Discussion.

The President. The PRESIDENT moved a vote of thanks to the Author for his Paper.

Mr. de Broë. Mr. V. E. de BROË remarked that the Author was in error in stating that with the Abt system it was impossible to make points and crossings. He had had occasion to study this question in connection with an Abt railway system in India, and had been able to obtain a 1-in-8½ crossing with ease on the rack on any gradient that was not more severe than 1 in 20. It was not recommended as feasible on 1 in 12½, but up to 1 in 20 it could be used freely. In Switzerland it was in use on this angle of incline.

Mr. Waring. Mr. F. J. WARING gathered that the Kitson-Meyer engines, which the Author evidently preferred, were carried on seven axles, four on the adhesion bogie and three on the rack bogie, the wheel-bases of the bogies being 10 feet 6 inches and 8 feet 11 inches respectively. From the Paper it would appear that the Kitson-Meyer engines of the latest type weighed about 90 tons. If the weight were equally distributed between the seven axles in the adhesion bogie and the rack bogie, that would give very nearly 13 tons per axle. It was improbable, however, that that weight was equally distributed, for, taking the diagram in Mr. Henderson's Paper as a guide, the bulk of the weight would be upon the adhesion bogie; besides which, all engineers would naturally like to get as much weight available for adhesion as possible. At about 13 tons per axle there would be, say, 51½ tons on the adhesion bogie and 38½ tons on the rack bogie, which certainly seemed to be very high for the 50-lb. rail used on the adhesion section of the line, especially when it was considered that there were only 1,810 sleepers per mile on that part of the line. He accepted the Author's statement, made in the Correspondence on Mr. Henderson's Paper, that after nearly 5 years of regular working neither the permanent way nor the locomotives on the Chilian Transandine line had suffered unduly from the loads handled; but the Author admitted there was a slight surface waving on the rails in some places, which he ascribed to the rails being run over before the road was properly ballasted and packed. It was evident that the Author, in speaking of surface waving, did not mean corrugation, but that the rails had a slight permanent set. If that was so, the rails were slightly crippled, and Mr. Waring could not help thinking that the trouble was bound to increase. He was surprised to hear that the heavy engines with the long wheel-bases had not caused undue wear and tear on the rails and on the tires, which he would have thought very likely to occur with the 6-chain curves on the adhesion portion of the line. Evidently the Author was not quite satisfied with the engines he had got, or he would not have proposed an alternative. The total weight of the proposed engine was to be 90 tons, but it was to be carried on eight axles, four on the adhesion bogie and four on the rack bogie. The figures showed that the total weight on the adhesion bogie would be reduced from about 51½ tons to 47 tons, and on the rack bogie would be about 43 tons. That reduction in weight on the adhesion bogie seemed seriously to detract from the value of the engine on the 1-in-40 gradients of the adhesion part of the line, where the rack was not used. The wheel-base of the adhesion bogie was to remain at 10 feet 6 inches, but the wheel-base of the rack bogie was to be increased from 8 feet 11 inches to 11 feet 9 inches, and he could not help thinking that even if the 10-foot 6-inch wheel-base did not cause undue wear and tear, the increase in the length of the rack bogie might do so. It might, perhaps, be possible to diminish the wear and tear by the omission of flanges on some of the wheels and by somewhat widening the gauge on the sharp curves. If the flanges were omitted, the tires would have to be made wider. He would be glad to know whether either or both of those expedients had been tried, and, if the gauge had been widened on the sharp curves, the extent to which that had been done. Also he wished to know whether, in view of the waviness of the rails, there was any undue proportion of rails broken in the road. He quite admitted that the best manner of working a railway of such an exceptional character must be determined experimentally, and in the particular case under discussion the difficulty was very largely increased by the intervention of gradients of 1 in 40 worked by adhesion only, between portions which had gradients ranging from 1 in 12½ to 1 in 14, worked by a rack. He was inclined to think that the ultimate solution of the question might probably be found in the use of two smaller combined rack-and-adhesion engines, each on one frame, as foreshadowed in Mr. Henderson's Paper, instead of one heavy engine, the engines when ascending being placed either both in the front of the train or one in front and one behind. In such engines the weight of the rack portion would be available for adhesion, instead of being as at present so much dead weight, on the 1-in-40 gradients. Objection was taken in certain quarters to the use of an engine at the back of the train, but on the Ceylon Mr. Waring.

Mr. Waring. Government railways, with gradients of 1 in 44 and sharp curves, trains had been worked in that manner for 40 or 50 years without any accident occurring from such working. The running-charges for two engines would naturally be higher than for one, because they would require two crews, and the consumption of fuel and oil, etc., would no doubt be greater than it would be on one engine of equal aggregate power. He noted from the Paper that in ascending the rack portion of the line speed was limited to 10 kilometres per hour, but in going down the speed was nominally limited to 15 kilometres per hour, though it sometimes actually attained 30 kilometres. He believed it would have been better had the authorized speed been the same both ascending and descending, and that great care should be taken that in descending the gradient the authorized speed was not exceeded. The superelevation given to the outer rail on the curves should of course be that due to the highest speed, and it was very important that a correct superelevation should be given. Not long ago his firm investigated a case of derailment, the only apparent cause for which was running down-hill round a sharp curve at too high a speed for the superelevation. If the superelevation was correct for the highest speed, it appeared to him that when the train was going up the incline at the low speed the inner rail would be doing an undue share of the work, and would be subject to much grinding and wear and tear.

Mr. Fox. Mr. F. DOUGLAS FOX said that the two rack railways which had been designed by his firm were the Snowdon mountain tram-road, constructed about 20 years ago, and still, he believed, the only rack railway in the British Isles, and a short length of rack which was in use on the Benguella Railway, which ran from Lobito Bay towards the Congo frontier in Portuguese Angola. The Snowdon mountain tram-road started from Llanberis at the foot of the mountain and climbed about 3,140 feet in a length of $4\frac{5}{8}$ miles, running to within 50 feet of the summit. Excepting one very unfortunate accident on the opening day, the cause of which had never been discovered, he believed the railway had been worked for about 20 years without accident. The gauge of the railway was 2 feet $7\frac{1}{2}$ inches, which was that of some of the narrow-gauge lines near by, and it was thought quite possible that at some future time the line might be connected up with these. The maximum weight of train now being run on the railway was 37 tons 11 cwt.: the engine weighed 17 tons 5 cwt., the passengers about 9 tons, and two carriages 11 tons 6 cwt. The normal service consisted of four trains each way per day, and additional trips were arranged whenever there were sufficient passengers to make it necessary. The reason for adopting the rack on the Benguella Railway was that the Portuguese Government insisted on passing an ancient town (Benguella) of small size but to which they attached some importance, and thus forced the railway to traverse a rocky canyon from the coast almost direct into the interior. The canyon was so narrow that there was no room for development of curves or gradients, and the railway had to follow the natural gradient, which was 1 in 16½. The length of the rack was 2,230 yards, and the actual length of the sections worked by the combined adhesion and rack system was 2½ miles. The remainder of the line, worked by adhesion, had a maximum gradient of 1 in 40. The engines for the rack were supplied by the Maschinenfabrik Esslingen, of Stuttgart, about 5 years before the war; they had been running ever since quite efficiently and had given no trouble. Mr. Fox.

Mr. MATEO CLARK remarked that the Author had had a unique opportunity of studying the rack system, because it was very seldom that one railway had four different types of locomotives. The Abt system might be said to be quite in its infancy. The railway had been started with the idea of building an adhesion line. A friend of his, a distinguished Chilian engineer and a member of the Institution, Mr. Enrique Budge, whom he was glad to see present that evening, had telegraphed to him that he could not do better than adopt the Abt system. As he had made tachometrical surveys and completed his plans, he had been able to see at once the importance of adopting that system. In the first instance, the elevation was reduced by 1,000 feet, and the length of the line by 15 kilometres on the Chilian side, and 20 kilometres on the other side. What had impressed him more particularly in connection with the Abt system was that it was possible with the same locomotive to carry the traffic on the adhesion and the rack system by adapting the locomotive to the work, and in that way the construction of the line was immensely facilitated. Many engineers were opposed to the introduction of a system of that kind, but anyone who saw the nature of the country in which the Transandine Railway had been built would say at once that the rack system had been expressly designed for the construction of that railway. The mission of the engineer was not only to build railways but also to see that they were economical and served their purpose. He believed the railway under discussion had shown itself to be very convenient for passenger-traffic, but it had yet to be seen what it could do with goods-traffic; unfortunately, very little had been done in that way, for reasons into which he could not enter. It was a question of tariffs. Mr. Clark.

Mr. Bach. Mr. F. W. Bach remarked that, although he had not had practical experience with rack working, he had had a good deal to do with steep-gradient working, and wished to say a word on the Shay engine. His experience of it was that, for anything like the speeds the Author referred to, the cost of repairs became hopelessly heavy. He did not think the Shay engine would be of any use on the gradients mentioned. It was being used, or had been used, on 6-per-cent. gradients on the Guayaquil and Quito Railway. He was glad to see that the Author was a strong advocate of the combination of adhesion and rack. He would go further and say that whenever an ounce of power could be applied to adhesion rails it could be applied very much more economically in that way than through any system of rack, in which there must necessarily be a serious waste of power. With regard to the vexed question of pulling or pushing up-hill, on the Central Railway of Peru there were a good many zigzags, so that the engine was at one moment pushing the train, at the next moment pulling it. Speaking from experience, he could say that an engine could pull loads that it could not push. There was probably a certain degree of elasticity in the draw-bar which was not found in the squeezed-up buffers, and as there was a tractive force which was anything but constant, a load which would bring a pushing engine to a standstill could be taken up comparatively comfortably by pulling. In the adhesion locomotive there was much more slip in pushing a train up than in pulling. As far as safety was concerned, he was absolutely at one with the Author in saying that there was no danger at all in the case of a breakaway if there were reasonably good brakes, either automatic, such as the Westinghouse, or even hand-brakes. The vehicles could be held quite well if they were properly braked, and not allowed to gain speed. With regard to the arrangement of the boiler and the slope of the fire-box for running in one direction, he quite appreciated that that was necessary; but when an engine had to run on such various and heavy gradients it would be a good plan actually to set the boiler on an incline, so that sometimes the water would be slightly down-hill and sometimes up-hill, rather than cut away the fire-box, as had to be done if the centre-line of the boiler was set more or less level with the axle-centres. The movement of springs, referred to by the Author in speaking of the solid fixing of the rack-pinions, was very much smaller on a good road-bed than most people thought. He had looked into the question in connection with some carriage-bogies of the American type, with a compensating beam outside and two coil springs between the beam and the frame, and had found that the whole movement only amounted to

$\frac{3}{8}$ inch at comparatively high speeds, so that he did not think there was anything to worry about at all in vertical movement. It appeared to him that the Author's practical alterations had been in the direction of eliminating complications which were thought necessary in theory, but which were not good in practice. It was often necessary to allow theoretical considerations to go when it was a choice between two evils. The question of the repression brake was a strong point in the Paper. It was a brake that was greatly neglected. It was the best possible brake for descending hills, and the problem of all steep-gradient railways lay rather in getting down than in going up. The repression brake was so efficient that he had much confidence in it. Once, when he was out on an inspection engine, the brake-gear broke, and the engine came down from the top of the Andes to the sea using nothing but the repression brake. The Author referred to possible difficulty in superheating the steam if a repression brake were used, but surely there would be no difficulty in designing a superheater that need not be used when descending. It might be thought, from the fact that the Author had mentioned nine brakes, that he was rather a "crank" on that subject; but there was no doubt that the brake question was of vital importance. With regard to the question of speed, if there was a continuous down gradient it was not possible to avoid taking automatic brakes off, and directly that was done the train gained speed. For that reason he was against the use of automatic brakes except for emergencies. He would much rather have any type of "straight" brake or hand-brake, and he thought hand-brakes were preferable, because the power-brake to which the Author referred was in one case equal to as much as 150 per cent. of the tare, and that meant that the wheels would skid with an empty wagon. It was not possible to design power brake-gear so that it would do its best for an empty wagon or a loaded wagon or a half-loaded wagon, but it was possible to use a hand-brake for that purpose. The brakesman could feel what was happening and knew when to slack or to put on. When speaking on Mr. Brodie Henderson's Paper[1] he had pointed out that in his opinion cylinders for the Kitson-Meyer engine could be made in duplicate with very great advantage. The Author advocated making the rack cylinders the larger, on the ground that it was better for repression coming down, and pointed out that it was not possible to get the power into the repression brake in coming down-hill that was needed in going up. The same power was not required. In going up- Mr. Bach.

[1] Minutes of Proceedings Inst. C.E., vol. cxcv, p. 151.

Mr. Bach. hill the engine was working against gravity plus the friction of the train, but in coming down it was working against gravity minus that friction. It was the power per unit of travel that had to be considered, so that speed did not count. He did not believe such big cylinders were required for repression purposes as the Author was inclined to think. Personally, he would advocate making all four cylinders the same size, so that all the pistons and parts would be interchangeable, which would be a great advantage.

Mr. Burnett. Mr. R. H. BURNETT thought it had been proved by Mr. Brodie Henderson beyond all question that a combination of rack and adhesion was necessary to overcome the difficulties in a mountainous district like the Andes. But while the need for such a railway was proved beyond doubt, he gathered from the Paper that the question of the stability of the various types of articulated engines was a somewhat open question, and as the Garratt articulated engine had been referred to he felt almost compelled to intervene in the discussion. He did not do so because of the interest his firm had in the Garratt engine, as The Institution was not the place for discussion from that standpoint; but in any circumstances he would advocate the Garratt engine with equal earnestness, because he believed it was based on very sound principles of construction. As he had dealt with the adaptability of the Garratt engine for working rack-and-adhesion railways on a previous occasion,[1] he would not enter into details; but he wished to say that while the Garratt system admitted of the production of a locomotive of very high power, as simple as an articulated engine could be, and maintainable at a minimum cost, it presented a method of producing a powerful locomotive capable of working either by rack and adhesion or by simple adhesion where heavy loads were required to travel round curves of very short radius. In his opinion, the Garratt locomotive had come to stay. He noticed it was disposed of by the Author with the cursory remark that it did not appear to be suited to the rough work of snow-ploughing. He did not question the judgment of those who came to that conclusion in considering the particular matter with which they were concerned, but it would be interesting to have some fuller particulars of the grounds upon which that conclusion had been arrived at. He was not aware of any peculiar delicacy in the construction of the Garratt engine that should render it less capable of dealing with the snow difficulty than any other articulated engine. Whatever its merits or demerits might be as a snow-plough, it did lend itself in its design to avoiding

[1] Minutes of Proceedings Inst. C.E., vol. cxcv, p. 181.

the difficulty referred to by the Author where he stated that in the Esslingen locomotive the chief trouble was in connection with the steam-pipes to the adhesion cylinders, which cylinders were near the centre of the engine, where the maximum relative movement with the boiler took place, amounting to 7 inches on a curve of 5 chains radius. The steam-pipes in the Garratt engine were laid from the boiler to the bogie, and then to the cylinders, in the exact centre-line of the pivots upon which the bogies turned, and therefore no side-play was experienced, the only movement being a slight turning one. The experience of all railways that had adopted the Garratt engine was that the steam-pipes were very satisfactory. The Author had rightly emphasized the importance of brakes. It was difficult enough to ascend a gradient of 1 in 12½ (8 per cent.) with a heavy load, but it was much more difficult to descend safely with a heavy load. That matter had been well thought out and provided for in the original rack-and-adhesion engines constructed by Messrs. Beyer, Peacock and Company for the Transandine Railway, to the specification of the consulting engineers, which had given entire satisfaction. He considered it to be in the interests of railways that the Garratt engine should be well known, and therefore that it should be brought to the notice of railway-engineers to judge for themselves. It took time for such a marked departure from the beaten track to be appreciated as it deserved; but the more it was known the more it would be appreciated, like all inventions based on sound principles of construction which met urgent and growing difficulties in a notable manner. Mr. Burnett.

Mr. Enrique Budge congratulated the Author on his lucid Paper, in which he had accumulated abundant and important data as to the practical working of an international railway, which was expected to deal with very heavy traffic in the near future, and which would naturally serve as a standard of reference in connection with other important undertakings, such as the Arica–La Paz and the Central Longitudinal railways in Chile, already constructed. His own action, as Government Engineer, in carrying out the line, from the time (1870) when its promoters, Messrs. Clark Brothers, conceived the idea of constructing it, up to the time when it was nearly finished, authorized him, he believed, to express his opinions frankly. In 1878 he visited almost all the existing railways working on heavy inclines, and found in Dr. Abt's system of rack and his combined locomotive a solution of the natural difficulties restricting the use of railways in many countries of mountainous configuration, especially Chile. Having given constant attention to the working of rack railways, he did Mr. Budge.

Mr. Budge. not hesitate in 1888 to ask Messrs. Clark Brothers to appoint someone to report on the working of the Harz Railway, as he was convinced that that was the most convenient system for the Transandine Railway. Mr. Victor Pretot Freire, who was requested to report on it, did so in very favourable terms, and the Paper showed that the system was working satisfactorily, but that there was still room for improvement in the locomotive power. In 1910 he had to order some 91-ton locomotives for the Arica–La Paz Railway, built to certain conditions, in which advantage had been taken of the experience on the Transandine Railway, including several of the points mentioned by the Author. Tenders were called for, and the Esslingen plans were accepted. Those engines were designed under the personal supervision of Dr. Abt, and had now been working for 4 years on a 25-mile gradient of 6 per cent. in what might be called one section. The locomotives had to be of the combined type, as they had to travel over some adhesion track at both ends of the section and had to pass through an intermediate station which was required for crossing trains. He was not yet in a position to say how they were behaving. At present the Baldwin works were constructing a locomotive for the line, which might confirm the Author's opinion that the Baldwin and Winterthur locomotives were ingeniously designed and might prove valuable under certain conditions. As the location of the Transandine Railway had required his approval as Government delegate, he had insisted on the line being built with minimum radii of 200 metres for rack and 150 metres for adhesion, with a maximum gradient of 2½ per cent. for adhesion. The original conditions of the concession fixed 150 metres as the minimum radius for rack and 100 metres for adhesion, and 3 per cent. as the maximum gradient for adhesion. The Author said that the minimum radius for adhesion was 150 metres, but actually there was only one curve of 150 metres, which was situated at the entrance to a rack section laid on the level. Practically, the minimum radius might be said to be 200 metres. With regard to the permanent way, the Author stated that after 9 years' service there was hardly any sign of wear on the flat surface of the rack-teeth, nearly all the wear taking place on the pinions. In 1897 Mr. Budge examined very closely the state of the rack track on the Argentine side, which had then already had about 9 years' service, and he was astonished to find extensive wear at various points on the teeth of the outside plate on the curves. It was plain that the wear was produced by the unequal running of the outside disks, for the central plate was as good as new, and the other side plate only slightly worn. Having in hand a project for a rack line in the north of Chile, he designed it with two plates instead of three. He then came to Europe and had a personal interview with Mr. Reinecke, Dr. Abt's partner, and after discussion Messrs. Abt and Reinecke decided never again to recommend a three-plate system. He next visited the Harz Railway, which had a three-plate rack. He observed that the wear of the rack-teeth was very regular, about 2½ millimetres, and that the cog-wheel on the locomotives had had to be changed for the first time, after 13 years' work. The difference in the wear noted between the Harz and the Transandine might be explained by the fact that the Harz Railway had been worked with lighter loads than the Transandine, and the locomotives of the latter line had been built for the first time in England. The two-plate rack was more rational than the three-plate, and he had recommended that type for the Arica–La Paz and Central Longitudinal railways in Chile. The train-loads on those lines, which were also of 1 metre gauge, were as heavy as on the Transandine. Up to the present he had heard no complaints against the two-plate rack. Mr. Budge.

Mr. G. C. Aitchison wished to know what objection there was to having the springs in the pinions. He took it that the Author meant the springs inside the pinions, to give play on the cog-wheel. [The Author assented.] He had had 20 years' experience of mountain-railway work, and had found that the springs prevented a large amount of wear on the rack. He did not agree with the statement that it was impossible to have points and crossings on an Abt railway. He had used them on mountain railways for nearly 22 years. From the practical point of view he believed the position of the engine should always be in front of the train coming down a gradient of the steepness mentioned in the Paper. He had been in some accidents himself, and on each occasion the accident would have been much worse if the engine had not been in front of the train when descending. Mr. Aitchison.

The Author, in reply, said his chief incentive to present the Paper had been the lack of literature on the subject, and the hope that the matter might be of use to those dealing with rack railways in various parts of the world. When he first arrived in Chile he felt very much the want of definite guidance. For instance, he was not quite sure as to the practicability or prudence of working trains exceeding a net weight of 100 tons on an 8-per-cent. gradient, but now he had no misgivings on that subject, as he believed a net weight of 150 tons could be handled on that gradient without undue strain, and brought down in perfect safety. As there were some criticisms of German locomotives in the Paper, he would like to say The Author.

The Author. that the Paper had been written about 2 months before the outbreak of the war. He regretted the absence of illustrations, but he had not anticipated that the Paper would be submitted for discussion. With regard to Mr. de Broë's remarks as to points and crossings, the word "impossibility" in the Paper should have been "difficulty." Mr. de Broë admitted that crossings were not feasible on gradients of more than 6 per cent., and it was gradients of 6 to 8 per cent. that the Author had had in mind, in conjunction with other difficulties due to the local conditions, such as keeping complicated points and crossings free from snow, gravel, and small pieces of rock. Moreover, he had been dealing with locomotives having three sets of pinions, and having a minimum pinion "wheel-base" of 7·78 feet, which he would not like to work over a 1-in-6 crossing. Possibly Mr. de Broë's experience was in connection with smaller locomotives with either one or two sets of pinions. He must admit that the weight of the locomotives was high for the rail, as suggested by Mr. Waring. In the Correspondence on Mr. Henderson's Paper, he had mentioned that the rail was admittedly light, but that there was every intention of replacing it by a heavier rail as soon as the increasing traffic justified it. In that connection there was an added advantage in getting in the extra axle—in lightening the axle-load on the rack bogie. A little loss of weight above the pinions did not matter; the teeth engaged so deeply that there was no risk of mounting, and therefore the extra axle was really an advantage in reducing the axle-load with regard to the rail. It was also of advantage in getting the pinions closer to the loaded axle. What he objected to in both the Esslingen and the Borsig design was having two pinions between two carrying axles, whereby there was a long length unsupported; there was no counteracting load to resist the action of the pinions, which tended to elevate the outer ends of the sleepers. Mr. Waring was correct in assuming the weight on the adhesion bogie to be greater than that on the rack bogie. The proposed locomotive, however, would have a slightly heavier axle-load on the adhesion bogie, as compared with the existing locomotives on the Chilian Transandine Railway, and the better distribution of load on the rack bogie by the employment of four axles instead of three did not affect this. By this means the former maximum axle-load of 13 tons 5 cwt., on the rack bogie, was reduced to 11 tons 15 cwt., on the adhesion bogie. The length of the wheel-base of the rack bogie involved by this design, 11 feet 9 inches, was only 3 inches more than that of the existing Esslingen locomotives, which worked quite smoothly on the curves, sufficient clearance being allowed on the inside of the flanges to permit this. The locomotives worked regularly on the rack section of the line, and were seldom run over the lighter rails and sharper curves of the adhesion section. Breakage of rails in the road was very rare, and, when it occurred, was usually due to the falling of rock. He did not consider the suggestion to equalize the speed for ascending and descending to be practicable, as any increase of speed in ascending would involve the provision of greater power, and a reduction in the speed of descent would merely delay the train, without any corresponding gain. It was quite exceptional to attain a speed of more than the regulation 15 kilometres per hour, as all the rolling stock, with the exception of the goods-wagons, which were little used, was now fitted with the "non-automatic control" brake. Mr. Waring had suggested that it would be better to work traffic of that sort with two smaller engines; but there were various reasons against that, including extra cost and extra men. It was very difficult to get together and keep a staff of engine-men, and the larger the staff the greater the difficulties. It was better to have a few good men and pay them well. In entering the rack, if one engine was in front and one behind, the first engine could not get into its stride until the second engine had entered, and that meant considerable delay and an added risk of the second engine mounting the rack. His experience of the Shay locomotive did not agree with Mr. Bach's. It could not be driven at more than 15 kilometres per hour, but up to that speed it had been found very reliable, and economical in repairs. It had worked for several weeks at a time ballasting, remaining in a tunnel at night, and only coming down to the running-shed once a week for washing out the boiler. If anything went wrong with the rack at any time it was a very handy engine to have on the line, because it could get up and down without using the rack. Mr. Bach had expressed a strong preference for the hand-brake, but the Author did not think Mr. Bach had done sufficient justice to the non-automatic control brake—the "straight-air" brake—which went right through the train. With that brake the driver had absolute control of the speed; he could increase or decrease the pressure, just as was required, at a moment's notice; and he was the man who ought to control the speed. In the early days of working, when dependence was placed on brakesmen in the train, the Author had heard the driver whistle for brakes and some few seconds had elapsed before they were put on: in those few seconds on steep gradients considerable acceleration might take place. Therefore he contended that brakesmen should not be employed, but that the driver should have complete control. Mr. Bach had spoken of having four cylinders of the same size. That The Author.

The Author. would be satisfactory from many points of view, but it was necessary to insist on having all the cylinder power that could be got for the repression brake. If necessary, the steam-cylinder should be made larger than was required for use under steam, with a view to get the power for the repression brake. The driver had to be trusted to use his discretion in opening the regulator. He could not open the regulator fully when starting, as otherwise the engine slipped. A man who had discretion could be trusted with a repression brake. No doubt the Garratt locomotive was a very useful one, especially on lines where the curves were sharp, but one of the main things to be borne in mind was the snow-plough. When a bank of hard snow was entered with a push plough the engine was shaken very much. The advantage of the Kitson-Meyer engine was that the bogie, besides being supported on the centre, had steadying plates at three other points, so that it could turn freely, but could not tip, and he did not think that advantage was obtained in the Garratt engine. There were very few lines, of course, where the engines had to contend with snow 10 to 15 feet deep. In answer to Mr. Aitchison, he thought he had expressed as clearly as he could in the Paper the objection to springs in the pinions. The springs allowed the teeth to yield, instead of coming up to their work solidly, and consequently the teeth, instead of wearing down the face, wore off the points; there was triangular wear. He had been much interested to hear Mr. Budge's observations on the wear of the rack-bars on two other railways, which did not coincide with his own. He could not venture on any comments on the causes without a knowledge of the local conditions, such as the average state of maintenance of the permanent way, the superelevation of the outer rail, the setting of the pinions, and whether full use was made of the adhesion power to avoid overloading the pinions and rack. With regard to the wear of the pinions and the rack on the Harz Railway, and in view of the relative work done by them, he could only surmise either that the rack-bars must have been of very soft material or the pinions exceptionally hard.

Correspondence.

Dr. Abt. Dr. Roman Abt stated that in 1906 a scheme was submitted to him in which locomotives were required capable of taking trains of 150 tons (excluding the engine) up the Chilian Transandine Railway, under very severe climatic conditions, and over curves