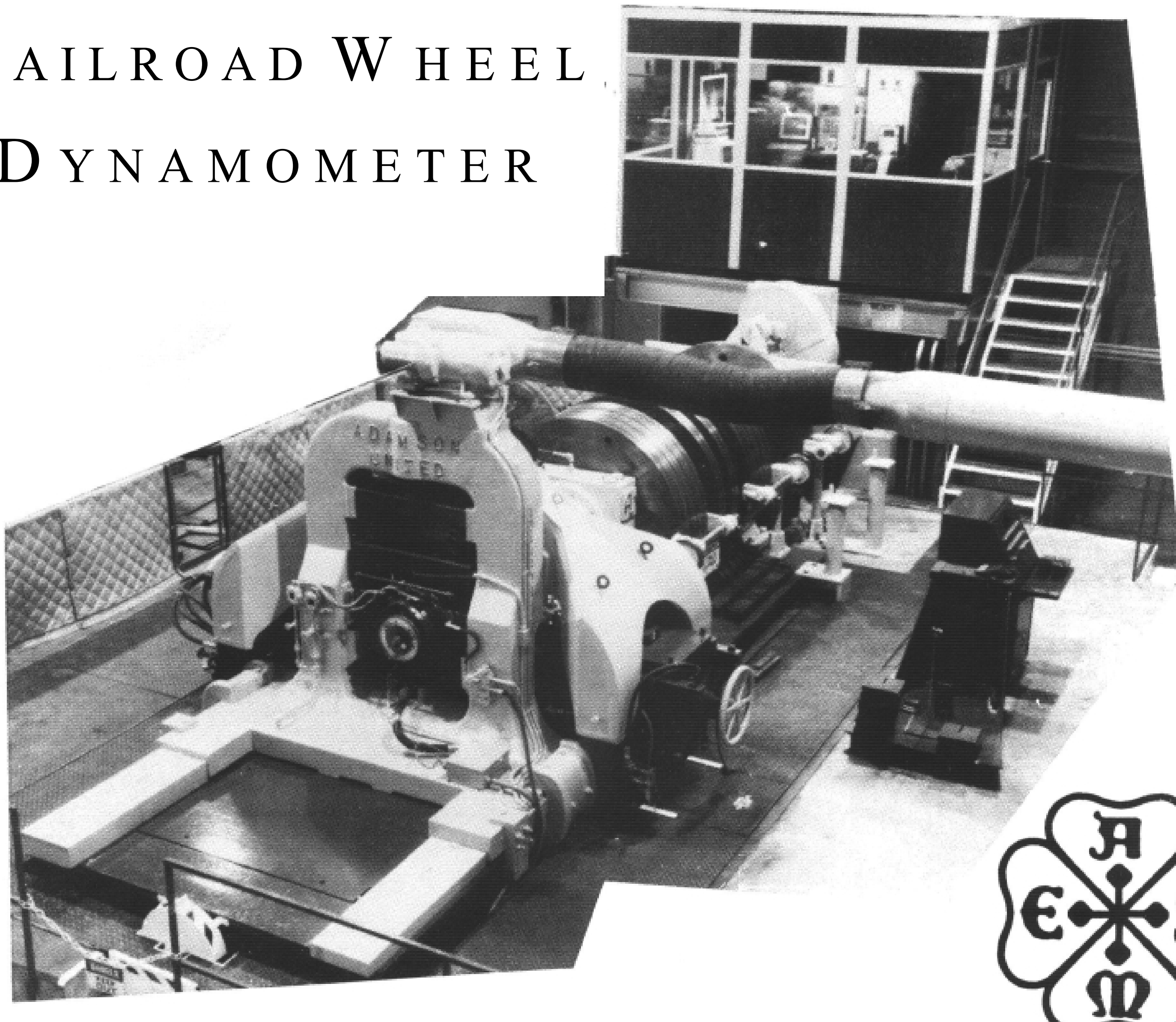
# Association of American Railroads

CHICAGO TECHNICAL CENTER

# Railroad Wheel Dynamometer



The American Society *of* Mechanical Engineers

***91** st* National Historic Mechanical Engineering Landmark

***Nov. 29, 1988***

## AMERICAN SOCIETY OF MECHANICAL ENGINEERS

## RAIL TRANSPORTATION DIVISION

## CHICAGO SECTION, REGION VI

### NATIONAL HISTORIC MECHANICAL ENGINEERING LANDMARK
### RAILROAD WHEEL DYNAMOMETER
### ASSOCIATION OF AMERICAN RAILROADS
### 1955

**THIS INERTIA DYNAMOMETER TESTS RAILROAD WHEELS UNDER CONTROLLED CONDITIONS EXCEEDING NORMAL SERVICE: (A) MAXIMUM BRAKE SHOE FORCE OF 40,000 POUNDS; (B) SPEEDS UP TO 178 MPH; (C) THE LARGEST EQUIVALENT INERTIA WHEEL LOAD IN RAILROAD PRACTICE OF 127,000 POUNDS; (D) SIMULTANEOUSLY APPLYING LATERAL AND VERTICAL LOADS OF 15,000 POUNDS AND 60,000 POUNDS, RESPECTIVELY (A UNIQUE CAPABILITY). SPECIFICATION: JOSEPH M. WANDRISCO (US STEEL); DESIGN AND CONSTRUCTION SUPERVISION: REX C. SEANOR (ADAMSON UNITED). IN 1983 IT WAS MOVED FROM US STEEL TO THE AAR. COMPUTER CONTROL ADDED IN 1987.**

INTRODUCTION

The railroad wheel supports the car or locomotive as it rolls on its tread along the rail and guides the vehicle through curves and switches with its flange which projects outward from the tread. The cast or wrought steel wheel also acts as a brake drum. When brakes are applied, the brake shoes press against the wheel tread, and through their rubbing friction slow down, stop, or control train speed. As running speeds and weights on wheels doubled and redoubled in the later part of the 19th century, the combination of mechanical and thermal stresses often caused cracks to develop in the cast iron wheels. Some of the cracks led to loss of large chunks of wheel material and disastrous wheel failures (train wrecks).

About 100 years ago, railway mechanical engineers and metallurgists began formal investigation of cast iron wheel failures, and of wheel and brake shoe design, materials and manufacture. This resulted in development of dynamometers so full-sized wheels and brake shoes could be tested under controlled conditions to improve service performance and enhance railroad safety.

Prior to the use of dynamometers, only a drop test was used to determine the resistance to fracture of cast iron wheels. However, the drop test did not adequately predict performance in grade braking (Ref. 1).

EARLIEST WHEEL AND SHOE DYNAMOMETERS

On the Southern Pacific Railroad, every route into California involves continuous heavy grade-braking for 20 to as long as 85 miles, as from the Sierra summit at Norden down to Roseville. To identify and cull out inadequate wheel designs and manufacture, Southern Pacific designed and built the first known full-scale wheel and braking dynamometer in 1891. A description of this machine and many test results appeared in the 1892 Master Car Builders' Association (MCB) Proceedings (Ref. 1).

Figure 1 shows a full wheel set, two wheels mounted on an axle, resting on track or drive wheels powered by a Corliss steam engine. An adjustable spring force beam loaded each journal, a brake beam with cast or wrought iron brake shoes applied braking forces to both test wheels, a scale beam measured retarding forces, and a brake cylinder and lever gave typical braking ratios and forces on freight and passenger car wheels of the day. Starting with 10 psi, brake cylinder pressure was increased 5 psi each five minutes through 50 or more psi. At 30 mph, up to 100 braking hp per wheel was generated which cracked any but the best chilled iron wheels. Continued difficulties in the next decade or so led Southern Pacific to start using all-steel wheels (wrought steel at the time).

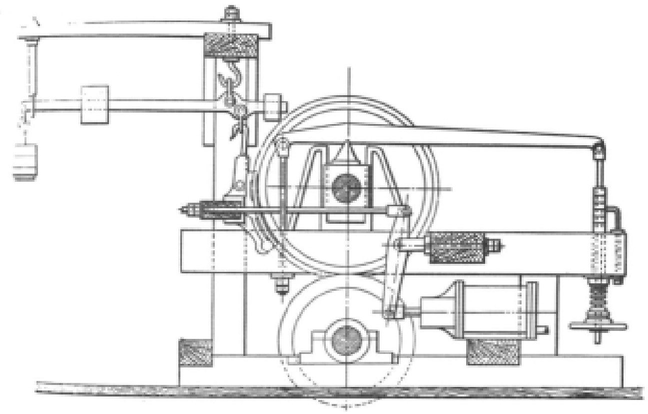


Figure 1. Southern Pacific RR 1891 Full Wheel Set Dynamometer.

In 1893, the MCB Association, forerunner of the Mechanical Division of the Association of American Railroads (AAR), determined that a full-scale brake shoe testing machine was essential to establish an industry-wide standard for friction and wear of the many makes of brake shoes in use (Ref. 2-4). With assistance from the Pennsylvania Railroad (PRR), George Westinghouse (later ASME President) and William A. Sellers Co., the brake shoe testing machine in Figure 2 was manufactured in the PRR shops and assembled in Westinghouse Air Brake's plant in Wilmerding, PA. Here the new machine and its dynamometer were put through exhaustive initial and operating tests. At the time, "dynamometer" referred only to the mechanical force measuring apparatus, which along with speed, time and distance we now include in the term "instrumentation". In 1900, the MCB testing machine was transferred to Purdue University in West Lafayette, IN (Ref. 5) where the official MCB tests were continued until the machine was scrapped in 1942.

Figure 2. Master Car Builders' (MCB) Brake Shoe Testing Machine Designed 1893.

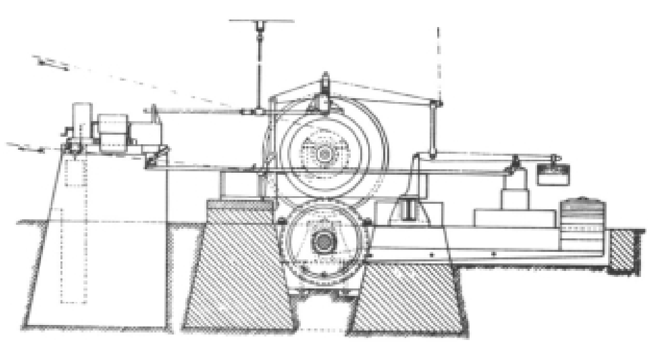
THE STEEL REVOLUTION: LONGER HEAVIER CARS & TRAINS.

The years from 1895-1905 saw steel rapidly take over in freight car construction and 40- and 50-ton capacity freight cars became common as all wood cars quickly disappeared. In passenger service, the move to stronger and safer all-steel cars became a reality before 1910. Two results of the MCB 50-car train air brake tests of 1886-7 were the conversion to the quick-action automatic air-brake starting in 1889 and the invention of the energy-absorbing friction draft gear. These three developments permitted longer and heavier freight trains to boost railroad capacity during the 1905 - 1925 era.

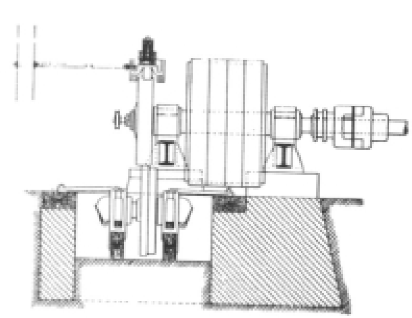
As car weights increased, heat input to the wheel treads increased. Higher operating speeds with more powerful locomotives increased the braking heat during stopping by the square of the speeds. These factors placed even further demands on the integrity of the wheels.

Several other dynamometers were built to investigate braking and its effect on shoes and wheels. American Brake Shoe and Foundry Co. designed and started operating the first of several dynamometers at their Mahwah, NJ, works in 1908 to study the effects of increased braking loads. The Mahwah dynamometer was used for detailed analyses of the several types of shoes used in the Pennsylvania-Westinghouse steel passenger-train tests of 1913 (Ref. 6). These tests brought together an improved Universal Control Valve with an electro-pneumatic option, and clasp-brake rigging (two shoes/wheel) with 150 percent braking ratio at 100 psi (1.5 x car weight). This system enabled a 1200-ft emergency stop from 60 mph with twelve 61-ton steel cars and a 200-ton 4-6-2 K2s steam locomotive and tender. Around 1910, the University of Illinois constructed a braking dynamometer. As nearly as can be determined, the Pennsylvania RR designed and built a brake-shoe and wheel testing machine about the time of WWI.

Although the quality of chilled cast iron wheels improved through the research of the Association of Chilled Car Wheel Manufacturers, steel steadily took over for passenger and locomotive wheels. Passenger car weights steadily increased to the 90-ton range through the 1920s and into the 1930s when mechanical air conditioning was added. Locomotive tenders similarly began their growth to truly mammoth size which required wrought steel wheels.



Elevation.



Section Showing Jaw-type Clutch.

## THE DAWN OF A NEW AGE: DIESEL-ELECTRIC STREAMLINERS

1933 and 1934 saw the light-weight diesel-electric streamliners burst upon the scene with Union Pacific's aluminum "City of Salina" and the Chicago, Burlington and Quincy's stainless steel "Pioneer Zephyr". Light weight, high speeds, air-conditioned comfort and modern design were the watchwords in helping railroads regain many passengers lost to the automobile in the late '20s and early '30s. After covering the 1070 odd miles from Denver to Chicago at over 77 mph average, and running long distances at 90 and 100+ mph, the "Pioneer Zephyr" was proudly displayed at the Chicago World's Fair. This first Zephyr and its 600-hp General Motors 201-A two-cycle diesel engine was ASME's 54th National Landmark in 1980 and is on display at Chicago's Museum of Science and Industry, some five miles south of the Illinois Institute of Technology and the AAR Technical Center.

Many railroaders felt the PRR/WABCO 1913 emergency train stop of 1200 ft from 60 mph had become a benchmark. By ratioing the squares of the initial speeds and adding about 8 percent, the 100 mph streamliner should stop in about 3600 ft in emergency on level track. At higher speeds and total shoe forces, cast iron shoe friction decreases. Therefore, speed sensitive brake equipment was developed which used much higher shoe forces than the then standard 150 percent braking ratio. Speed governor control provided 250 percent braking ratio from 100+ down to 60 mph, 200 percent to 40 mph, 150 percent to 20 mph, then stepping down to 100 percent. This enabled the 90-100 mph streamliner with HSC (High Speed Control) to make emergency and full-service stops in a mile or less. However, the instantaneous braking hp per wheel in high speed zones went up into the 500 to 1000 hp range!

By 1947, high speed streamliner service covered most of the country. As streamliner service grew, the diesel-electric locomotive expanded into the 2000-2250 hp range. Electric multiple-unit control enabled three or four to be operated from one control station to provide the 6000 to 8000 tractive hp required for quite long trains of 15-18 streamlined cars.

In the late 1940s, the 6000-7000 hp four-unit diesel-electric freight locomotives had amply demonstrated their worth and the full North American motive power revolution was off and running. Within 15 years, virtually every railroad in North America had changed from steam to diesel-electric. The last remaining unit of the original 4-unit 5400 hp General Motors "FT" demonstrator with the 567 diesel engine is preserved at the National Museum of Transport in St. Louis and was ASME's 77th National Landmark.

## WHEEL PROBLEMS FROM HIGH ENERGY TREAD BRAKING

During the late '40s and early '50s, increasing numbers of diesel-electric locomotive wheel failures were occurring. It became apparent that these wheels were being thermally overloaded. Wheel manufacturers began research to develop new designs and heat treatments. The University of Illinois dynamometer was used to conduct wheel industry research on thermal cracking and explosive failures. The AAR Chicago Technical Center acquired the Pennsylvania RR's brake shoe and wheel dynamometer (Ref. 7) in 1955 to examine thermal braking loads with cast iron shoes, Figure 3. These studies led to a more cautious approach to braking 36-40 in. diameter wheels with 27,000 to 33,000-lb wheel loads. As a consequence, modern 4000+ hp diesel reduces units have dynamic/blended braking which reduces the heat input to the locomotive wheels. The AAR dynamometer was scrapped in 1976 because of old age.

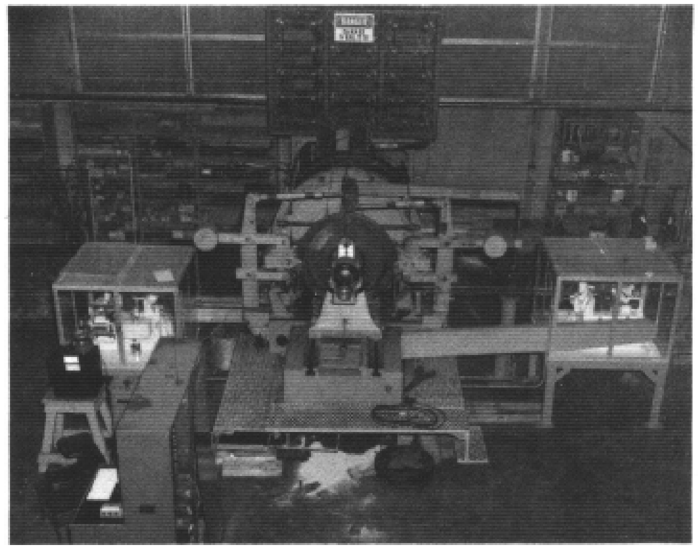


Figure 3. PRR Dynamometer at AAR Chicago 1955 - 1976.

## COMPOSITION BRAKE SHOES

In the 1960s, the high friction composition brake shoe, consisting of composite friction material bonded to a steel backing plate, became widely accepted. Composition shoes had as their chief advantage two to three times the kinetic friction on a steel wheel as that of cast iron brake shoes at medium to high speeds. Therefore, because much lower shoe forces could be used to obtain the same stopping ability, brake systems were redesigned and simplified. The clasp brake rigging with two shoes per wheel, needed with cast iron shoes, was in most cases replaced with a single composition brake shoe per wheel. Smaller brake cylinders and associated rigging parts led to lower brake system cost.

## THE LANDMARK DYNAMOMETER

U. S. Steel Corp., a major manufacturer of wrought steel wheels and axles, created preliminary design specifications for a railroad wheel and axle dynamometer in the early 1950s. USS wanted capabilities that went beyond those of braking dynamometers, such as those owned by American Brake Shoe and Foundry Co., American Steel Foundries, ARMCO Steel, The Budd Co., and Westinghouse Air Brake.

The Adamson United Company of Akron, Ohio (now a part of Wean Industries) was contracted by USS in 1954 to build the dynamometer for the Applied Research Laboratory in Monroeville, PA. Adamson United had extensive experience in building dynamometers for the automotive and aircraft tire industries. This machine was used at USS for nearly three decades to evaluate the performance of railroad wheels, axles, and brake shoes (Ref. 8).

In the early 1980s, The Association of American Railroads wanted to acquire a dynamometer to evaluate the effects of grade or drag braking parameters and rolling loads on residual stress alterations in various freight-car wheel designs. AAR also needed a dynamometer to test composition and metal brake shoes for certification and quality control purposes. Therefore, AAR purchased the AU/USS dynamometer in 1983. The cover and Figure 4 show the machine at the AAR Chicago Technical Center.

This dynamometer has the capacity to test wheels under a variety of braking and rolling-contact loading conditions. Grade, stop, and static braking tests can be conducted with a high degree of precision. In addition, axles can be tested as rotating cantilever beams (Ref.9).

A modern control and data acquisition system was installed in 1987 to provide automatic test sequence control, automatic speed control, closed-loop servo control of brake application, digital display of test inputs and test results, and digital data gathering.

The machine is powered by a 200-hp DC mill motor to speeds ranging from 0 to 1500 rpm (0 to 178 mph for a 40-in. wheel). For reference, maximum domestic freight and passenger train speeds are 80 and 120 mph, respectively. Up to 450 hp is available during acceleration or deceleration. The power supply for the motor is a 250 kW generator with an adjustable voltage regulator with current limit. The generator is driven by a 400-hp synchronous motor.

Ten thick and four thin 64-inch-diameter steel flywheel disks can be bolted to the flanged rotor shaft to produce the inertia effect of dynamic wheel loads. Thus, 54 increments of 95 slug-ft$^2$ each provide inertias ranging from 270 to 5405 slug-ft$^2$. This inertia capability is more versatile and larger than that of any other railroad dynamometer. The equivalent wheel load capability, which is dependent on wheel diameter, is shown in Table I for several wheel sizes.

TABLE I.

| Wheel Dia., Inches | Dynamometer Equivalent Wheel Load, Pounds | | Typical Vehicle | |
|---|---|---|---|---|
| | Min | Max | Type | Gross Wheel Load, Pounds |
| 28 | 6,400 | 127,000 | 45-Ton-Capacity Auto Rack Car | 24,375 |
| 33 | 4,600 | 92,000 | 70-Ton-Capacity Hopper Car | 27,500 |
| 36 | 3,900 | 77,000 | 100-Ton-Capacity Tank or Gondola Car | 32,875 |
| 38 | 3,500 | 69,000 | 125-Ton-Capacity Covered Hopper Car | 39,375 |
| 40 | 3,200 | 62,000 | 4-axle 3800 hp Locomotive | 35,000 |

The flanged stub axle, Figure 5, is instrumented with strain gages to measure torque during braking. This method of measuring retarding force and hp replaced the original method of measuring the differential output of load cells supporting the brake cylinder torque beam in 1968. Wiring for the torque cell and other strain or temperature sensors is routed through the hollow axle to a slip ring mounted on the outboard bearing.

The test wheel (28 to 46-in diameter) is mounted on the stub axle. The flange is bolted to a flexible coupling which is in turn bolted to the inertia shaft. The other end of the stub axle fits in the outboard bearing. When the rail wheel is used for tests, the outboard bearing is allowed to float to permit vertical loads of up to 60,000 lb to be applied to the wheel tread with the motor/screw and spring load frame.

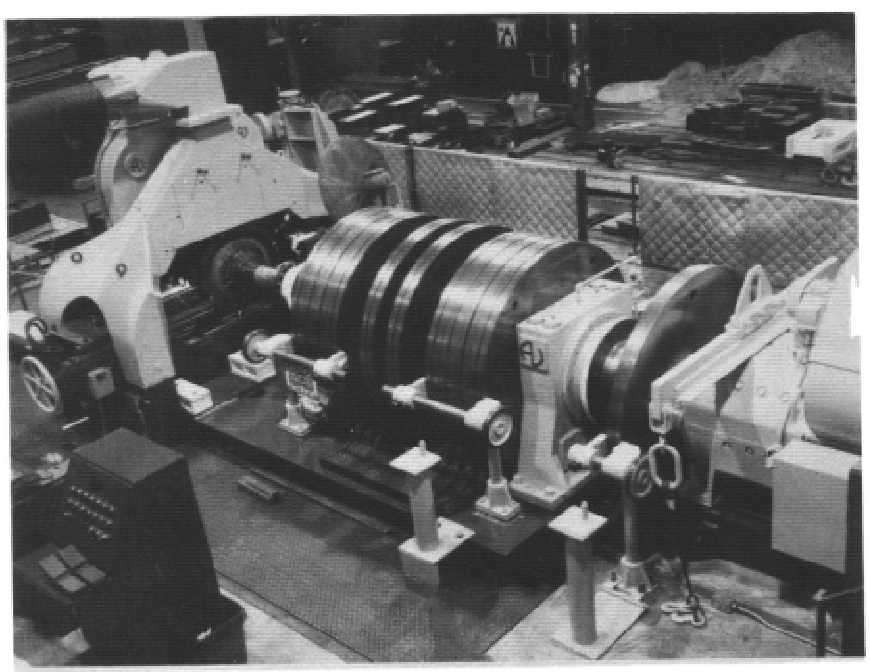


Figure 4. AAR Dynamometer (former US Steel) from Motor End.

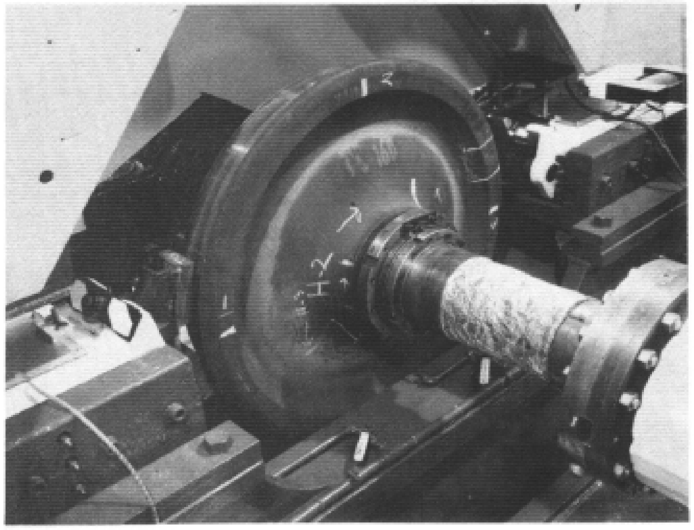


Figure 5. Wheel and Strain Gaged Axle with Brake Shoes, Load Cells, and Brake Cylinders.

Braking is provided by two single-shoe systems. One system, consisting of brake cylinder, load cell, brake head, and brake shoe, has a shoe-force capacity of 6,500 lb and is used for freight-car wheel, and brake shoe tests. The other system has a capacity of 13,000 lb and is used for locomotive and passenger-car wheel and brake shoe tests. The servo system permits constant torque and constant force tests to be conducted and also allows the torque and force build up rates to be controlled. The original clasp-type brake arrangement, suitable for testing locomotive cast-iron brake shoes at brake forces of up to 40,000 lb per shoe, is also available.

As shown in Figure 6, the replaceable friction-driven rail is a continuous ring of heat-treated rail steel and is bolted to a fabricated wheel. The rail wheel can be loaded laterally (up to 15,000 lb) with a hydraulic cylinder and can be oscillated laterally at 0.2 to Hz to simulate curving and lateral instability.

Two grinders are used to maintain proper profiles of the wheel and rail. An armor steel guard protects personnel should a test wheel fracture and also assists in the collection of dust for hydrostatic cleaning. Cooling for wheel and brake shoe tests is provided by suction from the air cleaning unit, an 8650 cfm fan, or water spray, if desired.

Briefly, the landmark dynamometer is capable of subjecting full-size railroad wheels to controlled brake-shoe forces of up to 13,000 lb with composition shoes and 40,000 lb with cast iron shoes at speeds up to 178 mph with equivalent inertia wheel loads up to 127,000 lb. In addition lateral and vertical contact loads up to 15,000 and 60,000 lb, respectively, can be applied during braking. These capabilities are in excess of those required to duplicate service conditions on North American railways.

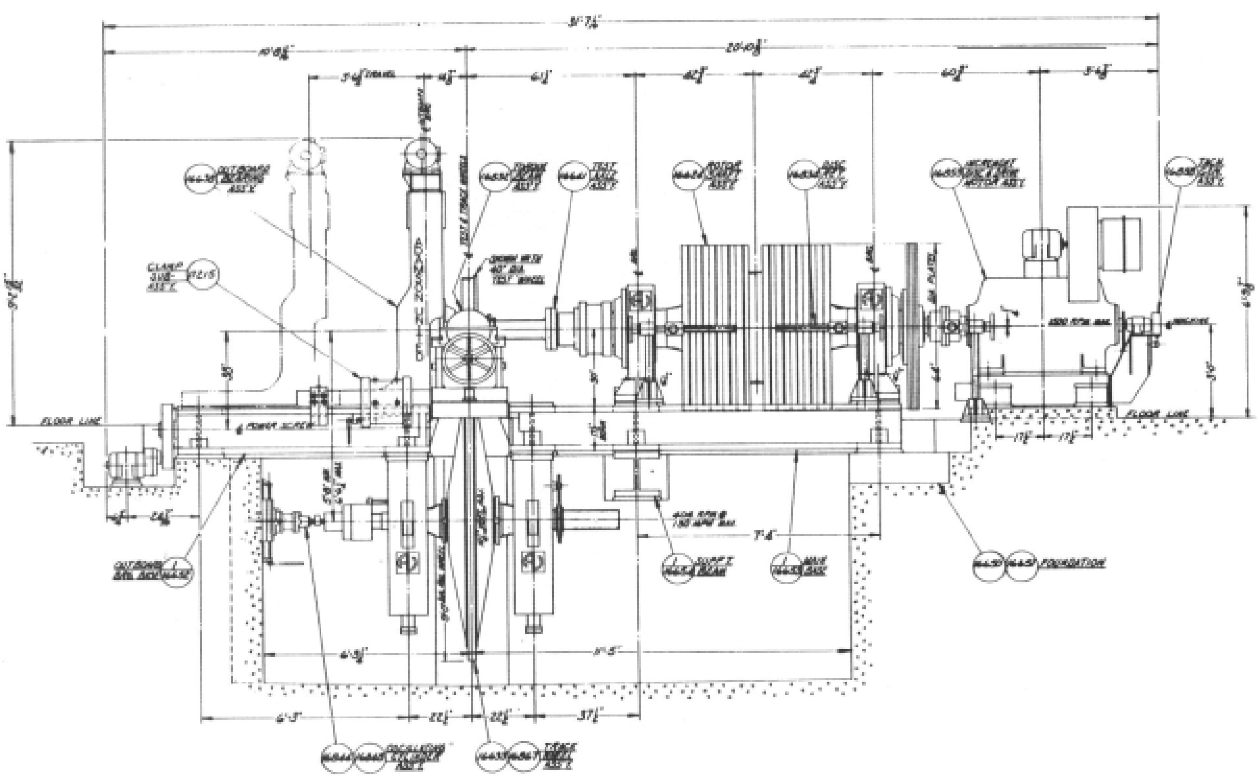


Figure 6. Elevation Drawing Showing Rail Wheel in Pit Beneath Machine.

## SUMMARY

During the past century, the use of dynamometers by AAR has been intermittent as various wheel and brake shoe problems arose and were solved. This progression started in 1894 with the MCB machine at WABCO and then Purdue until the WWII years, resumed with the PRR machine in Chicago during the 1955-1975 period, and continues with the present AU/USS machine in Chicago beginning in 1983. The ability to apply lateral and vertical rolling contact loads and thermal braking loads to the wheel tread with modern control and instrumentation makes this machine unique in the railroad dynamometer field.

## REFERENCES

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2. Master Car Builders' Association Proceedings 1894, Pages 149-161 (Description of MCB Brake Shoe Test Machine).

3. Master Car Builders' Association Proceedings 1895, Pages 131-161 (Tests at WABCO on various types of shoes and wheels).

4. Master Car Builders' Association Proceedings 1901, Pages 99-141 (Tests at Purdue University starting in 1900), Pages 466 and 489 (Brake Shoe Friction Limits and Adoption as Standard).

5. Young, G. A., M.E., Head, School of Mechanical Engineering, Purdue University "Purdue University and the American Railways," 1928, Purdue Library No.: Goss 625.0 Ro, 85p.

6. Pennsylvania-Westinghouse Brake Tests at Absecon, N.J. 1913, copyright 1913 Pennsylvania Railroad, Printed by Westinghouse Air Brake Co.

7. Research Center Annual Reports of 1956, 1957 and 1960, Association of American Railroads, Technology Center, Chicago, 16, IL. (Brake shoe and wheel tests with former Pennsylvania R. R. Dynamometer).

8. Wandrisco, J. M., and Dewez, F. J., Jr., "Study of Defects that Originate in the Treads of Railroad Wheels During Service," ASME Paper 60-RR-1, ASME-AIEE Joint Spring Railroad Conference, Pittsburgh, PA., 1960. (Wheel tests at U. S. Steel).

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## BIOGRAPHICAL SKETCHES

Joseph M. Wandrisco, Mem. ASME, was born and raised in the Pittsburgh, PA, area. He was graduated from Grove City College in 1939 with a degree in Chemical Engineering and also attended Carnegie Institute of Technology. His career with US Steel started in 1940 at the Homestead, PA, works and he joined the Research Department in 1950. He rose to become Chief Research Engineer, Railroad Products, at the Monroeville, PA, Applied Research Laboratory of US Steel, retiring in 1979. Mr. Wandrisco was responsible for the functional design specifications and successful operation of the Landmark dynamometer. He is known as the co-inventor of the highly successful USS CURVEMASTER Rail.

Rex C. Seanor, Mem. ASME, was Chief Engineer at Adamson United Co. when the Landmark dynamometer was designed and constructed. After obtaining his B.S. in Mechanical Engineering at Carnegie Institute of Technology in 1931, he began his career at General Electric Co. in Lynn, MA. In 1935 he joined E. W. Bliss Co. in Salem, OH, and designed rolling mills. He joined Adamson United Co. in 1946, was responsible for the design of large dynamometers for the aircraft industry and machinery for the rubber and plastics industries, and retired in 1973. He is a former chairman of the Akron Section of ASME and is a member of Tau Beta Pi and Pi Tau Sigma.

## ACKNOWLEDGMENTS

The Chicago Section and the Rail Transportation Division of ASME and Region VI gratefully acknowledge the efforts of all who have contributed and cooperated in the designation of the Association of American Railroads (AAR) Railroad Wheel Dynamometer as a National Historic Mechanical Engineering Landmark. In particular, we thank the AAR for their aid and assistance in preparing the dynamometer and allowing us to propose it for landmark status. Thanks also are extended to the Illinois Institute of Technology on whose campus the AAR Chicago Technical Center is located.

This brochure was written by D. G. Blaine and G. F. Carpenter. Photographs were by John F. Valente, typing by Rita A. Potts, and printing by Ethel M. and Rosetta Frazier. Thomas E. Johnson is presently responsible for operation and maintenance of the dynamometer.

## THE HISTORY AND HERITAGE PROGRAM OF ASME

The ASME History and Heritage Program began in September 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee, composed of mechanical engineers, historians of technology, and the Curator of Mechanical and Civil Engineering at the Smithsonian Institution. The Committee provides a public service by examining, noting, recording, and acknowledging mechanical engineering achievements of particular significance.

The AAR Dynamometer is the 91st National Historic Mechanical Engineering Landmark to be designated. Since the ASME History and Heritage program began, 128 Historic Mechanical Engineering Landmarks, five Mechanical Engineering Heritage Sites, and one Mechanical Engineering Heritage Collection have been recognized. Each reflects its influence on society, either in its immediate locale, nationwide, or throughout the world. A landmark represents a progressive step in the evolution of mechanical engineering. Site designations note an event or development of clear historical importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

The ASME History and Heritage program illuminates our technological heritage and serves to encourage the preservation of the physical remains of historically important works. It provides an annotated roster for engineers, students, educators, historians, and travelers, and helps establish persistent reminders of divergent paths of discovery. For further information, please contact the Public Information Department, The American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, 212-705-7740.