Joseph J. Cunningham

Howard Street Tunnel

origins of mainline railroad electrification

RAILWAY VEHICLES WERE THE primary focus of 19th century electrical inventors in their quest to develop practical electric motors. The motor concept was first demonstrated by Michael Faraday's spinning wire in 1821, while Thomas Davenport, a Vermont blacksmith, produced a rotating machine by late 1834 and demonstrated a model electric locomotive running on a 4-ft (1.2-m) diameter circular track in 1835. On 25 February 1837, Davenport was granted the first U.S. electrical patent (#132) for his battery-powered motor. The first railway application of electric power was a locomotive constructed by Moses G. Farmer in 1847. Soon after, Charles Grafton Page built an electric locomotive with a US$20,000 grant from the U.S. Congress, said to be the first government-funded scientific project in the United States. On 29 April 1851, Page demonstrated his locomotive to invited guests with a 3.5-mi (5.6-km), 39-min run from Washington, D.C. to Bladensburg, Maryland, after which the batteries were exhausted. Well ahead of his time in the field of electrical research, Page sought to build a stationary power source but was unable to secure funds. As a result, the Baltimore and Ohio Railroad (B&O), the nation's first common carrier railroad and pioneer of numerous railway techniques, remained limited to steam propulsion for the next four decades.

The Early Days

The electrical industry developed in the field of communications first and

The impetus for the founding of the Baltimore and Ohio Railroad (B&O) arose out of the completion of the Erie Canal that traversed the state of New York from Buffalo on Lake Erie eastward 363 mi (584 km) to Albany on the Hudson River. The canal was the first transportation system connecting the eastern seaboard of the United States with the Great Lakes region and the interior of the continent. The operation of the canal, beginning on 26 October 1825, opened western upstate New York to settlement, facilitated trade, and quickly made New York City the nation's chief and most prosperous port.

On 12 February 1827, a group of bankers and merchants met in Baltimore, Maryland, to consider ways to more effectively compete for eastern seaboard trade with New York City. They decided to build a railroad from the port of Baltimore westward some 380 mi (612 km) to the Ohio River. Building railroads as commercial ventures had begun in England but was at that time untested in the United States. The B&O was formally incorporated as the Baltimore and Ohio Rail Road Company on 24 April 1827. Construction began on 4 July 1828, and the first rail section from Baltimore to Ellicott City, Maryland, opened on 24 May 1830.

The B&O was the nation's first railroad to offer regular common-carrier service and is considered by most railroad historians to have been America's first major intercity railroad. During its 160 years of corporate existence before being merged into CSX Transportation in 1987, the B&O grew to be one of the largest and most successful of several major trunk lines that served the northeast quadrant of the United States. The B&O was noted for innovation and its development and introduction of new equipment, practices, and techniques. This article, authored by Joseph J. Cunningham who makes his second visit to these pages, covers one such major innovation, the world's first mainline railroad electrification.

Joseph Cunningham's interest in electric power systems dates to his youth when his high school science project "The Theory and Operation of Alternating Current" received a first place gold medal. This led to a college scholarship to study physics. Joe has also enjoyed a life-long interest in railroading and in railroad history. In this article, he combines both of these interests. He has researched and authored numerous booklets, articles, and books on topics such as industrial electrification and electric transportation. He has also lectured and taught widely on the history of railway technology, the development of public transit systems, and electrotechnology generally. In addition, he had consulted on numerous history projects and television productions. We are honored and pleased to welcome Joseph Cunningham back as our guest history author for this issue of *IEEE Power & Energy Magazine*.

—Carl Sulzberger
Associate Editor, History

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then lighting. The latter took two forms, arc and incandescent, and at least one pioneer promoted the potential for electric transportation. Fr. Joseph Neri, professor of physics at the College of St. Ignatius (now the University of San Francisco), installed an electric arc light system on campus in the 1870s and expanded it to public streets for Independence Day celebrations. In response to public acclaim, he declared that the future held far greater possibilities and that electricity would revolutionize daily life, specifically transportation. Soon afterward, the German industrialist Ernst Werner von Siemens operated a small electric railway at the Berlin Trades Exhibition in 1879. A 10-hp motor pulled three cars with benches able to accommodate a total of 30 passengers around a 985 ft (300 m) long circular track at 4.35 mi/hr (7 km/hr).

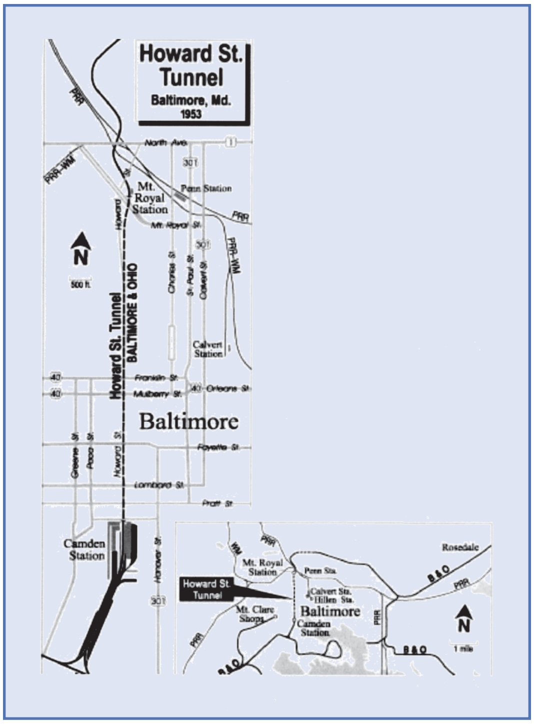

figure 1. Map showing the location of the Howard Street Tunnel and the Camden and Mount Royal stations (image courtesy of the National Railway Historical Society; used with permission).

One year later, Thomas Edison sought to expand his electrical business with an electric railway experiment at his laboratory in Menlo Park, New Jersey. He entered discussions with Henry Villard of the Northern Pacific Railroad on the possibilities of electric locomotion but he never produced a practical device. The first practical application of electric power to railways was that on urban streetcar systems. The most successful innovator, often regarded as the "father of electric railways," was Frank Julian Sprague. A graduate of the U.S. Naval Academy with extensive training in practical electricity, Sprague's ride on London's coal-powered Underground subway system convinced him of the need for railway electrification. Railway officials expressed minimal interest and, after developing electrical distribution concepts for Edison, Sprague began developing an industrial electric motor in 1883.

Edison expressed approval and added that he was occupied exclusively with lighting. Sprague introduced a practical direct current (dc) motor in 1884 that met instant success in a variety of applications. Edison declared it to be the first true motor and the only one approved for use on Edison lighting systems. It proved the basis for a practical railway motor, and Sprague developed a complete street railway electrification system. His first large-scale installation, considered the birth of the electric railway, followed in early 1888 with the operation of the Union Passenger Railway of Richmond, Virginia. That success initiated the development of electric trolley lines as an urban electric railway boom spread across the United States and beyond.

Opportunity

As electric traction matured, renewed interest by officials of mainline railways followed, and the B&O again took the lead. Operation through the line's home city of Baltimore, Maryland, had been hobbled for years by a cumbersome ferry crossing of the Patapsco River between Locust Point and Canton. By the 1880s, a new route was the only practical solution. After exploration of several routes, one of which required long elevated trestles, a 7.3 mi (11.7 km) Belt Line around the harbor was selected. Chartered in 1887, the Belt Line route involved extensive tunneling through neighborhoods of prime real estate in which smoke flues or vents were forbidden The longest tunnel required was the Howard Street Tunnel that ran on a 1.4 mi (2.3 km) north-south alignment beneath a densely populated residential and commercial thoroughfare (see Figure 1).

Long tunnels could severely restrict ventilation for steam locomotives, resulting in dense smoke that obscured visibility and was, at best, unpleasant to experience. Moreover, the toxic gases produced could cause illness or even threaten asphyxiation. Clearly, some means of smokeless propulsion was required. Cable operation was thought to be of minimal practicality. Confident that electric propulsion could be employed, the railroad completed surveys and initiated construction in 1891.

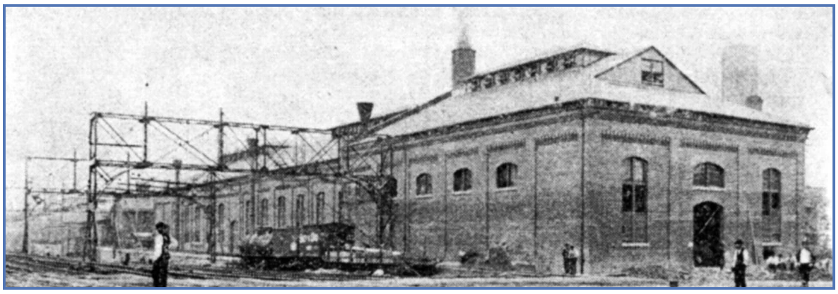

figure 2. Exterior view of the Camden generating station during construction, circa 1895 (source: 13 July 1895, *The Electrical World*, p. 54).

By 1892, the project had progressed to the point that the propulsion system design had to be finalized. Hundreds of electric street railway systems were under construction or in operation, but all involved light passenger vehicles. The only application of electric power to the movement of mainline trains was that of freight cars over street railways to warehouses and industrial plants. By contrast, the B&O required a system adequate to haul an entire mainline train, including steam engine and coal tender, through the Howard Street Tunnel which included a significant northbound uphill grade.

B&O management initiated discussions with the newly formed General Electric Company, an amalgamation of electrical manufacturing firms that held the railway patents of Sprague and other inventors. The Westinghouse Electric and Manufacturing Company, though relatively new to the railway business, also expressed interest. After a thorough review of the General Electric proposal, the company was contracted to supply a complete electrical system that consisted of a power station, a unique distribution system, and three locomotives.

Generation of Electric Power

The power station was located at the railroad's Camden Yards near the south end of the Howard Street Tunnel (see Figure 2). The brick structure was equipped with a dozen coal-fired water tube Root-style boilers that supplied steam to four Reynolds-Corliss horizontal cross-compound reciprocating steam engines built by the Allis Manufacturing Company. Each turned a General Electric 110 r/min multipolar generator rated at 500 kW, the power being delivered to a switchboard at the south end of the station. Eight 500-Kcmil positive cables delivered power to the overhead distribution system. Similar cables provided the negative return circuit.

An auxiliary system supplied power for tunnel lighting and plant machinery. A pair of 250-hp Armington & Sims cross-compound engines drove eight Thomson-Houston 50-lamp arc light generators for illumination of the plant and station areas. An additional pair of similar engines drove two alternators, each rated at 2,000 incandescent lamps of 16 candlepower, for lighting of the tunnel, power station, and passenger station. As the tunnel required only 1,000 32-candlepower lamps, one machine could be held in reserve at all times.

Total power output was 2,800 kW, a substantial rating for a generating station at that time. (By comparison, the total installed generating capacity of the five dc power stations of the Edison Electric Illuminating Company of New York was 3,600 kW distributed over a three-wire, 110/220-V lighting

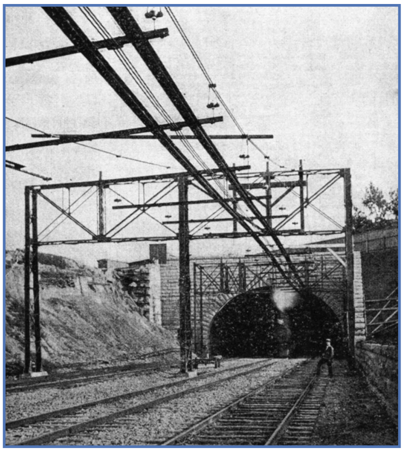

figure 3. Tunnel entrance with the overhead power distribution system employing insulated iron rods to suspend the power trough from the support gantries (source: 13 July 1895, *The Electrical World*, p. 54). See also Figure 4.

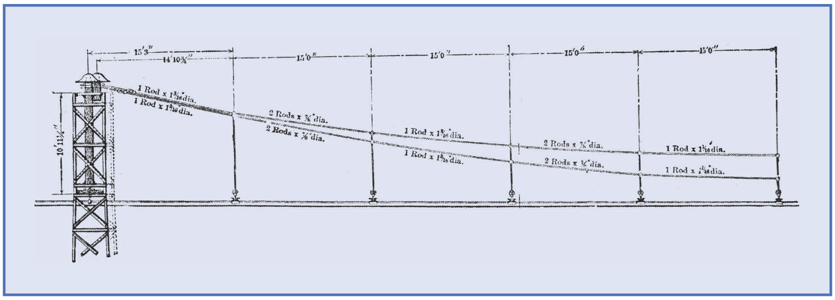

figure 4. Side elevation of the gantry-mounted suspension system of iron bars (source: 13 July 1895, *The Electrical World*, p. 56). See also Figure 3.

system.) The B&O system supplied traction power at a nominal 600 V. A provision was included in the compound generators to permit an increase to 700 V to accommodate peak loads without drawing excessive current. The incandescent lamps were of the standard Edison type. Batteries were added later to assist with peak loads.

Power Distribution

Power was distributed over a unique overhead conductor system utilizing a slotted metal trough suspended from steel gantries 22 ft (6.7 m) above the center line of the track. Within the tunnel, the trough lowered to 17.5 ft (5.3 m) and shifted to the side of the track to prevent hazard to brakemen who often walked atop cars at that time. At such locations, the troughs for both tracks were located between the two tracks, suspended from brackets at 15-ft (4.6-m) intervals. Double porcelain insulators were employed to mitigate to the greatest extent practical any stray current leakage and consequent electrolytic corrosion within the tunnel. Figure 3 shows the overhead conductor system.

The current-carrying capacity of the trough was rated as equivalent to a conductor of 1,000 Kcmil and was supplemented by a trio of parallel feeders rated at equivalent capacity. The running rails were used for the return circuit with the rails bonded with 0000-gauge wire and connected to heavy copper cables of capacity similar to the positive feeders but laid in a wooden trough at the center of the track. The return circuit design sought not only to optimize performance but also to prevent stray currents and consequent electrolytic corrosion damage. The return circuit was most probably modified to permit the use of alternating current (ac) track circuits for the color light signals installed later as signals were not utilized at the outset. The distribution system totaled 14,500 ft (4,420 m), of which 7,331 ft (2,235 m) was in the Howard Street Tunnel. Figures 4, 5, and 6 show additional details of the overhead conductor system.

Just as trolley wire had been deemed inadequate for the heavy current involved, power collection required greater capacity than that afforded by the standard trolley pole. A unique sliding shoe was devised that fit within a slot in the trough, and the shoe was mounted at the end of a pair of jointed arms similar to modern pantograph collectors. Unlike contemporary systems, the arms could not only compress but could also swing sideways to accommodate the shift in the placement of the power trough in the tunnel. A newspaper article in the *Baltimore Sun* compared the arms to the "lazy tongs" used for serving food. The sliding shoe was held to the arms by a

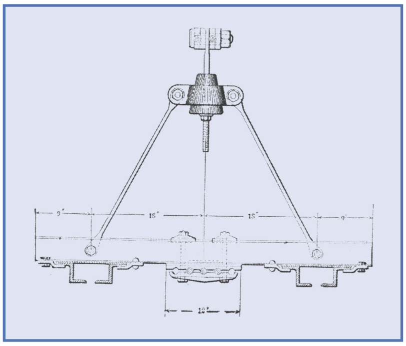

figure 5. Section through single suspension required to support power troughs for both tangent (straight) tracks in the tunnel (source: 13 July 1895, *The Electrical World*, p. 57).

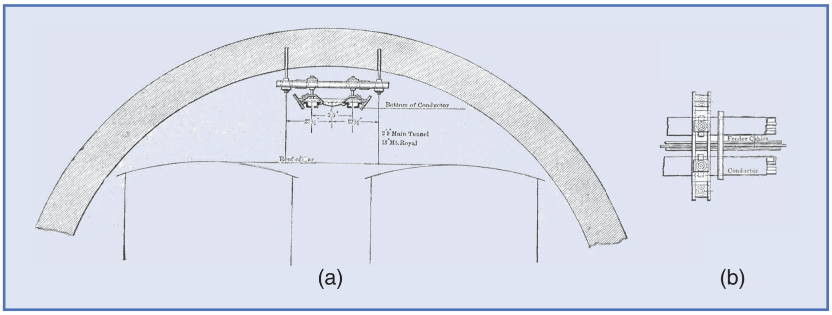

figure 6. (a) End elevation showing power troughs and bracket on the tunnel ceiling; (b) overhead view of the troughs (conductors) with the three feeder cables mounted between them and secured by the feeder support bar and clamps (source: 13 July 1895, *The Electrical World*, p. 56).

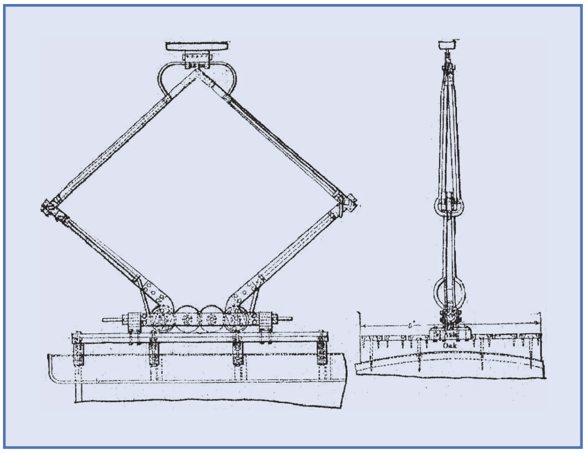

figure 7. Side and end elevation of the power collection arms mounted on the locomotive roof (source: 13 July 1895, *The Electrical World,* p. 57).

metal pin designed to break and release the shoe should an obstruction be encountered (see Figure 7).

Electric Locomotive

The locomotive was a major achievement. Built as two sections mounted back to back, it measured 35.8 ft (10.9 m) long and weighed 96 tons (87.1 metric tons), ten times the weight of any previous electric locomotive design. Each section had an operating cab above a rounded projecting nose on which was mounted an electric headlight. Four powered axles, each equipped with a six-pole, 360-hp dc motor, applied 24 tons (21.8 metric tons) to the rail to produce 49,000 lb (22,226 kg) of starting tractive effort at 25% adhesion with an absolute maximum of 60,000 lb (27,216 kg) of pulling force. Normal running tractive effort was rated at 42,000 lb (19,051 kg). The total dc motor capacity of 1,440 hp represented a 1,000% increase over any previous attempt. Sprague had constructed a 1,000-hp electric locomotive in 1893 for Villard's rail operations in Chicago, but the economic collapse of 1893 halted the program and the unit was never tested. Still, that effort likely impacted the B&O design as Sprague associate Cary T. Hutchinson led motive power development.

The running gear was unique. The motor armature shaft was hollow to permit the axle to pass through the center of the motor, which allowed both axle and motor to share a common center of gravity. The weight of the motor was cradled by springs on the truck frame to isolate it from excessive vibration while permitting 2.5 in (6.4 cm) of play between axle and motor armature. Power transfer from the armature shaft to the wheels was accomplished by a five-armed steel "spider" on the end of the motor shaft that also fit around the axle. The arms of the spider engaged the spokes of the 62-in (157.5-cm) wheels through iron-capped rubber blocks. As such, the motor, axle, and spider all shared a common center to produce a constant, even torque on the wheels. Figures 8 and 9 show details of the running gear.

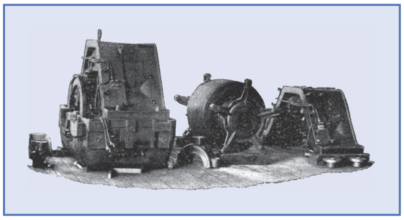

figure 8. Traction motor shown both assembled (left) and disassembled; motor armature with five-armed steel driving spider (center); upper half of motor housing and frame (right) (source: 13 July 1895, *The Electrical World*, p. 55).

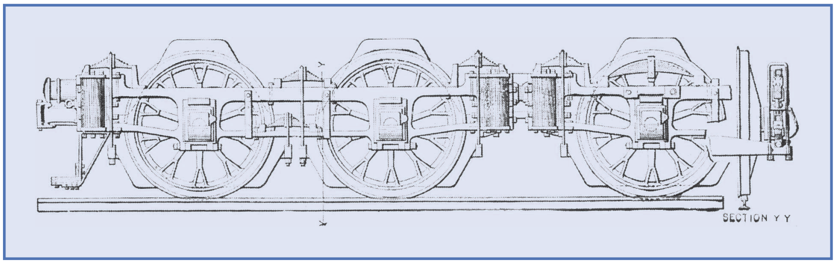

figure 9. Elevation diagrams of power truck; side view of one complete truck and half of the other truck (left/center); end view of wheel profile and journal bearing suspension (right) (source: 13 July 1895, *The Electrical World*, p. 56).

Resistance was employed for acceleration and speed control while braking air was supplied by an electric oscillating cylinder air pump which also supplied an air whistle and bell ringer. Resistances were located beneath the cab floor with the air tanks placed in the end hoods. Controls were basic and consisted of a series-parallel control lever and another for reversing. Also included were an air brake valve, circuit breaker, magnetic cutout, air gauges, an illuminated Weston voltmeter, and a similar 5,000-A ammeter. Lamp clusters illuminated the cabs.

The locomotive, designed to pull 1,200-ton (1,089-metric ton) freight trains through the Howard Street Tunnel, was put through extensive testing at the General Electric plant in Schenectady, New York. Before the locomotive was completed, a single truck representing half the final unit proved capable of overcoming a six-wheel steam engine in a tugging contest. The completed electric locomotive forced a powerful 0-6-0 steam switch engine into reverse in a pushing contest despite the best efforts of the steamer crew. In another test, the locomotive started and hauled three dead steam engines and a 36-car freight train. Performance was well beyond specifications; the locomotive proved capable of speeds up to 60 mi/h (96.6 km/h) and was able to start a 30-car freight train without "taking slack," a steam-era practice in which a freight train is started by first backing the locomotive to maximize the slack or play in each coupling until the last car moves. Then the locomotive starts forward, with the slack in each coupler being taken up sequentially so as to start each car rolling individually. In this way, the train is put in motion incrementally rather than imposing the total load on the locomotive at once, in which case substantially greater tractive effort (pulling force) would be required. At the conclusion of the tests, the locomotive was shipped to Baltimore and prepared for operation in the late spring of 1895 (see Figure 10).

World's First Electric Operation on a Mainline Railroad

On Wednesday, 1 May 1895, trains began operating through the Howard Street Tunnel with steam engines on a limited basis with operational restrictions. The formal debut of electric operation was held at 11 a.m. on Thursday, 27 June, with officials of the railroad, the component manufacturing companies, and the construction contractors in attendance. The locomotive started, entered the tunnel, and continued to the northern extent of the completed electrification. It then coupled to a southbound train and hauled it through the tunnel. It arrived 7 min later, the officials noting that speed would be held to 20 mi/h (32.2 km/h) until the bearings had received some wear. The locomotive was placed on display after the ceremony, and the press and public were laudatory; the most appreciative appeared to be a bunch of school boys for whom the summer vacation had just begun. To them it must have appeared to be a wonder of the future of the kind envisioned by novelists such as Jules Verne.

Regular electric operation began on Monday, 1 July, with the first trip including railroad officials and the entire "Royal Blue," the B&O's flagship luxury passenger train operating between Washington, D.C. and New York City (see Figure 11). From that morning on, electric propulsion was standard. Operation required all northbound trains to shut off steam and close dampers while the train was stopped at the Camden station. The electric locomotive then coupled to the front of passenger trains and hauled them through the tunnel, after which it was uncoupled. A passenger station named Mount Royal was constructed at the north end of the tunnel the following year.

Freight operation through the tunnel commenced on Sunday, 4 August 1895, as the railroad ferry across the Patapsco River ceased operating. The electric locomotive coupled to the rear of freights and pushed them through the tunnel with the steam engine idling and then remained

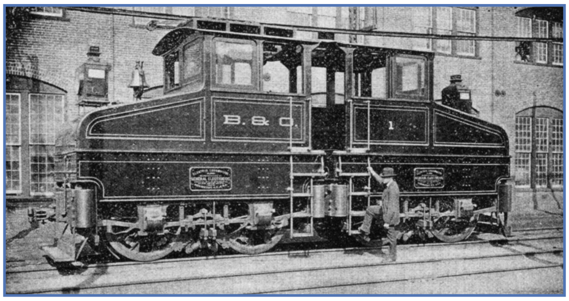

figure 10. B&O No. 1, the world's first mainline railroad electric locomotive (source: 13 July 1895, *The Electrical World*, p. 55).

on as a rear end "helper" to assist the reactivated steam engine on an upgrade north of the tunnel. Passenger trains were not pushed as no "helper" was required, and there was concern for the structural integrity of the wooden cars in the event of a derailment. Southbound trains took advantage of the downgrade and coasted through the tunnel. Since the steam engines were not working hard on this downgrade run, the production of heavy, toxic smoke was minimized.

Locomotive No. 1 of B&O class LE-1 remained the sole electric locomotive and performed all the work until the arrival of No. 2 in November 1895 and No. 3 in May 1896. The installation was an unqualified success, and the only problem encountered with the electric operation was corrosion of the overhead power trough from the gases produced by the banked fires of the steam locomotives. That problem was solved in 1902 by replacing the trough with a third rail of the type selected by the Manhattan Railway Company for installation on elevated rapid transit passenger lines in Manhattan and the Bronx in New York City.

Soon after, traffic required the purchase of additional locomotives and a greater electrical capacity. The Consolidated Gas, Electric Light & Power Co. of Baltimore assumed the traction load in 1909 with the supply of 13,200-V, three-phase, 25-Hz ac power to a new 5,000-kW rotary converter substation that supplied 675-V dc power to the dc traction system. The original railroad power plant was retained to supply lighting and stationary motors until 1914 when it was retired in favor of purchased power. The transition of the B&O power supply from private to utility was followed by similar transitions by railroads and transit lines throughout the United States.

Prior to 1910, most electric railways constructed private plants since the utility companies lacked sufficient capacity to handle the traction load; the exceptions were those street railways operated by electric utilities. After 1910, the development of large utility power plants of high efficiency led most rail electrification to adopt purchased power. Those railroads with significant investment in private generation usually continued to use it, but most later sold or leased the plants to a public utility to reduce expense and reap the economy inherent in large utility systems of great efficiency.

figure 11. Electric locomotives were placed ahead of the steam engine on northbound passenger trains as shown in this view that appears to show the inaugural run on 1 July 1895 (source: *A Guide to Trains*, Fog City Press, 2002, p. 55).

As traffic continued to increase, additional locomotives were acquired through the early 1920s. The original units were not equipped to operate in multiple and were retired in 1917. Locomotive No. 2 survived until 1927 when it was featured as No. 1 in the B&O centennial event named "The Fair of the Iron Horse." It was scrapped afterward, a fact most ironic in view of the extensive collection of rare railroad equipment at the B&O Railroad Museum, a collection that lacks an example of the world's first mainline electric locomotive.

Subsequent Developments

The true significance of the 1895 B&O electrification is evident in light of subsequent developments. General Electric became the prime advocate of railroad electrification and provided the system that made possible the construction of New York City's legendary Grand Central Terminal. Westinghouse won the contract to install a new high-voltage ac system on the New York, New Haven, and Hartford Railroad. That produced a true competition in which General Electric developed a high-voltage dc system. It was selected by the Chicago, Milwaukee, St. Paul, and Pacific Railroad for the electrification destined to remain the nation's longest until it was dismantled in the early 1970s. Though the General Electric system was not adopted for extensive installation elsewhere in the United States, it was selected for commuter and terminal installations and saw extensive application in Europe, Asia, South Africa, and in much of South America.

While Westinghouse succeeded in obtaining the contracts for most of the electrification projects in the United States, the most significant legacy of the B&O project was the dc traction motor. Westinghouse installations initially employed ac motors of various types, but the efficiency and simplicity of control of the dc motor produced numerous attempts to apply it to ac locomotives. Early 20th century efforts using mercury arc rectifiers met with minimal success, but interest in on-board ac to dc conversion techniques never waned. In the interim, motor-generator conversion was employed on slow speed freight and mountain railways.

The dc traction motor was refined substantially during the 1930s and 1940s as it proved vital to railway application of the diesel engine. After World War II, compact and reliable Ignitron-type mercury arc rectifiers installed in experimental Westinghouse electric locomotives were followed by General Electric orders, with ten New Haven passenger units in 1954–1955, and 12 heavy mountain coal haulers for the Virginian Railway in 1956–1957. Those orders were overshadowed by a 1959 General Electric contract with the Pennsylvania Railroad for 66 high-speed heavy freight units. Deliveries commenced in 1960, but that order was only about 50% complete when technical advance eliminated the Ignitron in favor of compact air-cooled silicon diode rectifiers.

After a 1962 test unit, 23 more locomotives were delivered with Ignitron rectifiers, but the last five locomotives were completed in 1963 with silicon diodes. The earlier units were then rebuilt with silicon rectification when in the shop for routine heavy maintenance. The silicon diode then dominated railroad motive power, in

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both electric vehicles and in diesel locomotives. In the latter application, it permitted the use of more powerful and efficient alternators in place of dc generators to increase substantially the capacity of diesels introduced in the mid-1960s. Thus, the dc traction motor retained primacy until the 1990s when ac induction motors supplied by inverters finally displaced it after more than a century of widespread use.

Later Years of the Howard Street Tunnel Operation

The B&O mainline railroad electrification remained in daily operation with minimal alteration for more than half a century. The only major change came in April 1938 when the substation was relocated to permit a street expansion project. As the new location above the tunnel could not accommodate the foundations required to support heavy rotating machinery, mercury arc rectifiers were installed. That arrangement lasted only 14 years as the economics of through diesel operation led to the elimination of the B&O's pioneer electrification in 1952, a fate that ultimately befell electric operation on all of America's mainline freight railroads.

Trains still operate through that Howard Street Tunnel that opened some 115 years ago. The importance of the line was demonstrated by a fire in the tunnel that resulted from the derailment of a 60-car freight train on 18 July 2001. With the tunnel closed for more than six days in July 2001, freight shipments were snarled throughout the mid-Atlantic region as alternative routes soon became clogged with delayed trains. The local area was impacted as smoke caused closure of the harbor and evacuation of some buildings. Among the casualties were Baltimore Orioles baseball games at Oriole Park at Camden Yards stadium, which is now located on the site of the power plant which energized the world's first mainline railroad electrification.

For Further Reading

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