The Author. working with a limited staff as suggested. In reply to Colonel Sir Gordon Hearn's remarks as to the operation of motor-trains by high-pressure steam rather than by the oil-engine, he thought he need only suggest study of what had taken place on the road and on the sea, as showing the great advance of the oil-engine as compared with steam. Mr. Hippisley had raised the question of series-parallel control. It had advantages, and eight sets had operated with this control very well indeed for about 4 years in Canada. It might have to be returned to in order to provide the high initial acceleration from the station-platform that now seemed to be called for. It was usual to drop the engine speed in changing over to keep the electrical side simpler.

He would conclude with the general remark that he felt considerably surprised that on first principles, apart from some detail of engine or electric gear, the railways did not place more value on the progress made in the handling of traffic by internal-combustion engines on the road and on the sea, than they did or had so far appeared to do in this country.

Correspondence.

Mr. Durtnall. Mr. W. P. Durtnall remarked that the attainment of 40 per cent. brake thermal efficiency by the Author's engine was, he thought, about the highest on record. The highest in Europe he had seen so far was given by a Diesel oil-engine, namely 36 per cent. brake thermal efficiency at full load, but that engine had, of course, the extra mechanical losses of the high-pressure air-compressor providing for the pneumatic injection of fuel. Did the Author consider that a material contribution to the high efficiency obtained with his engine was the fact that he used hydraulic injection of the fuel? In 1910 Mr. Durtnall was instructed to design a locomotive using heavy fuel-oil to operate over mountain ranges reaching an altitude of 8,000 feet. Although the general design of such a locomotive was not very difficult in itself, as his electrical transmission-system had been well tried in other directions, no Diesel engine maker would undertake the building of an engine that would give the same power at 8,000 feet as it would, with economy, at sea-level, so the matter fell through until the difficulty was overcome by entirely altering the heat-cycle of the engine. In the modified type of four-stroke engine, the inlet-valve closed before

Mr. Durtnall.

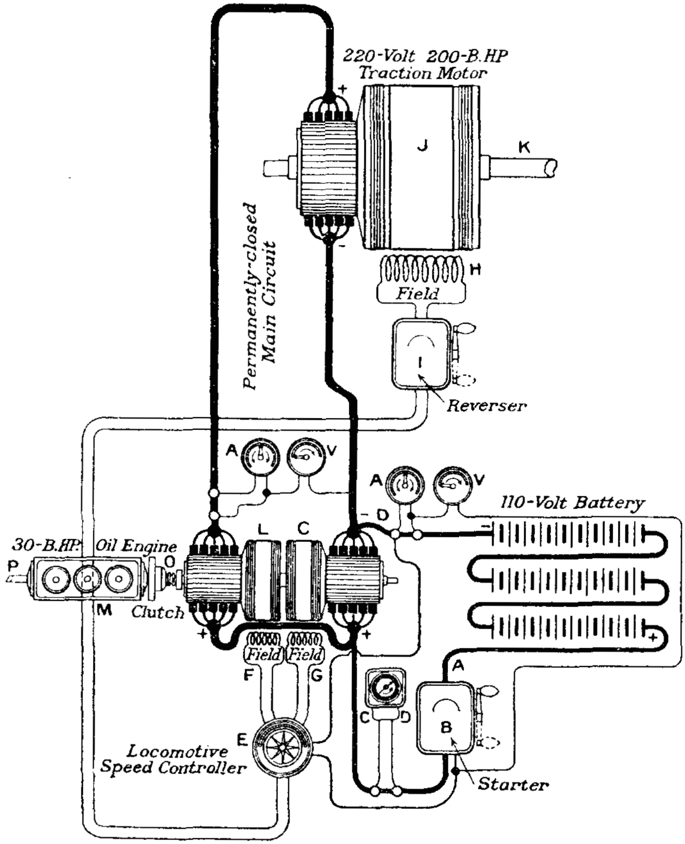
the end of the suction stroke, the induced charge of air being expanded during the latter part of that stroke, and the reduction in pressure acting as an air cushion. The compression volume was reduced to give a compression temperature high enough to ignite the fuel injected, in the same way as in the Diesel engine. Expansion was extended to atmospheric pressure, and the engine exhausted therefore at constant pressure, the theoretical thermal efficiency being higher than that of an ordinary Diesel engine. By allowing the inlet-valve to close later in the stroke, full power could be obtained at a considerable altitude above sea-level. He had also devised a two-stroke cycle of operation, scavenging by air-pressure. Using that long-expansion cycle a thermal efficiency equal to that of the four-stroke type could be obtained, with very much greater simplicity in construction, and thoroughly reliable operation. Although the high speed of revolution at which the Author's engine ran reduced the weight and cost of the electrical generating-plant, Mr. Durtnall's experience did not lead him to favour such high revolutions, nor such light engines, for application to main-line duties, where so much depended upon reliability. With the ordinary electrical power-transmission system, failure of the oil-engine would obstruct other trains. He had appreciated that fault of the oil-electric locomotive in 1922, and had completely revised the general design of his locomotive, his first electric-storage locomotive of the new type having been exhibited at work at the Wembley Exhibition in 1924. His 1922 type of oil-electric locomotive had engines of 320 HP., running at 450 revolutions per minute, and four driving-axles, the drive from the four electric traction motors being taken through a silent worm gear for the first time in main-line locomotive practice. He had had such a satisfactory experience with the worm drive that he would continue to use it. Professor G. V. Lomonossoff had stated recently in America that not more that 5 to 10 per cent. extra efficiency in railway-operation could be expected from Diesel-engined locomotives, and that, although the Diesel-electric locomotive had excellent operating characteristics, particularly for shunting duties, and any ordinary driver could handle it, there were only three men in Russia who could satisfactorily operate his Diesel mechanical-gear locomotive; he was also of opinion that the two-stroke-cycle engine would be most suitable, particularly for American locomotives, where as much as 4,000 HP. was required. Professor Lomonossoff had stated that it was of no advantage for the oil-electric train to coast for long periods whilst the oil-engine was running at its idling speed, as the Author rightly pointed out (p. 208). He believed that the Russian locomotive

Mr. Durtnall. did have a thermal efficiency when on test, or climbing gradients at full power, of about 24 per cent.; but that result was robbed of its lustre when the locomotive had to run down long gradients. Load-factor played a great part in the over-all commercial efficiency of locomotive railway traction, and railway managements would take less notice of high maximum thermal efficiency than of over-all ton-mile cost and good time-keeping. In marine propulsion work the Diesel engine had a better chance of showing to good advantage, by operating at most times with the highest possible thermodynamic efficiency. For that reason he was rather surprised that the Author referred to the success of the oil-engine at sea, because surely the operating characteristics were diametrically opposite to those of railway traction. At only one speed of revolution and at one particular load could any high-temperature internal-combustion engine yield its maximum thermal efficiency, as was shown by the typical U-shaped fuel-consumption curve. The steam-locomotive had a material advantage in the fact that heat-storage was possible in the hot water in the boiler, which could be partly drawn on when additional power was required. When the steam-locomotive was standing, or running downhill, it simply stored the heat of the burning fuel. The capacity of a steam-locomotive for climbing steep gradients with heavy loads was well-known and appreciated, and it was only when such a locomotive was under-boilered that difficulty in time-keeping arose. The Canadian National Railways' oil-electric locomotive No. 9000 recently took the famous "International Limited" at an average speed of 43·6 miles per hour from Montreal to Toronto. The oil-engines had a total capacity of 2,660 HP., and the run was done in 7 hours 40 minutes. Had the engines been able to run at full load all that time, they would have generated 20,340 HP.-hours. The fuel-consumption was 400 gallons, so that it was hardly likely that more than 7,200 actual HP.-hours were generated, the load-factor thus being only about 35 per cent. That was in connection with one of the fastest and best trains in Canada; in the case of slower locomotives the load-factor would be worse.

He quite agreed with the Author, when he stated (p. 208) that it was important to detach one's mind from the conditions of ordinary electric traction when dealing with the oil-electric type of locomotive. Professor Lomonossoff had experienced such severe heating of electric motors on long gradients that the oil-engine was prevented from giving its full power-output. Mr. Durtnall's experience was that the ordinary electric traction motors and control-gear were practically useless. Indeed, he had had so much trouble with standard electric railway equipment that he had gone to the trouble of designing motors, transformers, and control-gear of a much more robust and simpler construction. Such traction motors were much heavier than the usual types, and had a much more conservative rating, and although they cost slightly more, they gave satisfaction to users. With the ordinary oil-electric type of locomotive the engine-power had to be sufficient to meet climbing, acceleration, and other short-time peak loads. Further, the operation of compressed-air plant increased the over-all fuel-cost. Regenerative methods of braking were not possible. The consequence was that the higher thermal efficiency of the internal-combustion engine was largely counteracted by inefficient utilization. In most cases auxiliary plant had to be installed for the purposes of engine-starting and driving circulating-pumps, cooling-fans, etc. The cooling of large oil-engines was a difficult problem, particularly in climates with high shade temperatures; and if means could be employed for utilizing an engine of lower power for a given locomotive duty, the problem of cooling was simplified. In the case of the Russian 1,200-HP. locomotive, it was essential to provide in the summer an extra cooling-van weighing between 20 and 30 tons. The ordinary motor-car type of radiator was too fragile; and every cooler that he now used was tested to 120 lbs. per square inch hot-water pressure. The failure of an internal-combustion locomotive through loss of cooling-water could have very serious consequences. The results of his investigations, based on a good many years of practical experience in the actual design and testing of various types of locomotives, had led to the evolution of a type of locomotive which appeared to overcome the disadvantages he had mentioned. Any type of prime mover could be employed, being selected to suit the most economical fuel available, and operating on the locomotive with the highest possible thermal efficiency. As the engine only had to produce the mean power of the locomotive, it could be run under the most economical conditions A shunting-locomotive of this type suitable for a load-factor of 24 per cent. would have an electric traction motor of 50 HP., and a heavy-oil engine of 12 HP. A nickel-iron storage-battery would meet all demands for power above the capacity of the oil-engine. The engine was started by running an electro-kinetic transformer from the battery, there being a clutch mounted between the transformer and the engine flywheel for the purpose of engine-starting and also to take the drive from the engine to the shaft of the transformer. The drive to the axles was taken from the traction motor through two sets of worm gears, and the maximum starting tractive effort Mr. Durtnall.

Mr Durtnall. was between 7,000 and 8,000 lbs., the maximum speed on the level being 6 miles per hour. The fuel-consumption was 60 lbs. for a 10-hour working-day, during which period the engine generated 120 HP.-hours. The variable load for shunting duty was met by the engine and the battery jointly at full power, and when the power required was not in excess of that of the engine, the battery

Fig. 11.



simply floated across the terminals of the transformer; when the locomotive was standing, the engine automatically charged the battery; and when the locomotive was stopped or ran downhill, the kinetic energy available was transformed into electrical energy and stored in the battery. *Fig. 11* showed the wiring connections for a 200-HP. shunting locomotive for use in docks and collieries, where it was highly suitable because of the safety with which it could run with the oil-engine shut down, and operating entirely on the storage-battery. The load-factor was taken as 15 per cent., an engine of 30 HP. being necessary to provide the mean power. The storage-battery was of 110 volts. The total weight of the locomotive in working-order was 29 tons, and the maximum speed on the level was 10 miles per hour, the tractive effort being 6,000 lbs. at full speed, and 20,000 lbs. at starting. On taking the locomotive into use, the driver moved the handle on the starter B which sent current from the battery to the transformer armature C, and the fields F, G, and H. The transformer immediately ran as a motor, the armature L generating a counter-voltage, so that the armature of the traction motor remained at zero voltage. The oil-engine M was stationary, as the clutch O was not engaged. If it was desired to run the locomotive only a short distance, there was no reason to start the oil-engine, as the locomotive could be operated by the battery alone. Turning the locomotive speed-controller E to the left weakened the field F, the counter-voltage of the armature L was reduced, and the traction-motor armature J received a very low voltage, but a very heavy current was sent round the closed main secondary circuit (shown in thick lines) between the transformer and the traction-motor armature, with a result that a very heavy torque was set up by the traction motor, only a small quantity of energy being drawn from the battery 110-volt primary circuit. As the controller was still turned to the left, the field of the transformer L was further weakened until the counter-voltage fell to zero, the battery voltage was passing into the secondary circuit, and the traction motor was running at the battery-voltage speed, the locomotive speed being 4 miles per hour. By still turning the controller to the left, the field of the transformer L was excited in the opposite polarity, with the result that the armature L ran as a generator and boosted the battery voltage to 220 volts, the armature L being then driven by the armature C which acted as an electric motor. By turning the controller further to the extreme left, full speed was obtained, because the field G was weakened, and the speed of the armature C increased and caused the armature L to generate a still higher voltage for the traction-motor armature. The field H was also slightly weakened. If it was necessary to start the oil-engine, the clutch O was coupled to engage the engine to the transformer, which simply picked up the engine under compression; the engine immediately began to deliver 30 HP. to the shaft of the transformer. If the traction load did not exceed the power of the engine, the engine did all the work, and the battery simply floated across the armature C. To stop the locomotive Mr. Durtnall.

Mr. Durtnall. the driver turned the speed-controller to the right; first the fields G and H were strengthened again; and the field F was first weakened to zero, and then excited in the original starting direction again, until finally the voltage fell to zero across the traction armature, and the locomotive stopped. All this time, owing to the strengthening of the field H of the traction motor and the gradually falling voltage across its armature J, the momentum of the locomotive drove the traction motor as a generator, and the direction of the current in the closed main secondary circuit was automatically reversed. The regeneration current, plus the full engine-power current, passed into the battery. While the locomotive was standing, the engine was delivering its full power to the battery, the exact state of the charge in the battery being indicated by the meter CD. An interesting feature of that locomotive concerned its action in starting a heavy train from rest. The full-load starting current for the traction motor was 1,500 amperes, and in the ordinary way that would cause a very heavy drain on the battery, because at 110 volts the full engine-power contribution would represent only 245 amperes, and the battery would have to produce 1,255 amperes, with considerable electrical losses in the ordinary starting resistances. The transformer, however, played a very important part in the economical starting of the train. As the driver turned his controller to the left to start, the oil-engine did the full duty of train-starting, and sent 1,500 amperes round the closed main secondary circuit, at any voltage up to 12 volts, which represented the 18 kilowatts that the oil-engine could generate. That would enable the speed to be raised to 4 miles per hour. As the driver turned his controller for higher speeds, the battery automatically came to the assistance of the oil-engine in accelerating the train. As the train accelerated to its normal running-speed, the power demand fell, and what was then required was jointly met by the oil-engine and the battery. If this load happened to be a draw-bar pull of 10,000 lbs. at 4 miles per hour, the draw-bar power would be 107 HP.; the locomotive itself would require, including worm-gear losses, 15 HP., making a total of 122 B.HP. to be supplied by the traction motor. At 110 volts pressure this energy represented (including motor losses) 920 amperes, of which the oil-engine supplied 245, thus reducing the load on the battery to 675 amperes. That system, operating as an energy transformation system, met the variation of traction loads in the most efficient manner; it allowed the use of a prime mover running continuously at its most efficient load and speed; it provided the most efficient means for utilizing the constant voltage of the battery without the use of wasteful resistances, and it recovered a large part of the energy of the moving train when stopping or braking. It was impossible to stall the engine by too rapid excitation of the fields of the generator (as could happen with other systems), and, owing to the energy available in the battery, even more rapid acceleration of trains could be obtained than was possible in ordinary electrification. An ordinary Diesel-electrical locomotive of equal tractive power to the locomotive just considered would require an engine of at least 250 B.HP., and would never be able to operate to its best advantage. Mr. Durtnall.

The Author had without question produced what Mr. Durtnall had for many years been wanting to see, namely, a high-speed locomotive-type heavy-oil engine, for which there should be a big demand. He could appreciate the great amount of work and care put into the design and construction of that engine, which had evidently met with much success in Canada and other countries. The use of a plain mechanical, electrical, or hydraulic power-transmission gear, was, however, not the only point at issue; it had now been thoroughly demonstrated, in many countries, that no matter how simple an oil-engine and an ordinary transmission-gear were to operate, it was the cost per ton-mile over a given section of both-way traffic that really mattered. He believed that the new system he had described represented a much closer approach to that with which steam-locomotives had so long been successful in meeting the conditions of railway traffic. It allowed of the proper use of the very fine and efficient oil-engine to the work of railway traction generally, and it also allowed the use of alternative fuels where desirable. The system offered every facility for efficient operation from electrically-supplied traction energy, an electric motor taking the place of the prime mover. As only the mean load would have to be collected, the cost of the plant required for a given electrified railway section would be appreciably reduced.

Mr. C. E. Fairburn remarked that his firm had been associated with the Author in the experiments carried out on the London Midland and Scottish Railway and in supplying coaches to the Venezuela Central Railway and to a Spanish Railway; the technical details of the control and the special feature of the generator referred to on p. 210 had been developed by them. An outstanding feature of the proposal to use Diesel-electric locomotives was that the birth and development of Diesel-electric traction would bring straight electrification much more to the front. That might sound paradoxical, but those who had worked out ordinary electrifications would no doubt have been faced with the same difficulties Mr. Fairburn.

Mr. Fairburn. as he had. When a large railway-system was investigated, the outstanding point usually was that, if the main line alone could be electrified, straight electrification would be a very sound commercial proposition, and the return on money expended would be such that there could be no doubt about the success of the electrification. Branch lines introduced a difficulty. They often carried very light traffic, and if they were equipped with overhead lines or a third rail and sub-stations, the capital cost of the whole electrification would be very heavily increased without any adequate return; and the result was that, considering the railway system as a whole, the proposition became much less satisfactory commercially. To keep steam-engines running on branch lines was obviously unsatisfactory, as a steam service, with its coaling-supply, soft-water supply, and all the arrangements for dealing with boiler-washing, etc., had to be maintained. The steam-locomotives would have to run on the electrified line, and the smoky deposit on insulators and trolley wires was unsatisfactory. Further, there were the standby losses on the steam-locomotives for every branch line, and it was difficult to fit in such a steam service with the electric service. The introduction of Diesel-electric traction, however, put an entirely new complexion on that problem. Such machines were eminently suitable for lines with light traffic and as an auxiliary to straight electrification. The Diesel-engine could be shut down when not required. The repairs and maintenance of the Diesel-electric equipment were fairly akin to the repairs and maintenance of the electric locomotive, standby losses were eliminated, and at times when there was heavy traffic on a branch line Diesel-electric trains could be worked on the multiple-unit system without requiring a bigger operating-staff. Diesel-electric trains on branch lines would be classed as coach stock and not locomotive stock, and under those conditions it should be possible for them to be operated by one man. He had already worked out a main-line system on this basis, and he found that straight electrification on the heavy-traffic lines and the use of Diesel-electric traction on the light-traffic lines was very sound commercially. In that case electrification of the main lines for both light and heavy traffic, and the use of steam-locomotives on the branch lines had not been a commercial success. Diesel-electric engines could not compete with straight electrification on heavy suburban services and on heavily-graded main lines. The success of a suburban electrification depended on rapid acceleration; and it was only possible to get such an acceleration by employing unduly powerful and expensive oil-engines. The electric train could draw on a power-house for heavy loads; the Diesel-engine, of course, was

Mr. Fairburn.

restricted to its own maximum output. On main lines where there were gradients the straight electrical machine could be overloaded, drawing its power from the power-house, and as such a temporary overload due to one machine was balanced at the power-house by other machines taking less than the average power at that moment, the total horse-power required with straight electrification would necessarily be less than the total power if Diesel-electric traction was used to run to the same schedule as the straight electrification. With regard to the Author's remark at the top of p. 210, the horse-power of electric stock was usually stated on the 1-hour rating. The Author gave a figure of 2 HP. per ton for a steam-locomotive. On what basis was that horse-power computed? He had always found a difficulty when comparing the horse-power per ton of electric and steam stock—in fact, he thought that a comparison between electricity and steam on that basis was not really possible.

Mr. Sandberg.

Mr. C. PETER SANDBERG observed that one factor which perhaps more than any other had assisted in obtaining the encouraging results was the production of a fast-running engine of the Diesel type. In that comparatively new field there was scope for much progress, and he looked forward hopefully to further reduction in the cost of both the oil-engine and the transmission. A mechanical transmission was more desirable than electrical means, but it seemed that the use of the electrical transmission in the pioneering days of the Diesel locomotive was quite logical, owing to the absence of any other proved practical form of transmission for the larger powers. He thought it was fairly certain that in the comparatively near future Diesel or other types of oil-engine locomotives with a mechanical variable gear would have such a low capital cost that the adoption of this system of traction would be very rapid. The performances described in the Paper were extremely interesting and commercially attractive in special circumstances. While the cost of the Diesel-electric locomotive was still high, and the saving in fuel alone would not counterbalance it, the many other accruing advantages were sufficient to justify the adoption of this system of traction on an increasing scale. The facility of operation, the longer hours and distances which the locomotives could run, the saving in water, and the many other advantages dealt with by the Author, were even more valuable than the saving in fuel. The Author did not appear to have given any comparative figures of cost, as regarded fuel alone, of a Diesel locomotive and a steam-locomotive doing identically the same duty, and it might be of interest to quote some figures recently published in the United States showing that in shunting-work the cost of fuel was in one

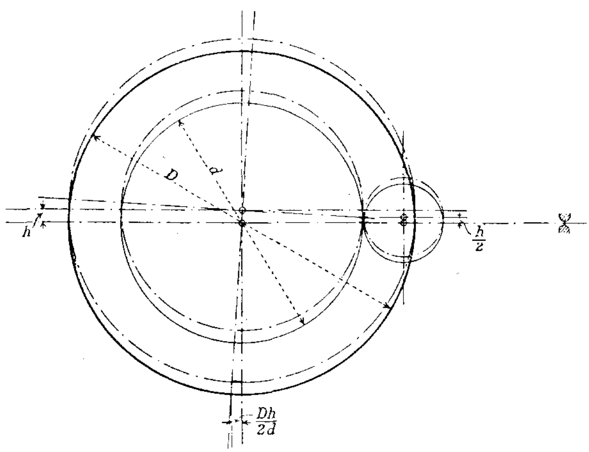
Mr. Sandberg. case \$72 for the steam-locomotive, while for identical work with a Diesel-electric locomotive the cost was \$12. Apart from the many attractions of the oil-engine locomotive which had already been enumerated, he thought it would be permissible to claim that there might be very important additional advantages compared with electric traction in the case of war or civil commotion. Electric power-stations were very vulnerable, especially from the air, whence the greatest danger might be expected in the future; and oil-engine locomotives would obviously be greatly preferred by some railways for this reason.

Mr. Twinberrow. Mr. J. D. Twinberrow thought that the Author's preference for electrical transmission was abundantly justified, but he doubted the desirability of adherence to the nose-and-axle mounting of the traction motors. The supremacy which that type had long enjoyed in the traction field was now being seriously challenged, even in its application to four-wheel bogie-trucks, as it possessed inherent features which rendered it undesirable for units of high power. Motors of that kind entailed the use of outside framing, with consequent difficulty in arranging an effective system of lateral and transverse bracing. The outside journals, coupled with the low value of the moment of inertia of the structure around longitudinal and transverse axes, rendered necessary the use of heavier bearing-springs in order to obtain riding characteristics equal to those obtainable with a closer transverse spacing of springs under a high centre of gravity. Impacts from the track were necessarily transmitted through the spur gearing to the motors, and *Fig. 12* indicated the resulting effects. A pair of driving-wheels, of diameter D, were fitted to an axle which carried a spur wheel, of diameter d, in mesh with a pinion on the armature-spindle, which ran in bearings in the motor-casing. The motor was supported at one side by bearings on the axle and at the other side by a nose bracket. Supposing that the position of the axle in the frame was changed suddenly by the vertical distance h, the contact point of the pitch-line of the teeth of the spur wheel was raised through the same distance, but that of the corresponding pinion-tooth by half the distance. Since the teeth remained in contact, the aspect of the spur wheel must be changed by an angle measured by h/d, or that of the armature by an angle $3h/d$, where the value of the gear-ratio was assumed to be 3 : 1, or finally the whole mass of the motor and armature might be accelerated round the axle as the centre of movement by the impactive increment of the pressure on the armature-bearings. The moment of inertia of the wheels and axle was less than that of the other parts subject to change of angular velocity, but in the absence

Mr. Twinberrow

of slip at the wheel-tread the linear velocity of the engine must change with the variation in the angular velocity of the wheel, and in that case the weight of the superstructure must be considered as forming an addition to the rotating mass at the periphery of the wheels. Under those circumstances the tangential force at the wheel-tread was likely to exceed the adhesion, and slipping oscillations would result. The amplitude of the movement would not exceed *Dh/2d*, but it was probably a not unimportant factor in determining the rate of wear of rails and tires. The space available within the loading-gauge imposed limitations on the height of the engine and generator and on the dimensions of radiators and other accessories. It seemed feasible to obtain

Fig. 12.



relief from these restrictions by increasing the length of the locomotive, the generating-set being carried in the central part of an underframe supported at each end upon a bogie-truck whereon the traction motors could be arranged with gearing not subject to impact, and in a position convenient for access. Small locomotives for industrial purposes and motor-coaches, when fitted with engines not exceeding 300 HP. each, were successfully operated through change gears having friction clutches engaged and lubricated by means of oil under pressure. The use of electrical transmission for heavier duty did not appear to make the portable generator acceptable for working a heavy suburban service. It was found from practical experience that 10,000-HP. generated in a central station sufficed to operate suburban trains fitted with

Mr. Twinberrow. motors having a collective available horse-power of 35,000. If those trains were fitted with generating plant having an over-all efficiency of 80 per cent., the moving weight would be increased by 25 per cent., with say 20 per cent. addition to the train-resistance. The capacity of the generators would then be $(100/80) \times (120/100) \times 35{,}000 = 52{,}500$ HP. The necessary capacity of the travelling power-plant would thus be $5\frac{1}{4}$ times that of the central station, in order to provide a similar service.

Mr. Willans. Mr. K. W. WILLANS observed that, in reading a description covering locomotives of more than 2,000 HP., he was conscious of the paucity of his own experience; but his firm had been building Diesel locomotives, ranging from 30 B.HP. to 120 B.HP., for the past 2 years, and the sizes within those limits had been highly standardized with a view to the lowest possible capital cost. As his firm did not build Diesel engines, it was possible to speak on the subject of such engines without bias, and he was rather sorry that the Author did not refer more in detail to the actual construction of the engines, and particularly of the fuel-pump and atomizer. From published descriptions, the Author's engine appeared to suffer from undue complication, as compared with the engines which Mr. Willans's firm was fitting to locomotives; and as the relative oil-consumptions of the two makes of engine appeared to be approximately equal, that complication should undoubtedly be eliminated. His firm had made quite a number of tests in which locomotives fitted with those engines had been run without any gear-changing at all, and he was somewhat surprised not to see any reference to the extraordinary flexibility of those high-compression engines. One locomotive was run for a fortnight without changing gear at all, and the driver reported that it would start in top gear any load which it could keep moving in top gear. The locomotive in question was fitted with an ordinary cone clutch. That feature, added to the very high cost of electrical appliances, led him to believe that the last word had by no means been said for the direct-driven Diesel locomotive, and the Author's courage had been equalled, if not exceeded, by the courage of those who had tried out the steam-Diesel combination. He felt that that type should be persevered with, but on somewhat different lines. In that connection also, he would call attention to the good economy obtainable with the Diesel engine over a wide range of loads. A very much larger engine than the duty warranted could be fitted without adversely affecting the fuel-bill, and the surplus power was available to take the place of change-speed gears. Those who (like himself) were only slightly acquainted with railway working found it difficult at first to appreciate that the vital factor in railway-working was the time-table, and that in turn defined the load that could be hauled behind an internal-combustion locomotive of given power. There was no question of dropping into second gear to climb a bank if by doing so the working of the line was upset; and whatever fuel-saving might result, it would be offset by the disorganization caused by blocking the traffic on a busy line. It seemed that the alternative to the Diesel-electric type was a Diesel locomotive with no change-speed gears, with ample engine-power, and with steam assistance for starting purposes, the steam being generated in a small high-pressure boiler, by an oil burner, and automatically controlled. The engine would be coupled to the wheels through the medium of a hydraulic clutch, designed to permit of running in a slipping condition for a period of, say, 2 to 5 minutes. His experience of quoting for large Diesel locomotives led him at the moment to the conclusion that, for home railway purposes, when such locomotives were fitted with electric transmission, the capital cost was too high. Having regard to the high degree of standardization on the railways, however, it did not seem beyond the bounds of possibility that an enlightened electrical firm should set to work to produce equipment at a figure which would reduce the capital cost to a commercial level, and the same cost-reduction could with advantage be applied to the Diesel engine. So far as reliability was concerned, he was convinced that the experimental period was passed 2 or 3 years ago—in one make of engine at any rate—and his experience of that particular type of engine had been uniformly satisfactory. Mr. Willans.

The AUTHOR, in reply, observed that the high thermal efficiency of the engine was due mainly to the high mechanical efficiency, which exceeded 85 per cent., the airless injection being an important factor. The reference in the Paper to marine practice referred to general suitability and not thermal efficiency alone. He could not follow Mr. Durtnall in his further remarks about load-factors, and what he intended to bring out thereby, unless it was to indicate how difficulties due to low load-factors were overcome by the use of an accumulator coupled with a smaller oil-engine. That proposal was always attractive on paper, but he did not feel that in practice it was worth while. A variable-speed engine gave a higher average efficiency and cost little more, whilst the upkeep was less. At the same time, it was highly desirable that Mr. Durtnall should develop his interesting proposal further. The remarks of Mr. Fairburn should encourage electrical engineers to help in developing the system described, at which they had looked The Author.

The Author. somewhat askance up to now. His further points illustrated how his practical experience with the system had led him to see its foremost advantages. The scheme that he indicated, of operating a railway by a combination of full electric and Diesel-electric traction, was worthy of being more fully dealt with, and he hoped Mr. Fairburn would prepare a Paper on the subject.

The rating of a steam-locomotive was, the Author agreed, difficult to compare strictly with that of an electric locomotive; but did it not depend on adhesion value at low speeds and boiler-capacity at higher ones? He thought 2 B.HP. per ton was not an unfair average.

He was interested in the views of Mr. Sandberg, and though he agreed that the mechanical transmission system had many attractions, it was hardly the most suitable for rail-cars and motor-trains, whatever it might be for a locomotive. He was indebted to Mr. Sandberg for the comparative figures given by him for an oil-electric and a steam shunting-locomotive. Mr. Sandberg's point about the effect of war on the wholly electric system was important.

He did not think he could enter into the vexed question of the electric motor drive which Mr. Twinberrow had dealt with. Standard motors were used on the recommendation of the electrical company concerned. He did not contend that the oil-electric system was suitable for suburban work, where accelerations were high, and powers ranged up to 10 B.HP. per ton; but for outer urban and secondary services, where up to 3 or 4 B.HP. per ton was sufficient, it was suitable. As to the remarks of Mr. Willans on the design of the oil-engine, Mr. Willans must have overlooked the fact that the Paper was on oil traction and not any particular engine. He had tried to deal with the economic advantages of the proposition, and any suitable engine or electrical system could be used. It seemed that Mr. Willans had not looked deeply enough into the actual transmissions required when working double-ended to and from terminals, with only one man to run a motor-train of sufficient capacity for the bulk of the passenger work of most countries.