Comparative Performances of Steam and Electric Locomotives.

A Valuable Paper Presented to the 222d Meeting of the American Institute of Electrical Engineers, and a Valuable Discussion Concerning Practical Results Attained by the Electrification of the New York Central & Hudson River Railroad and the New York, New Haven & Hartford Railroad Systems.

THE 222d meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineering Societies Building, New York city, on Friday evening, November 8. The secretary, Ralph W. Pope, announced that at a meeting of the board of directors, held during the afternoon, associates were transferred to the grade of members as follows: Clifford Wayne Humphrey, Chicago; Robert Carr Lanphier, Springfield, Ill.; Albert Gustav Wessling, Cincinnati; William Nelson Smith, New York; Charles Ezra Scribner, Chicago, and Kempster B. Miller, Chicago.

President Stott announced that Professor Morgan Brooks, of the University of Illinois, and a party of thirty-five students were present, and welcomed them to the meeting.

He then called for the paper of the evening, by Albert H. Armstrong, engineer, railway department, General Electric Company, entitled "Comparative Performances of Steam and Electric Locomotives." Mr. Armstrong presented his paper, an abstract of which follows:

The general shape of the steam locomotive characteristic is given in Fig. 1, which shows the relation between the speed and tractive effort of a simple consolidation locomotive designed for heavy freight service. Owing to clearances it is seldom that a locomotive can work at more than ninety per cent of the theoretical full stroke, and hence the maximum tractive effort at starting with lever in the corner will not be much greater than eighty-eight per cent of the theoretical tractive effort available with gauge pressure in the cylinders. An inspection of Fig. 1 shows that the steam locomotive is limited as to maximum tractive effort by its engine design, and limited as to the speed at which this tractive effort is available by the capacity of the boiler to supply steam. Thus, assuming that the locomotive will give eighty-eight per cent of its theoretical tractive effort when starting, it is capable of providing but eighty per cent tractive effort at a speed of 10.6 miles per hour (with the constants of the particular locomotive chosen for illustration) at which the boiler is giving its full output. Hence higher speeds can only be reached with a lesser cut off and a consequent reduction in mean effective pressure and tractive effort.

On the other hand, the tractive effort of the electric locomotive is limited only by

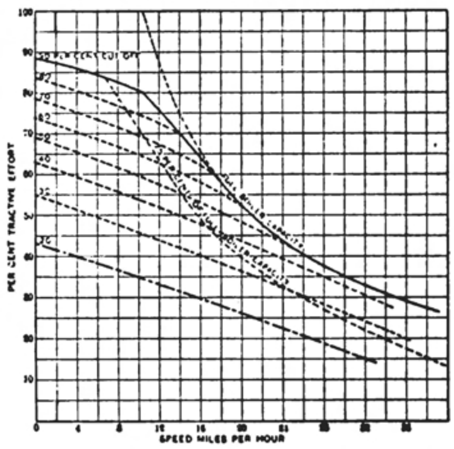

FIG. 1.—TYPICAL STEAM LOCOMOTIVE CHARACTERISTIC (SIMPLE.)

the adhesion between driving wheels and rail, and aside from some fifteen per cent greater adhesion possible with the uniform tractive effort provided by the electric locomotive, it is possible with this type of motive power to take momentary advantage of abnormally good rail conditions or to derive full benefit from the use of sand; indeed, tests have been taken

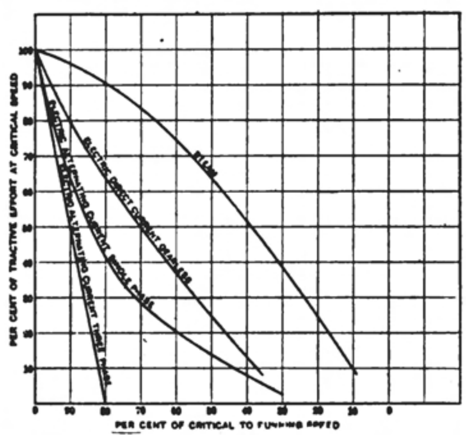

FIG. 2.—TYPICAL CHARACTERISTICS OF STEAM AND ELECTRIC LOCOMOTIVES.

with electric locomotives showing as high as thirty-five per cent coefficient of adhesion between driving wheels and rail. This point is emphasized as with the greater tractive effort of electric locomotives it becomes possible to give them a higher tonnage rating for the same weight upon the drivers than would be possible with steam locomotives operating over the same track profile.

There is a marked difference in the speed characteristics of the steam and electric locomotive, and indeed there is also a marked difference in the speed characteristics of different types of electric locomotives. Although this paper is not intended to enter into any discussion of the relative merits of different types of electric locomotives, there is so striking a difference in the several speed characteristics, each of which possess special advantages for certain operating conditions, that Fig. 2 has been prepared contrasting the characteristics of the steam locomotive and the direct-current gearless, alternating-current single-phase geared, and alternating-current three-phase geared electric locomotives. As all types of motive power share in common the fact of a certain critical speed beyond which full tractive effort can not be maintained, the curves in Fig. 2 have been prepared on the basis of showing the relation between percentage of maximum tractive effort available at speeds higher than the critical speed, ordinates being tractive effort and abscissas percentage of critical speed to running speed.

A more familiar presentation is given in Fig. 3, showing a concrete case of a twenty-two by thirty steam locomotive of the simple type equipped with fifty-seven-inch drivers, contrasted with both an alternating-current geared and a direct-current gearless electric locomotive designed for the same tractive effort both maximum and running, but for a higher speed. The contrast of these different speed characteristics brings out sharply the small speed variation with different tractive efforts delivered by the electric locomotives, this small variation being even more marked in the case of the direct-current gearless than in the case of the alternating-current geared motor working at a lower iron saturation and thus affording a more sloping speed characteristic.

The steam locomotive chosen is typical of those in general use upon our mountain-grade divisions, the tonnage rating in operation of this particular locomotive being such as to call for a tractive effort of 25,600 pounds on average grade and 33,200 pounds on the maximum ruling grade occurring on a certain engine division, thus leaving a margin of 6,300 pounds above the demands of maximum tonnage on maximum ruling grade for starting the train from rest.

What might be termed the "performance capacity" of a steam locomotive may be worked out from the speed and tractive effort characteristics given in Fig. 3, using as a basis the 1,000 ton-miles trailing load moved per hour on a level or any gradient selected. The prevalence of 2.2 per cent ruling grade on many of our western roads perhaps jusifies the selection of that figure for demonstration purposes; and the coal consumed, crew wages, and maintenance charges, may all be worked out

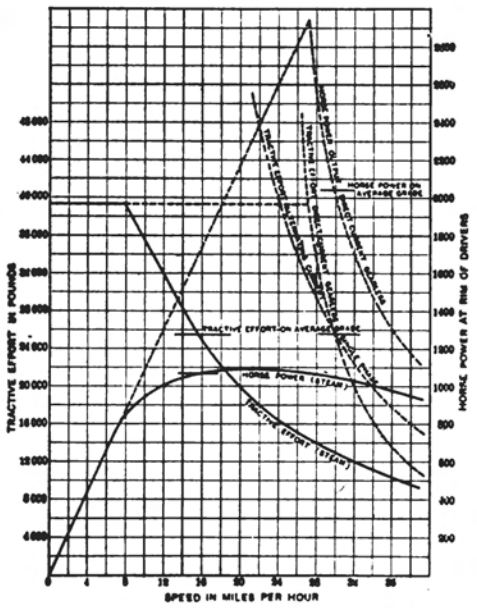

FIG. 3.—STEAM AND ELECTRIC LOCOMOTIVE CHARACTERISTICS.

from the basis of continuous operation per 1,000 ton-miles trailing load on 2.2 per cent grade, these results being shown in Fig. 5.

Certain assumptions are necessary and are as follows:

Cost of coal	$3 per 2,000 lbs.
Engineer, wages per hour	$0.50
Fireman, wages per hour	0.85
Conductor, wages per hour	0.40
Three brakemen, wages per hour	0.90
Total crew	$2.15

Average mileage per locomotive per year, 36,500.
Total maintenance, including round-house charges, $5,000.
Maintenance per locomotive mile actually run, 13.7 cents.
General locomotive constants are the same as previously given.

Considered broadly, the one expense in train operation that is fundamental is the cost of fuel, this factor being influenced only by the economy of the fuel-burning plant. Other expenses, such as locomotive maintenance, crew wages, etc., are affected entirely by the method of operation, and no radical departure from present methods is to be looked for until the coming of a type of motive power

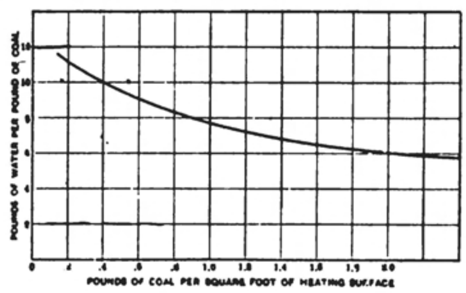

FIG. 4.—RATE OF EVAPORATION.

which offers possibilities not equally enjoyed by the steam locomotive.

This point is further illustrated by reference to the operating sheet of one of our greatest western roads using the simple consolidation locomotive previously described.

SPEED RELATIONS. ROAD "A," MOUNTAIN DIVISION.

	Up Grade. Miles per Hour.	Down Grade. Miles per Hour.
Schedule speed	7.35	12.5
Average speed while running	12.1	20.0
Number stops per mile	0.177	0.149

The average schedule speed of a number of trains, including all layovers due to the despatcher or failure of motive power, as obtaining on another mountain division of a different road, showed values as low

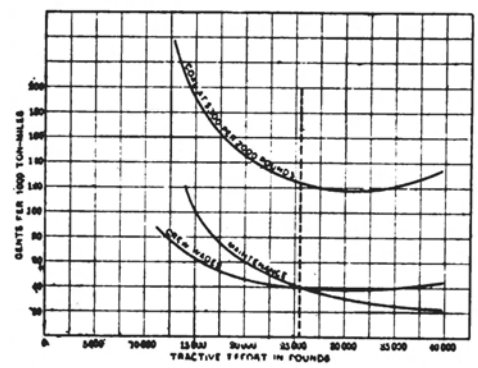

FIG. 5.—PERFORMANCE CAPACITY STEAM LOCOMOTIVE (SIMPLE) GRADE 2.2 PER CENT (UP).

as 6.7 miles per hour up grade. In general it may be stated that the freight movement over mountain divisions is effected at very low schedule speeds, and the cause is evident from an inspection of the steam locomotive characteristic. Except for the fact that curves are usually of shorter radius on heavy grades than on levels, there is no reason for the slower speed of trains, provided a type of motive power is available that is capable of supplying great draw-bar pulls at high speeds. It is just this characteristic which the electric locomotive possesses to an almost unlimited extent, and such locomotives can be built which are even more powerful and operate at higher speed than can be utilized at present.

For example, the simple consolidation locomotive considered is capable of sustaining a tractive effort of 25,600 pounds at a maximum speed of 15.4 miles per hour, and weighs 165 tons with tender, while a single New York Central electric locomotive of the 6,000 type is capable of delivering the same tractive effort at approximately thirty-seven miles per hour, and the weight is only 100 tons.

The electric locomotive may be equipped with motors of several different types each having characteristics best qualifying it for certain classes of work. Fig. 6 and Fig. 7 illustrate the usual speed, torque, and efficiency curves of two typical motors, the direct-current gearless and the alter-

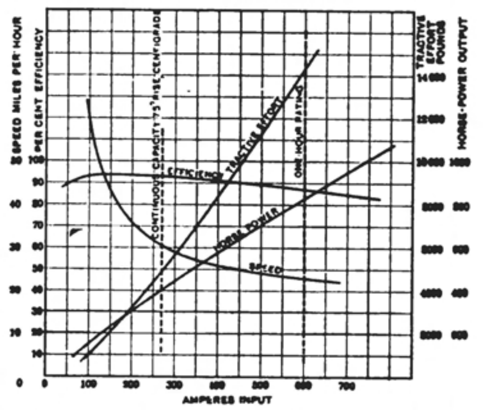

FIG. 6.—DIRECT-CURRENT GEARLESS MOTOR CHARACTERISTICS, 1,200 VOLTS.

nating-current single-phase geared type. The type of motor to be adopted is a matter requiring full local knowledge of the conditions obtaining in each individual instance before a proper selection can be made.

As the direct-current gearless motor can be built in the largest sizes, is the best understood, and is in successful operation upon a very important division of one of the largest steam roads, it is here chosen as the equipment of a typical electric locomotive.

The large output, 840 horse-power for one hour and 400 horse-power continuous, shown in Fig. 5, illustrates what can be accomplished with this type of motor. The output of the complete locomotive is dependent upon the number of motors permitted with the construction adopted. Thus, such a four-motor equipment is capable of delivering a tractive effort of 56,800 pounds at a speed of twenty-three miles per hour approximate (depending upon the voltage) while the efficiency of conversion at this output would be eighty-seven per cent, rising to a maximum of ninety-three per cent at higher speeds and lower tractive effort. Another form of construction, say one similar to that employed in the largest Mallet compound, would permit the use of two four-axle articulated trucks, providing an equipment of eight motors and an output of 113,600 pounds at a speed of twenty-three miles per hour.

Returning to the direct comparison of the simple consolidation and electric locomotive, Fig. 3, was plotted on the basis of a speed of thirty miles per hour for the electric and 15.4 miles per hour for the steam locomotive, giving in each instance a tractive effort of 25,600 pounds at the

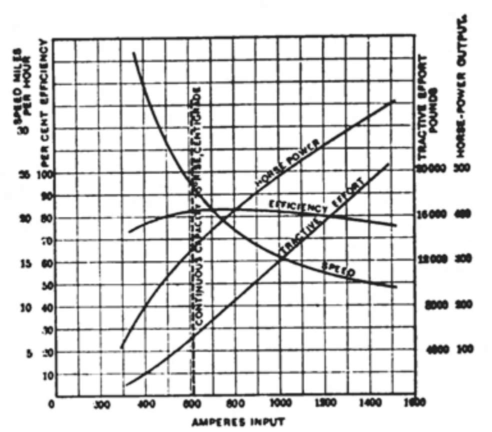

FIG. 7.—ALTERNATING-CURRENT SINGLE-PHASE MOTOR CHARACTERISTICS, TWENTY-FIVE CYCLES, 375 VOLTS.

rim of the drivers. Though the electric locomotive could very readily be designed to give the same tractive effort at a higher speed, thirty miles per hour was assumed as the highest speed permissible due to the alignment of the track on heavy grades.

To plot a performance capacity curve for the electric locomotive, certain further assumptions are necessary.

TYPE OF EQUIPMENT, DIRECT-CURRENT GEARLESS MOTORS.

Weight of total locomotive	125 tons
Weight on drivers	100 tons
Engineer, wages per hour	$0.50
Conductor, wages per hour	0.40
Three brakemen, wages per hour	0.90
Total wages of crew	1.80

Efficiency of transmission rail to bus-bar, seventy per cent.

Maintenance of locomotive, five cents per mile run.

The train crew is so divided as to permit the location of a brakeman in the engineer's operating cab.

The cost of electrical power must in this instance be most arbitrarily assumed, owing to the widely different cost of coal, possibility of water power, etc., obtaining in different localities. As the cost of coal for steam locomotives will also vary greatly as to price and quality, it has been assumed at $3 per 2,000 pounds, and a cost for electric power of one-half cent per kilowatt-hour is based upon using the same price and quality of coal. As it is further assumed that an entire engine division of say 150 miles is to be electrified, it gives

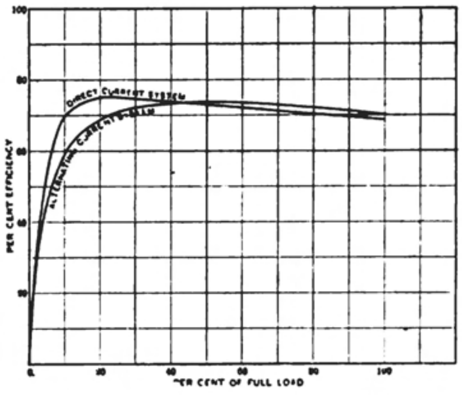

FIG. 8.—EFFICIENCY OF DISTRIBUTION TO RAIL.

promise of a twenty-four-hour load-factor of fifty per cent and this figure has been taken. Approximating the first cost of installation of the generating station at $100 per kilowatt, and allowing ten per cent per year for interest and other fixed charges, the cost of power is brought up to possibly $0.0075 per kilowatt-hour at the station bus-bar. Other conditions obtaining will in a given instance modify the figures arrived at, but for purposes of demonstration $0.0075 is a conservative estimate, and such a figure is needed to compare the cost of power with the fuel item in steam-locomotive performance.

The effect of increased speed on cost of operation is clearly shown by comparing the performance capacity curves of the steam and electric locomotives, Figs. 5 and 9.

It will be observed that the reduction in the operating expenses is effected in the two items of crew wages and maintenance of locomotives, and that the cost of fuel

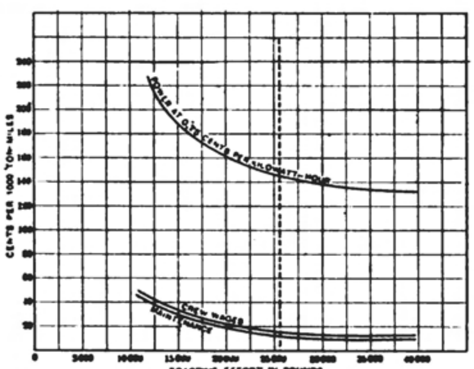

FIG. 9.—PERFORMANCE CAPACITY ELECTRIC LOCOMOTIVE (DIRECT-CURRENT GEARLESS) GRADE 2.2 PER CENT (UP).

remains practically unchanged. This is as it should be, as the cost of fuel in the case of steam locomotives or power with electric locomotives is the only fundamentally necessary expense in train movement. Overcoming train friction and raising a train up-grade against gravity represents useful work performed, and this work is accomplished at an expenditure of approximately four pounds of coal per horse-power-hour at the drivers with simple engines and 2.66 pounds of coal per horse-power-hour at the drivers with electric locomotives, including all intervening losses between rail and generating station bus-bar. The speed at which this work is performed, therefore, does not affect the cost of fuel or power, it being assumed that the motive power for the various speeds is so proportioned as to operate at the point of greatest economy.

It is evident that the cost of fuel or power, being fundamental, constitutes a

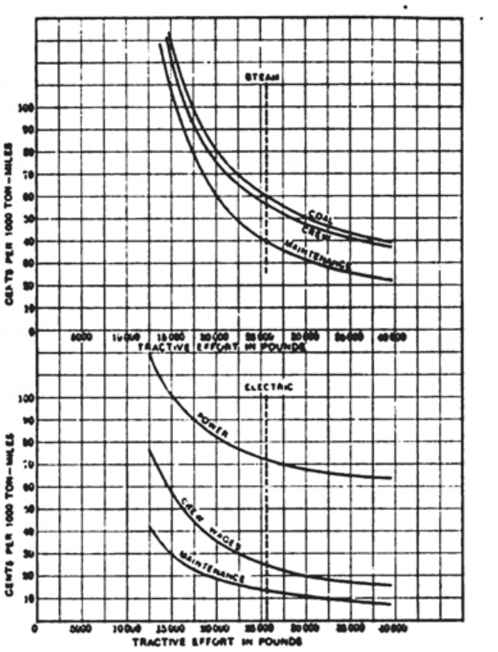

FIG. 10. — TRACTIVE EFFORT IN POUNDS. SERVICE CAPACITY STEAM AND ELECTRIC LOCOMOTIVES AVERAGE OF UP AND DOWN 2.2 PER CENT GRADE.

fixed item in the total cost of operation, while the other two items, crew wages and maintenance expenses, will be determined solely by the method of operation and the excellence of motive power used. We have become so accustomed to consider that fuel, crew wages, and engine maintenance each constitute approximately ten per cent of the total cost of operating a railway that we rather lose sight of the fact that two of these items are theoretically needless expense and subject to considerable modification in practice with the adoption of another type of motive power possessing characteristics which will permit making radical changes in operating methods.

While the figures shown in Figs. 5 and 9 indicate a certain relation among the three items of fuel, crew, and maintenance expense, this is not the true relation obtaining in practical operation, for the reason that the values given in the curves assume continuous operation up-grade under the conditions outlined. Unfortunately, train crews must be paid full value per mile whether the mile be up-grade or down, and with steam locomotives there is also a considerable loss in fuel resulting from engines standing or running light which must be also taken into account; hence it becomes necessary to modify the figures arrived at, and for this purpose certain references must be made to current railroad practice on mountain-grade divisions in order to arrive at the proper tonnage relations, schedule, speeds, etc., obtaining in up-grade and down-grade operation.

Previous figures have been given showing that the schedule speed on several mountain divisions is approximately fifty per cent of the average running speed and this figure is assumed in the following statement of cost of operating 1,000 ton-miles with steam locomotives, averaging the cost of up-grade and down-grade running. Owing to the higher schedule speed of electrically operated trains, resulting in fewer meeting points with the same tonnage handled, and due to the absence of forced stops to take on fuel and water, etc., it is assumed that with electric motive power the schedule speed may be sixty per cent of the running speed.

With the electric locomotive standing, or coasting down-grade, there is no demand whatever made upon the generating station, and hence the only expense carried through these periods is that for train crew and a certain amount for maintenance. On the other hand, with the steam locomotive there is a considerable amount of fuel burned and water wasted when standing at sidings and when coasting. In the case of mountain railroading, with its frequent and prolonged delays, this waste may reach considerable proportions.

The following results of a carefully conducted series of tests will illustrate this point. Two test locomotives and trains were operated over a mountain division under regular service conditions—steam and fuel consumption, duration of delays, etc., being carefully noted. The total work expended up-grade was 5,700 horse-power-hours at the rim of the drivers including allowance for 1.54 per cent average grade and seven pounds per ton track and curve friction. The total water evaporated on the trip divided by the total horse-power-hours gave a steam consumption of thirty-six pounds per brake-horse-power-hour at the rim of the drivers. Indicator cards taken upon the engine in question at all cut-offs up to ninety per cent showed that the greatest steam consumption did not exceed thirty-two pounds per indicated horse-power-hour, or 35.5 pounds per brake-horse-power-hour, allowing ten per cent internal engine friction. Values as low as twenty-three pounds of steam per indicated horse-power-hour or 25.5 pounds per brake-horse-power-hour were recorded for the average cut-off of forty to fifty per cent used throughout the run. A third and fourth series of tests conducted up the same grade gave similar results, except that the values were slightly higher than those quoted, showing that there was a considerable loss of water unaccounted for by indicator cards and useful work performed.

Operating down-grade, it was necessary to accomplish 1,110 horse-power-hours on account of the somewhat broken profile, and again the water consumption showed

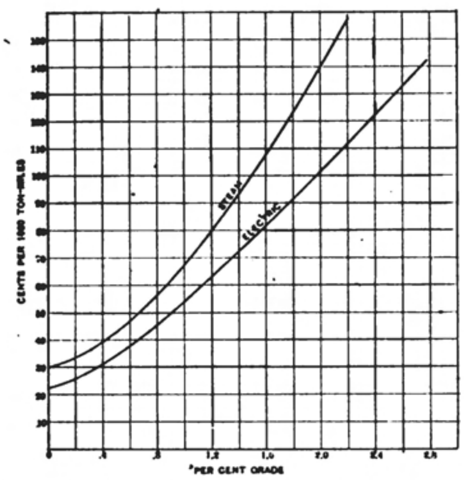

FIG. 11.—SERVICE CAPACITY OF STEAM AND ELECTRIC LOCOMOTIVES AVERAGE BOTH DIRECTIONS AND ANY GRADIENT.

on two trips 57.7 pounds of steam per brake-horse-power-hour, and on two subsequent trips 66.5 pounds, values entirely unaccountable on the basis of useful work performed.

During all tests the usual service delays occurred, and as the traffic on the road in question was very much congested, these delays constituted a considerable proportion of the total elapsed time. In fact, during the runs up-grade the trains were in motion but sixty-six per cent of the total elapsed time, and down-grade the trains were in motion from fifty-two per cent down to forty per cent of the total elapsed time. As these delays were frequent and undetermined, it was necessary to maintain full steam pressure while waiting for the momentarily expected release from the block, hence the waste of fuel and water was considerable. Averaging this waste at 400 pounds per hour, at which low rate of consumption the water evaporation would approximate ten pounds of water per pound of coal burned, or 4,000 pounds of water evaporated per hour, and reducing the total water consumption measured by the waste losses thus obtained, the steam consumption in eight different tests up and down grade ranged 34.7 pounds, 32.4 pounds, 28.1 pounds and 25.3 pounds, etc., water per brake-horse-power-hour. These values are fairly commensurate with results of indicator cards taken, and, with the type of engine used and under the operating conditions obtaining, an allowance of 400 pounds of coal stand-by losses per idle locomotive-hour seemed not too great a value to allow, and this figure has been taken in subsequent calculations.

Locomotive performance capacity curves may therefore be plotted which will show approximately the true relation between the several items of fuel, crew wages, and motive power maintenance, by adhering to the following assumptions:

Ratio schedule to running speed up-grade, steam locomotive	50 per cent
Ratio schedule to running speed up-grade, electric locomotive	60 per cent
Schedule speed down-grade, steam	15 miles per hour
Schedule speed down-grade, electric	18 miles per hour
Cost of coal	$3 per 2,000 lbs.
Cost of electric power	0.0075 per kw-hr.
Efficiency of distribution	70 per cent
Crew wages per hour, steam	$2.15
Crew wages per hour, electric	1.80
Maintenance locomotive, steam	0.187 per mile
Maintenance locomotive, electric	0.05 per mile
Fuel waste per idle hour, steam	400 lbs.

An inspection of the performance curves shows that in practical operation the fuel expense approaches more nearly to the value of the other items considered, instead of being greatly in excess of them as indicated in the theoretical performance curves, Figs. 5 and 9, showing up-grade operation only. For operation on lesser grades than 2.2 per cent, all items are reduced and the total and subdivided comparative costs are given in the following table and in Fig. 11.

COMPARATIVE OPERATING EXPENSES PER 1,000 TON-MILES STEAM (SIMPLE) AND ELECTRIC LOCOMOTIVES.

AVERAGE OF UP-GRADE AND DOWN-GRADE OPERATION.

Steam Locomotives.

Grade	½ per cent	1 per cent	1½ per cent	2 per cent
Coal	15.0 cents	25.5 cents	38.0 cents	53.0 cents
Crew	13.5 cents	24.0 cents	36.0 cents	50.0 cents
Maintenance	10.5 cents	17.8 cents	26.0 cents	36.0 cents
Total	39.0 cents	67.3 cents	100.0 cents	139.0 cents

Electric Locomotives.

Grade	½ per cent	1 per cent	1½ per cent	2 per cent
Power	20.0 cents	35.5 cents	50.5 cents	66.0 cents
Crew	7.2 cents	12.2 cents	18.0 cents	24.0 cents
Maintenance	3.6 cents	6.2 cents	9.0 cents	11.9 cents
Total	30.8 cents	53.9 cents	77.5 cents	101.9 cents

Saving Effected by Electric Operation.

Grade	½ per cent	1 per cent	1½ per cent	2 per cent
	8.2 cents	13.4 cents	22.5 cents	37.1 cents

So far, the matter has been viewed from the standpoint of comparative operating expenses for a given tonnage moved. There is another argument for electrification which may in certain instances be of a much more controlling nature. Most of our mountain roads are single track and transcontinental tonnage has so increased as seriously to congest these mountain divisions. The heavy trains of the plains, weighing 2,000 to 3,000 tons, must be split up into units of about 1,000 tons in order that the present steam engines, operating double and even triple, may haul them over the heaviest grades. The slow speed obtainable makes the number of trains on a mountain division large, the meeting points frequent, and hence, however good the despatching system employed, there will of necessity be a considerable amount of lost time introduced. Add to this the failures of motive power being worked to its limit, and there is reason for the claim that the tonnage capacity of the division will be greatly increased by the introduction of electrically hauled trains.

The discussion was opened by the reading of a communication from William J. Wilgus, formerly chief engineer of the New York Central & Hudson River Railroad Company. Mr. Wilgus congratulated Mr. Armstrong upon his able presentation and endorsed his view with regard to the matter of capacity being the basis upon which the solution of the electrification of main lines rested. Mr. Wilgus presented some very interesting figures which had been secured in the practical working of the electrification of the New York Central & Hudson River Railroad Company's system. The results are even more gratifying than were expected. Because of the lower cost of maintenance of electrical equipment and the less idle time in shops, the greater cost of interest charges and depreciation is not only neutralized, but a net saving in repairs and interest charges over steam equipment of nineteen per cent is effected. Electric locomotive inspection and light repairs, as compared with coaling, watering, drawing fires, etc., of steam locomotives shows a saving in time in favor of the electric system of over four hours per day, equal to eighteen per cent. The electric locomotive, while busy, is a much more nimble and efficient machine than the steam locomotive, showing an increase in daily ton-mileage of twenty-five per cent. While not so important in freight service, the question of locomotive weight is a large factor in a comparison of the relative economies of handling passenger traffic by steam and electricity. For instance, in switching service at the Grand Central terminal, sixty-five per cent of the total steam ton-mileage is due to locomotive or dead weight, while the electric locomotive percentage is but fifty-four per cent, a saving for the latter of eleven per cent. In the regular schedule service the steam locomotive shows fifty-one per cent dead ton-mileage, as against thirty-five for the electric equipment, a saving for the latter of sixteen per cent. When we realize that this saving has a direct proportionate effect on the cost of fuel and current, and an indirect effect on wages and fixed charges, its importance is manifest. The speed advantage of electric over steam locomotives in mountain grade operation is strikingly apparent in the New York Central installation, where the increase in coal consumption for car-ton-mileage in high-speed steam service, as compared with slow-speed service, is shown to be 165 per cent; whereas, under exactly the same conditions, the increased consumption of current for electrical equipment is but eighteen per cent, a difference in favor of electrical operation of 147 per cent. The net result of all of the economical advantages of electric operation over steam for the conditions existing on the New York Central, including all elements of cost of additional plant, shows a saving in summer months of from twelve per cent to twenty-seven per cent, depending upon the character of service. A larger sum may be expected under winter conditions.

Dr. Cary T. Hutchinson was called upon, and he also complimented Mr. Armstrong for his clear outline of the relative capacities of steam and electric locomotives. Electrification has always been undertaken on account of some special problem, and the element of economics has not largely entered into the calculations. He did not think that we have reached a point where we can determine the matter from its economic aspect, as the data are too uncertain. All data bearing on this subject are liable to severe criticism at present, no matter how conservative they may seem to be.

Dr. Hutchinson looked at the matter of comparative capacities of steam and electric locomotives from a somewhat different point of view from Mr. Armstrong. With a steam locomotive there is a limit generally of a certain weight on the driving axle. For the purpose of comparison, 50,000 pounds might be taken. It is not safe to build a locomotive with more than 50,000 pounds on one axle. The coefficient of traction will not be over twenty-five per cent, say, 11,000 pounds tractive effort per axle. This will mean 9,000 pounds drawbar pull per driving axle. With a steam locomotive 9,000 pounds drawbar pull can be given in continuous service, but it can not be secured in continuous service with an electric locomotive. There is not room enough to secure anything like 9,000 pounds continuous tractive effort; therefore the steam locomotive, on that basis, has a higher capacity than the electric locomotive. But the capacity of the electric locomotive will be determined by its average performance. If the grade is a broken grade, a machine will have to be used so that the heating will not be excessive in the average performance, and therefore a motor can be secured which will give an average of 5,000 or 6,000 pounds per driving axle. This same machine, on the ruling grades, will easily take 10,000 pounds before slipping the wheels, or possibly 15,000 pounds. From that point of view the consideration of the ruling grade is eliminated in determining the size of motor. An electric motor is chosen or designed to have sufficient capacity to give average service. With a steam locomotive a machine must be chosen to give maximum service. This is the fundamental difference in the method of rating. The Mallet compound steam locomotive of the six-axle type, with which Dr. Hutchinson happens to be familiar, can not do better in every-day service than pull 800 tons or less up a 2.2 per cent grade at a speed of 8.5 miles per hour. This is equal to about 1,200 horse-power at the driving wheel. This locomotive will weigh, with the tender, 250 tons. An electric locomotive weighing 100 tons will haul this same 800 tons up the same grade at a speed of fifteen miles per hour instead of 8.5 miles, and will develop approximately 1,800 to 1,900 horse-power instead of 1,200. It will not do it for six or eight hours, but it will do it long enough to get up a grade of fifteen or twenty miles. That gives a horse-power output per ton for the steam locomotive of the six-axle type of only 4.8, and the electric locomotive of 18.6—nearly four times as great a specific output for the electric locomotive as for the steam locomotive. Another point with regard to the electric locomotive, due to the lesser weight, is the saving of dead haulage. There is 150 tons difference in the two machines working under the same conditions, and taking a mileage of 100 miles a day, there is 1,500 ton-miles a day, worth $30 a day, or $10,000 a year difference in the actual cost in the dead haulage of the two machines.

N. W. Storer endorsed Mr. Armstrong's conclusion that the keynote of the whole subject of electrification of steam railways lies in the capacity. The greater loads per train crew that can be hauled; the greater speeds, both on level tracks and on grades; the greater safety on grades, all tend toward greater capacity, and that is what is going to force the electrification of a considerable number of roads in this country. With regard to the different types of locomotives, Mr. Storer said that the direct-current locomotive is able to control the train on the down grade at almost any speed that it is desirable to operate at, by the use of resistances for absorbing the regenerative power. The three-phase, alternating-current locomotive will control the train at speeds above synchronism by absorbing the excess power in resistance and the single-phase locomotive will control the train at almost any speed at which it is desired to control it and restore energy to the line efficiently at all speeds. He said that the single-phase locomotive would have a higher tractive effort at higher speeds proportionally than the direct-current locomotive. He exhibited a curve which showed an efficiency with an alternating-current motor without gears of about ninety-one per cent. With a reasonable allowance for gear losses, this should be at least eighty-six per cent. This was with a fifteen-cycle motor.

W. S. Murray, electrical engineer of the New York, New Haven & Hartford Railroad Company, presented some very interesting figures which had been secured through a series of elaborate tests on the New York division, between New Haven and Woodlawn. The following tabulation shows the saving of fuel which will be effected when all freight and passenger trains now operated by steam receive their drawbar by the electric method of propulsion:

	Ton-Miles per Annum.	Tons of Coal Steam Traction.	Tons of Coal Electric Traction.	Cost of Coal Steam Traction.	Cost of Coal Electric Traction.	Saving of Electric Over Steam Traction.
Express	592,240.000	57.447	29.870	$183.830	$89.620	$94,210
Express (locomotive).....	348.000.000	58.300	28.600	186.560	85.800	100,760
Freight	2,223.000.000	187,844	139,010	563,530	417,030	146,500
	3,163,240,000					$341,470

With regard to the drawbar which can be developed by the electric method of traction for coal burned under the boilers of a stationary plant, as compared with the coal burned in the fire boxes of locomotives, his observations showed that in express work 2,055 indicated-horse-power-hours are developed in the evaporation of 57,594 pounds of water, giving an average of twenty-eight pounds of water per indicated-horse-power. On local trains this figure is slightly increased, the evaporation being 42,987 pounds of water for 1,435 horse-power-hours, making the rate thirty pounds of water per indicated-horse-power-hour. These figures were mentioned in comparison with the turbine guarantees of twenty pounds of water, including auxiliaries, per kilowatt-hour at the switchboard, which, reduced to a horse-power basis, would be fifteen pounds of water as measured at the switchboard. The average figures which he has been able to secure on electric engine repairs per locomotive-mile are about two cents. Increasing this figure twenty-five per cent for safety, and assuming the same number of electric engines replacing steam locomotives, the total would be $120,924 per annum, showing a saving over steam locomotives of $196,038. The net saving on fuel and locomotive repairs in favor of electrification gives a round sum of $562,470 per annum.

William McClellan called attention to the necessity of the electrical engineer's being prepared to show to the steam railroad operator where actual economics could be secured through the electrification of the system. In every case there should be an absolute justification for the change. The electrical engineer is not in a very good position to prove that electrification will be successful from an economic standpoint, and it is fortunate indeed that figures have been secured from Mr. Wilgus and Mr. Murray.

C. F. de Muralt mentioned a system which his office had recently had occasion to work out a problem for, involving a road of something like eighty miles of double track which was actually at the end of its capacity to handle traffic so far as steam locomotives were concerned. The investment for additional tracks would have been something like $15,000,000. Electrification, with complete new power-stations and new distributing system, with new locomotives, would cost something in the neighborhood of $3,000,000. By the handling of the present traffic by electricity there would have been a saving of something like $200,000, while with the electric equipment pushed to its limit, the traffic increase would have been something like forty to fifty per cent over the present traffic capacity.

The paper was also discussed by W. N. Smith and B. F. Wood.

Dr. Charles P. Steinmetz called attention to the characteristics of the steam locomotive and the electric motor. One characteristic of the steam locomotive is that it is essentially a constant-power motor. The steam locomotive can give approximately the same power whether running at high or low speed. The drawbar pull does not tell the whole story. The limit is the steaming capacity of the boiler. The faster you move, the oftener the cylinders are filled; but the capacity of the boiler to produce steam must not be exceeded. If this is done a lower drawbar pull is secured. With the electric motor the limitation essentially consists in constant loss of power. The limit of the electric locomotive is that it can lose only so much power in the motor, in the general average, to be within sufficient heating limits. Since efficiency rapidly increases with the speed, it means that more power can be got out of it at higher speeds up to a certain limit; therefore the electric locomotive is better at the higher speeds than is the steam locomotive. You have to take advantage of this feature if you desire to get the best results.

Mr. Armstrong closed the discussion and announced his pleasure at finding that the figures which he had, of necessity, been obliged to assume, had been checked up, to a considerable degree, by the figures presented by Mr. Wilgus and Mr. Murray in actual operation.

With regard to the conclusion arrived at by Dr. Hutchinson, that the total drawbar pull or tractive effort could not be sustained by an electric locomotive, he pointed out that it was rarely possible to have any gradient of road so constructed as to use the full tractive effort of the locomotive indefinitely. Except in one case, on the Sacramento division of the Southern Pacific, which has a 1.54 per cent grade for eighty-three miles, rising 7,000 feet in that distance, there was no continuous grade of more than twenty-five to forty miles that he knew of. On the Sacramento division it is expected that an electric locomotive operating over that section would make the run in something less than four hours, so that the continuous capacity of the locomotive is not of permanent importance. But the capacity of the locomotive must be designed for the actual road over which it operates, and it will be found that, including delays, and also taking account of the limited extent of the maximum gradient, it is impossible to use much more than an average of fifty or sixty per cent of the maximum tractive effort, so that, with 10,000 pounds maximum and sixty per cent as a continuous output, the 6,000 pounds given by Dr. Hutchinson is arrived at, and it is found that the electric locomotive, instead of being handicapped in its average performance, corresponds closely to the service requirements of any type of motive power.

The meeting was then adjourned.

BOOK REVIEW.

"Alternating-Current Motors." A. S. McAllister. Second edition, enlarged and revised. New York. McGraw Publishing Company. Cloth. 304 pages, 131 illustrations. 6 by 9 inches. Furnished by the ELECTRICAL REVIEW for $3.

The first edition of this work has met with such success that a second edition has been necessary within a year. The author assumes the reader to possess a fair general knowledge of electromagnetic phenomena and upon that assumption works out in a very clear and understandable manner the characteristics of all forms of alternating-current motors. The treatment in most cases is both graphical and algebraical without complex quantities.

In preparing the second edition, changes have been made in a number of places and additional matter has been inserted in other places, making the treatment somewhat clearer. The following are some of the most important changes. To Chapter IV, on "Induction Motors as Frequency Changers," a discussion of the motor-converter has been added. After the theory of the motor-converter has been worked out, the principles involved in its excitation are, in a very logical manner, shown to apply to the secondary excitation of the Heyland motor. In Chapter IX, on "Magnetic Field in Induction Motors," the treatment of the revolving field of single-phase induction motors has been made considerably clearer. A supplement has been added to the chapter on "Synchronous Motors and Converters," giving circular current loci and V-curves of the synchronous motors. These diagrams are novel and are of material aid in understanding the synchronous motor. An appendix on leakage reactance of induction motors has also been added. With these revisions, the second edition is quite an improvement over the first.

ELECTRICITY APPLIED TO STAGE LIGHTING.

BY JNO. H. KLIEGL.

The extent to which electricity is used and applied for stage illumination purposes has greatly developed in recent years. In order to economize space, the stage electrical instruments and appliances have to be constructed so as to occupy as little room as possible. Architects and stage designers seldom make allowances for sufficient room for the electrical end of the stage equipments. Therefore the hardest problem to solve for the practical stage electrician is to condense every piece of apparatus designed for stage use into the smallest space possible, and at the same time make them strong and durable enough to give the best results and to pass all inspection.

All stage and auditorium lights in a theatre are controlled from one central point—the switchboard. Only by having the control concentrated can the proper changes be obtained which add so much to the success of a play. A theatre switchboard has more current-supplying switches in the smallest space than any of the large power plant switchboards, and the arrangement of the switches must be so simplified that they can be within easy reach of the operator. At the same time the small switches used for stage purposes should have twice the amount of current-carrying capacity, so as to make them extra strong, to withstand the rough usage a switch will invariably receive during a performance.

Lately switchboards have been designed by the Universal Electric Stage Lighting Company which have no live terminals on the face of the board. This actually means two boards, one in front (the main board), which has the switch mountings and dimmer controlling devices, while the rear board holds the switches, fuses and bus-bars. This device takes more room for the depth of the board, but at the same time allows the space in front. No railing is required in front of the board.

One of the latest and most modern electric stage installations is found in the Metropolitan Opera House, New York city. This is well shown in Fig. 1. Upon the stage of this theatre, no matter how elaborate or varied the scenery, any play may be produced without the slightest alterations or the necessity for new installation. The equipment is such that any scenic or light effect may be obtained.

Underneath the stage floor in front near the centre is located the main switchboard (Fig. 2). By placing the switchboard below the stage floor, several advantages are obtained. It is out of the way, safe from all interference by irresponsible persons, and no flashes of light can be seen by the audience or performer when switches are operated.

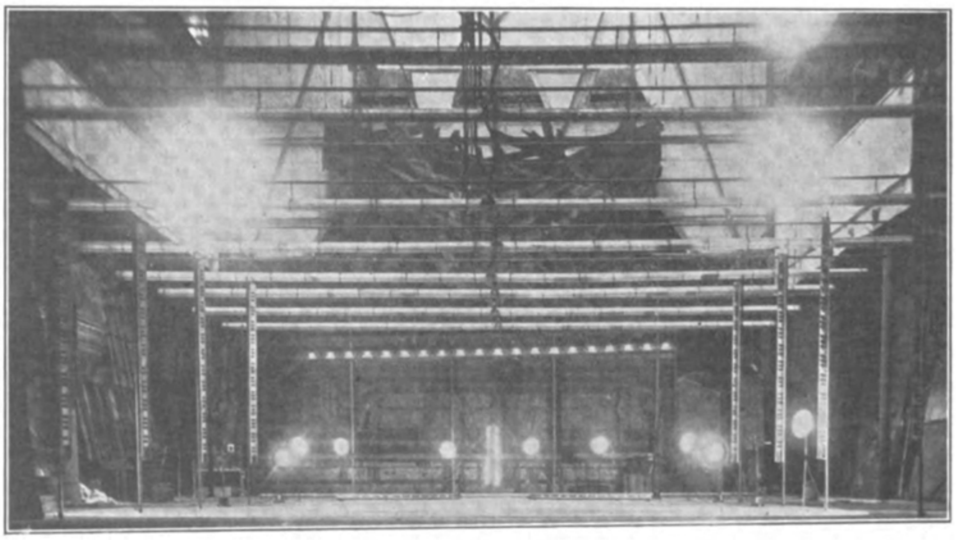

FIG. 1.—THE STAGE OF THE METROPOLITAN OPERA HOUSE, NEW YORK CITY.

The wires and cables occupy a minimum of space above the stage floor. It enables the operator of the switchboard to have control of all the master switches and master wheel for dimmer shafts at the same time, and the operator has the great advantage of overlooking the stage, having a view of all the lights under his control. This is most important when manipulated light changes are desired. Through an opening in the stage floor the operator watches the progress of the play and is therefore prepared to make the proper light changes at the right moment. The operator's head is shielded