeum, and a founding trustee of the Massachusetts Institute of Technology (MIT).

What Was the Ohio Mechanics' Institute?

The Ohio Mechanics' Institute sponsored the engine trials at the 1881 Cincinnati Industrial Exposition. The institute was organized in 1828 to suit the needs of Cincinnati businesses by instructing young artisans and apprentices in various trades through lectures, discussions, and participation in the Queen City's great industrial exhibitions that were held between 1869 and 1888. The first of these fairs were hosted in Exposition Hall, which was also called Saengerfest Hall when the North American Saengerbund, a German music festival, was held there in the summer of 1870. Exposition Hall measured 250 feet by 100 feet and was 80 feet tall. Three temporary buildings communicated with the main structure. The current Music Hall, a Cincinnati landmark, opened in 1878. Anyone who has attended an event within the splendid edifice can attest to the fact that Music Hall is one of the grandest and most imposing auditoriums in the nation. Its outer wings were intended for the annual industrial exhibits, as well as for shows of paintings and other fine art.

Although - with justice - the industrial expositions are said to have begun with a modest exhibition in 1869 and a larger event in 1870, the Ohio Mechanics' Institute was sponsoring fairs to showcase the variety and quality of home industries to prove their superiority over imported goods as early as 1838. The institute numbered among its members machinists, patternmakers, carpenters, plumbers, blacksmiths, foundrymen, toolmakers, and engineers. The students earned professional certificates by spending four hours per week attending evening lectures and honing practical skills. It is often said that Thomas Alva Edison, who spent many hours in the institute's library, regarded the Ohio Mechanics' Institute as his alma mater. Edison looked back on Cincinnati with fondness. We wonder if Hoadley did.

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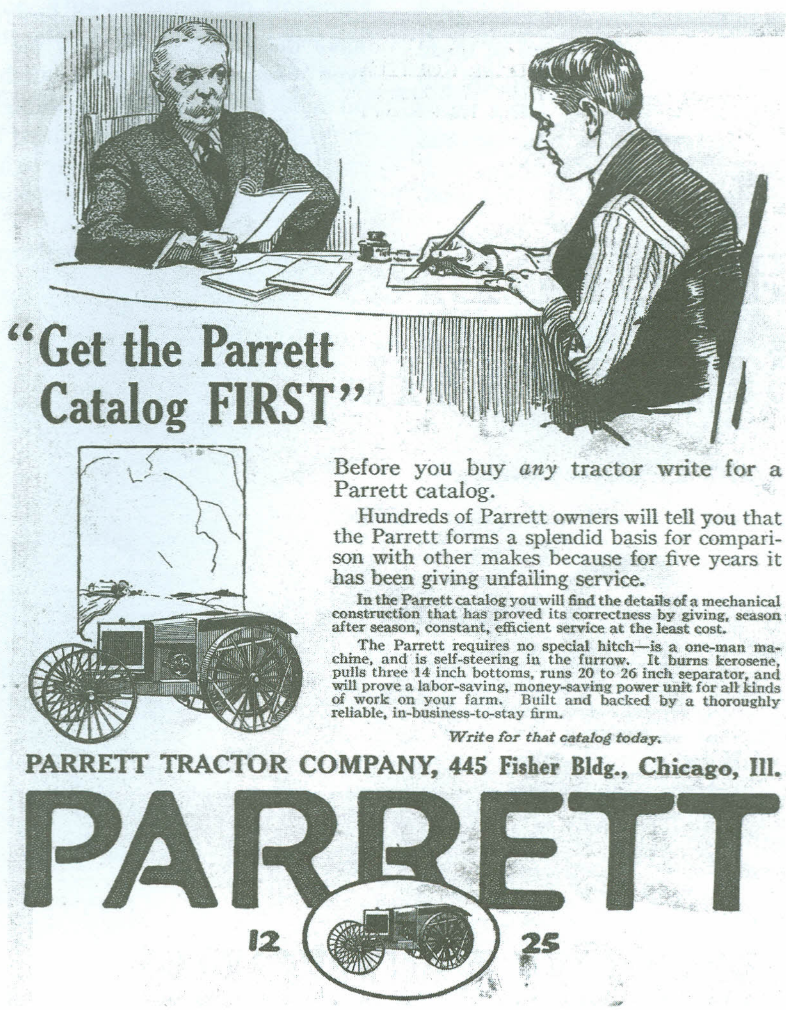

Ad from an old American Thresherman Magazine. From the collection of Morris Young.