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THE VIRGINIAN RAILWAY ELECTRIFICATION

The World's Most Powerful Locomotives

By L. P. DOYLE, '27

THE inauguration of electric service by the Virginian Railway marks an important step in the history of its development of "mass" transportation. The Virginian Railway is pre-eminently a coal-carrying road having a heavy east-bound traffic, a large majority of which is coal.

The Virginian has, during the past few years, been conspicuous for its 120-ton capacity coal cars, its 2-10-10-2 Mallet type locomotives, and the operation of very large coal trains, including one of 16,000 tons.

The electrification was contracted for in May, 1923, in order to provide for the further growth of traffic. The greater part of the coal tonnage is concentrated at Elmore. The major obstacle encountered in handling this traffic is a 2.07 per cent, fourteen-mile grade from Elmore to Clark's Gap, since after Clark's Gap summit has been reached the maximum grade against traffic is one of only 0.6 per cent, crossing the Allegheny Mountains at Whitethorne.

The main line of the Virginian extends from Deepwater, W. Va., where connection is made with the Chesapeake and Ohio R. R. to Norfolk, Va., a route distance of 441 miles. The line is single track except from Mullens to Clark's Gap, which section includes the heaviest grade against load movement and is double tracked. The very rich New River and Pocahontas coal fields near the western terminus are served by the main line and by various branches. The coal from practically all of these mines is collected in the Elmore yard and is hauled to tidewater at Norfolk. The Winding Gulf branch connects with the main line at the north end of the Elmore yard, which is at Mullens, and much of the coal comes in from this branch where the load movement is down grade.

The condensed profile shows that between the coal receiving yard at Elmore and Norfolk the heavy grades, reaching a maximum of 2.07 per cent, are confined to the section between Elmore and Roanoke. The curvature on this section is heavy also, reaching a maximum of 12 degrees. From Roanoke to Norfolk the maximum grade against loaded movement is only 0.2 per cent and the curvature is not so severe. There are some heavy grades against the load on the main line north of Mullens, but only a part of the coal moves over them because a large portion comes into the main line over the branches which connect east of these grades. All of this means that the section from Elmore to Roanoke is the bottle-neck of the system, and with improvements made to increase the tonnage capacity of this section the remainder of the road can well take care

of the resulting increase with little or no expenditure.

In order to increase the capacity of this section with steam operation it would have been necessary either to increase the train speed or to put down more tracks, or to do both. Additional trackage in this mountain territory with many tunnels and bridges would, of course, be very expensive. An increase in train speed could only be accomplished by using more locomotives per train and this would pyramid delays. The alternative to increased trackage and more steam locomotives, was electrification. This offered a means of applying still more powerful locomotives which would be used to haul heavier trains at much higher average speed than was being done with steam motive power and without increasing the maximum speeds now common practice with steam operation. Furthermore, the electric locomotive capacity which can be concentrated in a single train can be indefinitely increased.

In order to provide for the application of increased power to trains with the growth of traffic, the transformer stations, trolley line, and locomotives have been designed for either 11,000 or 22,000 volts between trolley and rail. The locomotives for this electrification are of the split-phase, constant speed type with one three phase induction motor driving, through a jack shaft and side rods, two of the driving axles in each truck. The locomotive equipment consists of three single phase Westinghouse Electric units, as follows:

Total wt. of unit, 425,300 lbs.
Classification of wheels, 2-8-2
Weight on drivers, 309,300 lbs.
Number of driving axles, 4
Capacity at one hours rating:

2,030 hp.	14.1 m. p. h.
2,375 hp.	28.3 m. p. h.
Starting tractive effort at 20% adhesion....	77,325 lbs.
Maximum starting tractive effort at 29.9% adhesion	92,500 lbs.
Tractive effort—	
Hourly rating 54,000 lbs.	14.1 m. p. h.
Hourly rating 31,500 lbs.	28.3 m. p. h.
Speed—hourly rating	14.1 m. p. h.—28.3 m. p. h.
Tractive effort—	
Continuous rating, 45,000 lbs.	14.2 m. p. h.
Continuous rating, 26,250 lbs.	28.4 m. p. h.
Speed—continuous rating	14.2 m. p. h.—28.4 m. p. h.
Maximum speed	38 m. p. h.
Total wheel base	37 ft., 6 in.
Rigid wheel base	16 ft., 6 in.
Length overall (between pulling faces of coupler knuckles)	50 ft., 9 in.
Width overall	11 ft., ¾ in.

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During the past summer, Doyle was connected with the Radio Engineering Department of the Westinghouse Company at East Pittsburgh. From this department he was sent to Princeton, W. Va., on the Virginian Electrification work and was present during the locomotive acceptance tests and the inauguration of electric operation on the Virginian.—EDITOR.

Height from rail to locked position of pantograph	16 ft., 0 in.
Diameter of driving wheels	62 in.
Diameter of idle truck wheels	33 in.
Voltage and type of conductor—11,000 or 22,000 volt, 1 phase overhead.	
Number and type of motors.....	2 type 452-A
Method of drive.....Flex. gears, jackshaft and side rods	
Gear ratio	21:100
Type of control.....	Electro pneumatic (H. B.)
Number of this type of unit being furnished.....	36
Track miles electrified.....	213

Three of these units are semi-permanently coupled together to form the largest and most powerful locomotive in the world. This locomotive measures 152 feet in length, weighs 637.5 tons, can exert 7,125 horsepower and develops a maximum tractive effort of 277,500 pounds. The locomotive is built in three sections in order to negotiate curves, some of which reach as high as 12 degrees.

Single phase, 25 cycle power at a potential of either 11,000 or 22,000 volts will be supplied to the transformer on the locomotive through a pantograph collector. Low voltage power for the three phase traction motors and for the auxiliaries is taken from the transformer and phase converter. The traction motors are of the induction type arranged for two comparatively constant running speeds of 14 and 28 miles per hour. These motors, which have very desirable constructional and operating characteristics for locomotive use, are simple and rugged in construction and have a high weight efficiency. With the three phase induction motor, acceleration is accomplished by varying the external resistance inserted in the motor secondaries. Very high starting torques are obtainable with this type of motor, as well as capacity to carry heavy loads. As constant speed is maintained irrespective of the load, the horsepower input will vary almost directly with the tractive effort. As no commutators are used the questions of commutation and stability do not have to be considered. A very desirable feature of this type of motor for heavy duty service, is the ease with which it lends itself to regeneration. The induction motor is inherently the best by far as it automatically, without additional apparatus for switching, separate excitation or regula-

tion of any kind, becomes a generator whenever the locomotive, descending a grade, exceeds synchronous speed.

The voltage of the A. C. motors is low, their stability high, and they may be run on ungrounded circuits so that under proper conditions their operation is comparable to direct current motors. The condition of current supply is a factor of less importance owing to the transformer which is interposed between wire and motors. Control of speed is easily accomplished and is relatively simple and efficiently secured by the use of taps from the transformer without changing motor grouping or the use of external resistance.

Acceleration to the running speeds is obtained by varying the resistance in the rotor circuit of the traction motors, a liquid rheostat being provided for this purpose. The amount of resistance is determined by the height of the electrolyte in the rheostat and this is directly controlled by the engineman through the master controller. The master controller consists essentially of two parts, a speed drum for changing the motor connections to secure the desired running speed, and an acceleration drum. The control position also includes an auxiliary controller in which are placed switches for operating the pantograph, buttons for independent operation of the different rheostats, and a button for tripping the circuit breakers.

An especially interesting feature of these locomotives is the oil insulated force cooled transformer, the windings and core being immersed in a tank of oil. The oil is continuously circulated through a special radiator by a motor driven centrifugal pump, and air for the radiator is supplied by a blower driven by the same motor which drives the pump. By using this type of transformer, the advantages of the oil insulated transformer are secured without the space required by the self-cooled type.

The locomotives are automatically regenerative; that is, when descending a grade such that the net tractive effort becomes negative, the motors become generators and return power to the line. With regenerative braking 9,000 ton trains can be held to a constant speed of slightly less than 15. m. p. h. down grade. It is necessary to use the air brakes only to bring the train



A 6,500-Ton Train Nearing Herndon

to a complete stop, and this results in considerable saving in brake shoes and brake rigging maintenance.

Each motive power unit has the Mikado or 2-8-2 wheel arrangement, the weight per cab being approximately 425,000 lbs., so that the weight of the three-cab road engine is 637.5 tons. Each driving motor has mounted at each end of the shaft, a pinion which meshes with a flexible gear and the gears are mounted on a jack shaft, the power being transmitted from the gear centers to the drive wheels by means of side rods. The continuous tractive effort of the three-cab locomotive is 135,000 lbs. at 14.2 m. p. h. and 78,800 lbs. at 28.4 m. p. h. This is 57 per cent greater than the compound rating of the 2-10—10-2 Mallet steam pusher used by the Virginian. In the high speed connection of the motors the locomotive can exert 6,000 horsepower continuously, which makes the locomotive more powerful than any other steam or electric locomotive in existence. The horsepower of an electric locomotive increases with increasing tractive effort, while the reverse is true in the case of the steam locomotives.

With steam operation, trains of 5,000 tons have required three Mallet locomotives of the 2-10—10-2 type, between Elmore and Clark's Gap. With electric operation, 6,500-ton trains require one road engine and one pusher, the speed being 14 m. p. h., which is at least double that of steam operation. This means that through the bottle-neck of the system, two electric locomotives, replacing three Mallets, are pulling a greater tonnage at twice the speed, thereby practically doubling the coal output. With electric operation, a maximum of 20,000 horsepower per train is utilized in starting, which is about three times as much power as is developed under steam operation, but even this can be exceeded by 33 per cent at such a time as the strength of the rolling stock used will permit the addition of another motive power unit.

One of the most interesting features of the tests held on the Virginian last September, was the radio signalling between the front and rear of trains nearly a mile long. The handling of heavy trains by electric operation is a little more difficult than by steam operation and requires the skill of experienced enginemen. It is customary on the grade between Elmore and Clark's Gap to operate one locomotive at the head of the train and one locomotive at the rear. The primary problem is to get synchronous action between these two locomotives, particularly in starting and stopping.

Under steam operating conditions, this is accomplished by the rear locomotive allowing the throttle to remain partly open, thus picking up some of the slack of the train. When the forward locomotive starts, the motion of the train becomes evident to the engineer driving the pusher locomotive. The signal for such procedure is usually a bump received from the road engine transmitted through the train when the air is released and the slack is let out. This not only results in time delays, as it sometimes requires 10 to 15 minutes to reach 7 m. p. h. from stand-still on the grades, but also extreme punishment to the equipment.

Obviously with electric propulsion it would not be economical to follow the same procedure. This section of the grade lies over the Allegheny and Blue Ridge mountains and with numerous curves and tunnels, hand signalling cannot be used as there is but one place on this grade, a stretch of about a quarter of a mile, that the road engineer can see the rear of the train. The air whistles operating on 140 pounds pressure are not audible more than a quarter of a mile away at some places in the mountains, and as the Virginian trains are approximately a mile long, this method of signalling cannot be used.

After considering several methods of communications between the head and rear of the trains, the carrier-current radio signalling and telephony system was decided upon. The initial experimental work with the carrier-current system, under actual operating conditions on the Virginian, was found to be very successful. Both transmitter and receiver are mounted in steel boxes and all elements are very rigidly made mechanically, to withstand the vibrations encountered in railway service.

The electrical circuits used are very similar to those used in regular radio communication. The transmitter consists of a 50-watt master oscillator tube operating two 50-watt power amplifying tubes in parallel. The 1,000 volt plate voltage is supplied from a small 32-volt motor-generator set. The signalling is done by a remoteley controlled relay. The receiver consists of the necessary tuned circuits and a detector tube and two audio-frequency amplifying tubes. The "B" batteries are self-contained, and the filaments are operated from alternating current. The antennae equipment consists of a rigid brass rod mounted on top of the middle locomotive unit, in close proximity to the trolley wire.

Control relays and loudspeakers are mounted in the cabs at both ends of the locomotive. The only operation necessary when the engineer desires to signal is that he pulled the signalling cord attached to the control relay. When the cord is pulled half way down, the motor-generator is started, and sends high frequency current out over the system. On pulling the cord all the way down, the output is modulated by a 500-cycle modulator, producing a note in the loud speaker at the other end of the train. By using a code of signals similar to that used for whistling, any message can be transmitted. Furthermore, the signal can be acknowledged and communication carried on in the opposite direction. The advantages of this system are obvious. The only equipment needed is that on the locomotives. Any other communicating system would require equipping all of the rolling stock of the railroad to make it universal and effective.

The power for this electrification is supplied by the new turbo-generator station on the New River at Narrows. There is installed in this station four 25-cycle, 3-phase, 11,000-volt, turbo-generators with a maximum single phase rating of 15,000 k. w. each. Three units will be sufficient to carry the maximum load. An ample supply of water for condensing purposes is available from the New River and condensers of the surface type are installed. A complete pulverized coal equipment will be used in this plant. There are four 11,000 to 88,000-volt, 10,000-k.v.a., single-phase, water-cooled type transformers installed just outside the power station building. All high tension switching equipment is also installed outside the main building.

Power from the generating station is supplied to the locomotives through transmission lines, step-down transformers and a catenary contact line. There are two single-phase, 88,000-volt transmission lines connecting the generating station with seven step-down transformer stations, one of which is located at Elmore and another at Princeton. These step-down transformers are of special type with two windings on the secondary. One of these windings is connected to the 11,000-volt trolley rail circuit and the other to a feeder rail circuit with a potential of 22,000 volts. This gives a secondary transmission circuit composed of the trolley and feeder wires, which is used to supply auto-transformers connected between the main step-down transformer stations. By securing the proper balancing of impedance, through the transformers and the trolley-feeder, trolley

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ley-rail and feeder-rail circuits, the rail currents are reduced to a minimum and the through feed of earth current and stub-end effects are practically eliminated. The entire distribution system is designed for a trolley voltage of either 11,000 or 22,000. It will have the necessary capacity to handle the maximum day traffic specified at 11,000 volts, but the change to 22,000 volts can be made easily when the traffic increase warrants this change.

The Virginian electrification is of outstanding importance as indicative of what may be expected of other American railroads, and is particularly noteworthy because it involved an expenditure of over \$15,000,000 based upon belief in the growth of American industry and improved stability of railroad conditions.
