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

Dr. Abt.

having a minimum radius of 80 metres (4 chains). He was aware that the Argentine section had been built for trains of 60 tons and locomotives of about 40 tons, with permanent way accordingly. A train of 150 tons on a gradient of 8 per cent. required a tractive effort of about 13 tons, or, say, 15 tons, allowing for unavoidable irregularities in speed. In these circumstances the question arose whether it was not to be feared that under the action of such forces the frames of the carriages and wagons would be injured, and that the vehicles, especially in mixed trains and on sharp curves, would be derailed by the sudden changes of speed. For trains of this weight on such gradients very powerful locomotives were required. The Kitson engine weighed nearly 100 tons, including fuel and water, and the total tractive effort required would therefore be 22 tons to 25 tons. Another question was whether the permanent way—rails, fish-plates, sleepers, and rack—was strong enough to withstand the stresses due to such loads. After careful consideration, he had expressed the opinion that in the interests of the line the scheme submitted to him was not without its dangers, and it scarcely appeared to him to be reasonable: on the other hand, it was possible to construct an excellent locomotive to work trains of 100 tons, and even 120 tons if the permanent way would stand it. He was glad to say that his advice had been listened to. The normal weight of the trains had been reduced to 120 tons. In spite of this precaution, some months after the new locomotives were put into service frequent breakages of sleepers had occurred, a disquieting displacement of the entire permanent way had been observed at the moment when a locomotive passed, and other equally grave phenomena had occurred, causing serious consideration to be given to the question of substituting stronger sleepers. All this had confirmed his apprehensions. It was true that on the Swiss rack railways the maximum tractive effort did not exceed 11 tons; but these were tourist lines—not one of them had any heavy traffic. In many other countries railways combining adhesion and the Abt rack had long existed on which the normal tractive effort of the locomotives was 15 to 16 tons, of which about 10 tons was available for the haulage of vehicles, as had been recommended for the Transandine Railway. This figure, however, was not a rigid maximum. He had foreseen for years the advent of locomotives having tractive efforts of 25 to 30 tons in the cases of new lines, whose rolling stock had yet to be designed. It was not, however, simply a matter of continually increasing the power and weight of the locomotives; a better aim was the reduction to the minimum of the weight required for a given power. From this point of view the existing locomotives showed very

Dr. Abt. different results. Those of the Transandine Railway were not the most favourable, which was due to the permanent way, especially the rails, being too weak for the desired load. For the same reason the Esslingen engines also exceeded the weight that would have sufficed with sufficiently heavy rails. On the other hand the mechanical design of these locomotives embodied a number of excellent features whose value had been proved by experience. If the steam-pipes had not been satisfactory from the first, the cause was to be sought rather in the sharp maximum curvature of the line, namely, 67 metres radius instead of the 100 metres expected. However, that had been recognized, and the hinged joint of the steam-pipes had been replaced by an arrangement of more rational design, while the radius of the curves had been increased; and since that these locomotives traversed all parts of the line with ease. It was quite understandable that the wear of their tires was greater than that in locomotives which were worked over sections of the line having easier curves. The Author's views as to the elastic arrangement of the rack-pinions were not shared by everyone. On sixty-five other rack railways worked with more than 500 locomotives on the Abt system, the spring-fitted pinion was in strong favour and worked well so long as the pinions were carefully maintained, broken springs were replaced promptly, and the wear on the faces of the teeth was not allowed to become too pronounced. He had received from a very competent source the following statement: "Our experience on the Transandine Railway is that when we have taken out these springs the wear on the pinion and on the rack rail appears to us to be excessive." There was no doubt that these springs were a very effectual means of diminishing the injurious influence of the irregularities in the steps of the rack (which were the inevitable consequence of dilatation at the joints of the segments), and of distributing the pressure uniformly over all the pinions and the various parts of the rack. Wherever it was a question of the transmission of considerable forces at high speeds the experience was the same. The constructors of electric motors, after disagreeable experiences, were now seeking means of improving the working of their gears, so as to avoid injurious shocks and too rapid wear of the teeth. The elasticity of the pinions had not been devised to facilitate the automatic engagement of rack and pinion, the objects to be attained being sweet running of the pinions, good distribution of the stresses transmitted, and diminution in the wear. There was no need to lay stress upon the advantages of arranging the pinions so that they were not affected by the play of the springs of the locomotive itself. He admitted that there were cases in which this arrangement might be dispensed with without detriment to good working, as the Esslingen locomotive showed. But in the case of a railway on which the trains ran at speeds up to 20 kilometres (12½ miles) per hour and more, the arrangement of the axles of the pinions independently of the play of the locomotive-springs was of very considerable advantage to the gears and the sleepers. The Author was in error in saying that it was impossible to make points and crossings with the Abt rack. For more than 30 years Abt rack railways had been furnished with points and crossings that worked excellently. On combined rack-and-adhesion lines, however, it was usually preferred to locate the crossing-places on level ground, where the line could be worked by adhesion alone. Dr. Abt.

Mr. H. BRODHURST contributed the following notes on the working of the Argentine portion of the Transandine Railway:— Mr. Brodhurst.
This might be considered as divided into two sections at Zanjón Amarillo, which was 134·4 kilometres (83½ miles) from Mendoza, and 41·7 kilometres (26 miles) from Las Cuevas. The lower of these sections—that between Mendoza and Zanjón Amarillo—contained no rack portion, and adhesion engines were used exclusively over it. The upper section contained all the rack portions, and rack-and-adhesion engines only were used over it. The first rack engines for this railway,[1] made by Messrs. Beyer, Peacock and Company, did good work in the early days and gave no trouble with the rack, but they were unable to work the heavier trains of the present day, and were only useful for trains of less importance. Next came the Borsig rack engines, which had six coupled wheels 2 feet 11½ inches in diameter and pony wheels at each end 1 foot 11⅝ inches in diameter. The leading and driving coupled axles were 6 feet 3¼ inches apart, the two rack-pinions being carried on and between them, as mentioned in the Paper. The two outside (adhesion) cylinders were 15¼ inches in diameter by 19¾ inches stroke, and the two inside cylinders (rack-pinions) were 15¼ inches in diameter by 17¾ inches stroke. The original boiler-pressure was 220 lbs. per square inch, and the total weight of the engines loaded was 48 tons. The next rack engines were made by Messrs. Kitson, and were of a type similar to one shown[2] in Mr. Brodie Henderson's Paper. The smoke-box end was carried on a bogie with eight wheels coupled, 3 feet in diameter; these were driven adhesively by two outside cylinders 16½ inches in

[1] Minutes of Proceedings Inst. C.E., vol. cxcv, p. 156.
[2] *Ibid.*, vol. cxcv, Figs. 8, Plate 4.

Mr. Brodhurst. diameter by 19 inches stroke. The bunker end was carried on a six-wheel bogie; between the axles of this bogie, and carried by it, were placed the two rack-pinions driven from two cylinders 18 inches in diameter by 19 inches stroke. A third pair of cylinders, 13 inches in diameter by 14 inches stroke, was provided and placed above the adhesion cylinders. These were intended to work a third rack-pinion, placed between the first and second axles of the front bogie, but this additional engine had been put out of use. Later Messrs. Kitson supplied two more locomotives [1] without this additional engine. The boiler-pressure of these locomotives was 200 lbs. per square inch, and the total weight in working order was 90 tons. This was much heavier than any engine used on the lower section, and, looked at from the point of view of working, it would be much better if the rails on the upper section were heavier than 55 lbs. per yard. The engines could well haul 140 tons, as mentioned by the Author, but to avoid excessive strain on the rack their load had been limited to twenty-six axles, or say 126 tons. No difficulty had been experienced in getting the engines to steam at high altitudes. The fuel used was Welsh coal, the price of which was, of course, very high by the time it reached the bunker of the engine. Oil-fuel had not been tried on the Argentine Transandine Railway; none had hitherto been discovered close at hand, and if it were imported it would be about as expensive as coal. However, it was being tried elsewhere in the Republic, so it might in time reach the Transandine Railway. The curves on the rack sections were easier than those lower down, and no trouble due to excessive friction had been experienced with the rack engines. As the maximum gradient did not exceed 7 per cent., it had not been thought necessary to cause an engine running down light to have wagons attached to it. Every care had been taken to keep down the tare of rolling stock. The weight of a first-class coach, which had forty seats, was 15¼ tons. On the International trains seats had to be booked in advance, so as to avoid running more vehicles than were absolutely necessary. The journey across the Andes was always made during the daytime, so that sleeping-accommodation had not to be provided. The tare per passenger was therefore about one-fourth of what it was on the broad-gauge line between Buenos Aires and Mendoza, where sleeping-accommodation was required. Two engines were now never used on one train (except on extraordinary occasions, when clearing snow). One engine in front and one behind had been tried, but the practice had been abandoned,

[1] Minutes of Proceedings Inst. C.E., vol. cxcv, Figs. 8, Plate 4.

as it had been found to cause severe strain on the rack-rails; moreover, in the snow-sheds the fumes from the first engine nearly asphyxiated the engine-men on the second engine. Speed was limited to 15 kilometres per hour on the rack, and to 5 kilometres per hour on entering it. This rule had to be very carefully observed by drivers: the working time-table showed the minimum times which a train might take between points, and drivers were not allowed to take less than that time. Referring to the spring keys in the rack-pinions, on the Argentine engines these were found to break with much frequency, and the key-ways to become worn. A trial of solid keys, mentioned in the Paper, was made, but the engineers at once said that they caused damage to the rack-rails; for this reason they had to be taken out and spring keys put back. The trial was not continued long enough to determine whether the life of the rack-pinions was lengthened. With the springs, the pinions become worn down after the engine had run 15,000 to 20,000 kilometres (after being reversed) and had to be renewed. Mr. Brodhurst.

Mr. JOSIAH HARDING considered the Paper to be a valuable addition to the literature of rack railways. He endorsed nearly all the Author's ideas, an exception being those with regard to the hand-brakes. He thought that a simple arrangement of screw brake such as was in use in Antofagasta and Junin was much better than a chain brake. It was more reliable, capable of more exact adjustment, and quite as rapid and light as the chain brake. On the 250-mile continuous incline on the Antofagasta Railway frequent adjustments were required, which were performed with greater precision than was possible with a chain. His experience, like the Author's, was in favour of spoke wheels. He had, on the Junin Railway, used cast-steel wheels with curved spokes and no tires, with complete success. Of course, the ideal system for the Transandine Railway was electric traction, and when this was adopted no doubt many of the Author's ideas for the steam rack-locomotive would be worked in on the electric line. Mr. Harding.

Mr. FRANK REEVES remarked that, in expressing his appreciation of the Paper, he would like to emphasize the Author's brief allusions to the rack. As responsible for the maintenance of the way and works of the Argentine Transandine Railway, which was the continuation of the Chilian Transandine, was of identical construction, and used similar engines and rolling stock, he had been confronted with considerable trouble due to overstraining of the rack. The rack and the engine were portions of one mechanism, but, unfortunately, their maintenance was entrusted to separate departments, and when rack-bars were found to be damaged and Mr. Reeves.

Mr. Reeves. strained there was sometimes difficulty in tracing the cause. The rack on both the Transandine railways appeared to have been designed for the type of engines first employed, which weighed about 35 tons and gave a maximum tractive effort on the rack of 6½ tons (piston under full boiler-pressure, train not moving). The modern engines weighed about 93 tons, and could exert nearly 15 tons tractive effort. Although the maximum gradients on the Argentine side were only 6·1 per cent., against 8 per cent. on the Chilian side, he had found evidence of great straining and distortion and wear of the teeth, or rather cold-flow of the metal at the upper corners on their up-hill sides, due to intense pressure. There was also continual breakage of bars. This was obviously due primarily to the disproportionate power of the modern engines, and the following palliative measures had been adopted with success:—

(1) Only one engine was allowed to a train. It was found impossible to ensure uniform effort on the rack with two engines, especially at the entrances to rack sections.
(2) The train-load was limited to 150 tons.
(3) Drivers were made to use the adhesion engines to their full power, and to limit the use of the rack to the minimum absolutely necessary. (Previously the reverse had been the practice.)
(4) In descending, the repression and Westinghouse brakes were the only brakes normally used. The rack-brake was used only in emergencies.

He had suggested the radical remedy of lining down the 18½-inch rack-engine cylinders to a smaller diameter, but difficulties had been encountered in adopting this plan. Therefore, when the engines were used to push snow-ploughs, the drivers still had this great power at command and a good deal of damage was done to the rack-bars. The experience with the spring keys had not been the same as on the Chilian side: in October 1912 they were removed from two of the engines and a large increase of breakages and damage to the rack immediately took place. That, however, was before the adoption of the reduced train-load and other measures, detailed above. The spring keys were reinstated. He considered that some device to distribute the effort over the various parallel bars of the Abt rack was necessary. It must be borne in mind that on curves the difference in length of the inner and outer bars was all concentrated at a single tooth at the joint of the bars (about every 8 feet) which falsified the pitch to an amount reaching about 2 millimetres. In the absence of any distributing device the effort must all come upon one tooth—at least until this was worn down. Examination of the teeth at the joints confirmed this; the wear was obviously more severe there than elsewhere. Mr. Reeves.

Mr. A. H. Shield remarked that the section of railway of which the working was described by the Author had a rise of 6,137 feet in a length of 22·7 miles, an average of a little over 5 per cent.; but the air-line distance between Rio Blanco and the summit, according to the map[1] was only 15 miles, giving a gradient, if a straight line were possible, of about $7\frac{3}{4}$ per cent. Under such conditions the work done by the locomotive might fairly be considered in relation to vertical rather than horizontal transport. It was to be assumed that the proposed locomotive, of which particulars were given in the Appendix, had been designed to work at the prescribed speeds, namely, 6·2 miles per hour on the rack, and 18·6 miles per hour on the adhesion sections. In the case of the maximum rack-and-adhesion gradients (8 per cent. and $2\frac{1}{2}$ per cent.) the power at the rails (that was, exclusive of the internal resistance of the engine) required to haul a train of 150 tons, taking the weight of the locomotive, as estimated, at 90 tons and the resistance on the level at 0·4 per cent., was 746 HP. on the rack sections and 772 HP. on the adhesion sections. Allowing for the additional internal friction when the rack-engine was working, these figures were sufficiently close to indicate that the full steaming-power of the boiler was intended to be used at these speeds. Comparing the work done in terms of the height to which the train was lifted by 1 hour's work of the engine at full power— Mr. Shield.

On the 8-per-cent. rack gradient the train was lifted 2,619 feet.
" $2\frac{1}{2}$ " adhesion " " " 2,457 "

This was about 6 per cent. in favour of the rack gradient. In respect of fuel, repairs (so far as they related to the boiler and its appurtenances), and wages of the train-crew, the cost per engine-hour was the same on either gradient. The remaining items of cost of working were in some respects heavier on the rack gradient; but in others—tire-wear, for instance—lighter, owing to the lower speed and consequently less distance travelled per hour. The items which differed, and at the same time partly balanced each other, were so far below those which were the same, that the locomotive-hour in such a case formed a better measure of the cost of working than either the train- or the ton-mile. The result of its application as above to the data given in the Paper appeared to him to substantiate

[1] Minutes of Proceedings Inst. C.E., vol. cxcv, Fig. 2, Plate 3.

Mr. Shield. the general principle that when a fixed height had to be surmounted in a distance as short as, or shorter than, that required by the steepest practicable gradient, the shortest and steepest practicable line was the most economical in working. It was at the same time to be noted that the journey-time was somewhat less on the steeper gradient, and that, consequently, the capacity of the line was increased rather than diminished by the use of the rack. The application of the locomotive-hour per 1,000 tons raised 1,000 feet as a measure of economy in working steep gradients had been more fully dealt with by him in *The Engineer*.[1]

Mr. Stoney. Mr. E. W. Stoney observed that he had been closely connected with the working and maintenance of the Nilgiri mountain railway,[2] $16\frac{3}{4}$ miles long, $4\frac{3}{4}$ miles of which was an adhesion line with maximum gradients of 1 in 40, and 12 miles was Abt rack with 1 in $12\frac{1}{2}$ gradient, and curves of 100 metres (328 feet) radius, the gauge being 1 metre. The rails were flat-bottomed, weighed 50 lbs. per yard, and were laid on sleepers 6 feet by 6 inches by 6 inches. While Mr. Stoney was Chief Engineer of the Madras Railway system, numerous heavy and extensive slips occurred shortly after the line was taken over by the Madras Railway, necessitating the closing of the line for about 3 months for extensive repairs. Some of the deep cuttings were nearly filled, and the material, among which were many large rocks and boulders, had to be removed from the cutting-ends, which occupied a good deal of time. Many of the rails and rack-bars were much bent and damaged by the falling rocks, which had to be broken up for removal. From what he then saw—and had seen since, for slips still took place —he considered that most of this trouble would have been avoided had the line been kept farther out, and cuttings, especially deep and long cuttings, avoided as far as possible; by doing so the natural steep hill-sides would not have been laid bare and would have been interfered with as little as possible, and when slips did occur they would for the most part roll over the line, down the lower slopes, and be very easily and quickly cleared. Keeping the line farther out would have lengthened the viaducts. In two of the worst cuttings where bad slips recurred, covered ways had been built. In one case a large boulder rolled down a steep stream-bed and destroyed a 20-foot girder bridge. No derailments took place during the time

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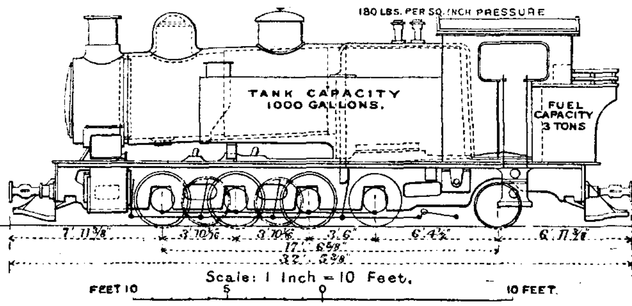
[1] Vol. cxviii (1914), p. 383.

[2] W. J. Weightman: "The Nilgiri Mountain Railway." Minutes of Proceedings Inst. C.E., vol. clxv, p. 1.

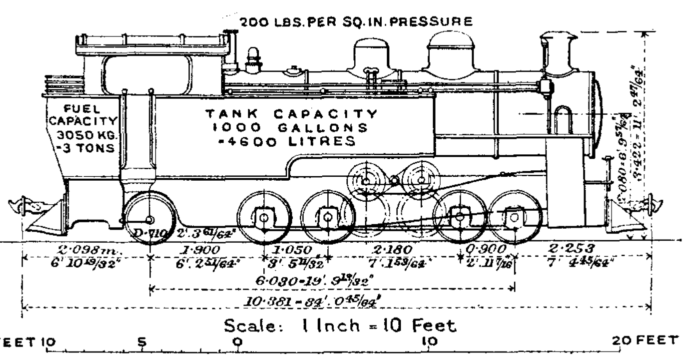
the Nilgiri Railway was under his supervision, but the permanent way was very well and carefully maintained in every way, and it had been well laid originally. A good deal of trouble was caused by rapid wear of engine-tires, which cut away the inner flanges of the outside rails on curves, so that they looked quite rough, as if Mr. Stoney.

Fig. 1.



shorn. The use of a fine water-jet prevented this, and the rails became quite smooth again, but he understood the use of such jets had been given up, as the engine-drivers thought it interfered with

Fig. 2.



adhesion. The following Table showed the great increase in size, weight, and power of the four classes of engines used. Engines of classes "P" and "X" were illustrated in *Figs. 1* and *2*. The line between Coonoor and Ootacamund was an adhesion one with a ruling gradient of 1 in 40.

Mr. Stoney.

		Class R (2–4–0).	Class S (0–6–2).	Class P (*Fig. 1*).	Class X (*Fig. 2*).
Adhesion cylinders	diameter, inches	13	$14\frac{3}{4}$	$16\frac{1}{2}$	$17\frac{23}{32}$
,, ,,	stroke, ,,	16	16	16	$16\frac{9}{64}$
Rack cylinders .	. diameter, ,,	$10\frac{3}{4}$	$16\frac{1}{2}$	$16\frac{1}{2}$	$17\frac{23}{32}$
,, ,, .	. stroke, ,,	14	$14\frac{1}{4}$	$14\frac{1}{4}$	$16\frac{59}{64}$
Heating-surface—					
Fire-box	square feet	74	94	100	82·8
Tubes	,,	612	909	1,000	793
Superheater . . .	,,	..	..	..	243
Total		686	1,003	1,100	1,118·8
Grate-area . . .	square feet	15	$19\frac{1}{2}$	$21\frac{1}{2}$	19·4
Working-pressure .	lbs. per sq. in.	..	..	180	200
		T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.
Weight in working order		36 4 0	41 15 0	49 12 0	48 3 1
		Tons.	Tons.	Tons.	Tons.
Ascending load	Mettupalayam–Coonoor	45	65	70	..
	Coonoor–Keti . . .	45	60	70	80
	Keti–Ootacamund . .	60	75	75	80

Dr. Zollinger. Dr. A. Zollinger remarked that railways such as those referred to in the Paper were suited primarily for the transport of passengers. For goods-traffic they were not remunerative, because the cost of working was too high, especially where in winter snow presented additional difficulties. Experience in Switzerland had proved clearly that the profits realized in summer were entirely absorbed by the extraordinary expenses in winter. Electrification had given a better result, but sources of cheap water-power were essential, and the quantity of water available must not be subject to too wide a variation between maximum and minimum. Too often, unfortunately, the mistake had been made of adopting rack railways for important lines in order to diminish the cost of construction, regardless of the fact that it was chiefly the cost of working that determined the return from a system of transportation.

The Author, in reply, expressed his gratification that the Paper had elicited criticism which would be of value in throwing further light on the subject. Caution was required, however, in comparing the practice on one mountain railway with that on another without very complete data, as the physical and other conditions varied greatly. The Author.

He had a very high opinion of the Abt system as compared with others, on account of its smooth running, distribution of stress, the ease with which a damaged rack-bar could be replaced, and other good qualities; in fact, he was disposed to claim more for it in the way of load-capacity than Dr. Abt himself. It was fully recognized that the rack material, adopted in 1887, when the present heavier train-loads were not anticipated, was somewhat light for the present requirements. But this was a case for making the best use possible of the existing line until increase of traffic should justify re-laying it with stronger material; and meanwhile there should be no difficulty in dealing with net train-loads of 140 or 150 tons, provided the track were kept in true and good order, special attention being given to suitable stone ballasting, and provided the maximum axle-load were not too high. On the Kitson-Meyer locomotives at present in use on the Chilian Transandine railway this was 13·25 tons on the rack bogie, and he had proposed to reduce it by using an extra axle, the maximum then being transferred to the adhesion bogie, with 11·75 tons as compared with the present 11·05 tons. Dr. Abt's statement that in 1906 a scheme was considered for locomotives capable of taking trains of 150 tons (excluding the engine) over curves having a minimum radius of 80 metres, was evidently due to a misunderstanding somewhere, as the minimum curve on the upper (rack) section, on which these engines worked, had always been of 200 metres radius. When they were occasionally brought down to the workshops at Los Andes, the engines had to travel over the lower (adhesion) section of the line, having some curves of 100 metres radius, which they passed over slowly without any difficulty. The mention of "the sharp maximum curvature of the line, 67 metres radius," was also an error, and probably referred to an adhesion siding leading into the running-shed at Los Andes, which should have had a radius of 100 metres, but which at one time, the Author was informed, had become reduced to about 80 metres radius. This curve had been subsequently flattened to 112 metres radius. As to the steam-pipe and other difficulties with the Esslingen locomotives, these were observed and continued for some time after this minimum radius had been corrected; and with regard to the comparisons made between the Esslingen and the Kitson-Meyer types, it should be clearly under-

The Author. stood that they were working over the same portions of the line and under the same conditions. Dr. Abt's opinion of the Esslingen locomotives was not shared by the officials of the line, and the cost of maintenance of those engines was considerably higher than that of the other locomotives. Dr. Abt's statement (p. 43) as to frequent breakages of sleepers and displacement of the entire permanent way did not agree with the information given to the Author on the spot regarding events before 1911, though there had been, as mentioned in the Paper, a little difficulty due to the cracking of sleepers in some places, which was subsequently overcome. As to the elastic arrangement, or spring keys, he could add little to the statement of facts contained in the Paper, but he surmised that a large number of the 500 locomotives said to be using spring keys were doing much lighter work than those on the Chilian Transandine Railway, in which case the detrimental results would not be so apparent. He contended, however, that for heavy work a solid drive was preferable, in order to eliminate the surface friction, on the face of the teeth, due to the action of the springs. He was at a loss to understand the statement (p. 44) quoted by Dr. Abt as received "from a very competent source" that "our experience on the Transandine Railway is that when we have taken out these springs the wear on the pinion and on the rack rail appears to us to be excessive;" the solid keys had been continuously in use on the Chilian Transandine Railway since May 1911, and had given the results stated in the Paper. Possibly Dr. Abt's information related to the Argentine Transandine Railway, which, though connecting with the Chilian Transandine Railway, was an entirely separate line and under different control and management. The carrying of the pinions on the main frames had proved very satisfactory, as the vertical movement was small and the clearances ample, which had been proved by the fact that no marks of fouling had been observed on the teeth or in the gaps of the rack-bars or pinions. The normal maximum speed on the rack was not 20 kilometres (12·4 miles) per hour, but only 15 kilometres (9·3 miles) per hour. Mr. Brodhurst's interesting notes as to the practice on the Argentine Transandine Railway confirmed the Author's experience of spring keys for the pinions; but his account of the trial of the solid keys was inconclusive, as he made no comment on the state of the permanent way. The reversion to the former conditions, when the spring keys "were found to break with much frequency, and the key-ways to become worn," made it a matter of surprise that a life of 15,000 to 20,000 kilometres was obtained. Possibly some stronger design of spring was used. The life of a set of

The Author. pinions with solid keys on the Chilian Transandine Railway would be about 50,000 kilometres; but, assuming the distance in both cases to be that run on the rack sections, including the adhesion, the comparison would be still more favourable to the Chilian railway on account of its greater length of rack and its steeper gradients.

Mr. Harding's preference for screw hand-brakes was shared by the Author for cases where no continuous power-brake was used; but on the Chilian Transandine Railway this was fitted, and the hand-brake was only used normally for shunting purposes and in the station-yards. Electric traction might come when heavier and more frequent traffic justified its adoption; but the difficulties connected with the heavy snowfall and occasional falls of rock could not be overlooked. The evils of cuttings on a mountain railway, to which Mr. Stoney alluded, were intensified where deep snow had to be dealt with. They had been experienced on the Chilian Transandine Railway, but most of the cuttings had now been cut down or levelled on the lower side, thus reducing the accumulation of snow or rock and facilitating clearing.

He agreed entirely with Mr. Reeves as to the difficulty of obtaining good results in rack working when the responsibility was divided, unless there was perfect co-operation and harmony between the two departments concerned. He suggested that the wear or cold-flow of the metal at the upper corners of the rack-teeth might be due, not to overloading or strain, but possibly to the depression of the sleepers which might occur on soft or imperfectly ballasted parts of the track, whereby the thrust of the pinion would come, not in its proper place on the face of the rack-tooth, but towards the point which was worn. With regard to the "palliative measures" adopted: (1) he agreed that it was preferable to employ one engine to a train whenever possible, and it was therefore desirable to obtain its full capacity; but he could not agree with the objection to using two engines at the front of the train when necessary, as two engines were frequently used for snow-ploughing. (2) He was interested to note that the load-limit had been raised to 150 tons, and congratulated Mr. Reeves on having thus increased the capacity of the line. In 1913 and 1914 the maximum train-load on the Argentine line had been reduced to 120 tons, and Mr. Brodhurst mentioned 126 tons, but Mr. Reeves's figure was evidently corrected up to date. (3) He entirely agreed with the full use of the adhesion power, which he had always advocated. (4) It would appear that the repression brake on the rack, which, in his opinion, was very valuable, was

The Author. not used; but the power developed under repression, being not more than 60 per cent. of that under steam, could not be held to strain the rack, while greater security and steadiness were obtained, with less wear of brake-blocks, tires, and air-pumps. For this reason, in particular, the proposed reduction of the diameter of the rack cylinders did not appeal to him. From his own observations, he did not think that there should be any practical difficulty in working smoothly on the easy curves existing, provided the pinions were properly lubricated and the track were firm, for readjustment was continuously taking place at every tooth and not at the end of the rack-bar only. The extra wear found by Mr. Reeves on the teeth at the joints might be due to the fact that each joint came on a sleeper, with the possible difficulties already mentioned.

Mr. Shield's proposal of the "locomotive-hour" would be useful as a basis of comparison for alternative routes, and also in estimating or checking costs of working. It was similar to the method proposed by Mr. F. W. Bach for arriving at the coal-consumption on heavy gradients.[1]

He strongly dissented from Dr. Zollinger's view that this line was unsuited for goods-traffic, unless Dr. Zollinger meant that of "low class," which would not stand a sufficient tariff. While such a line could more than pay its working-expenses from a normal passenger-traffic, the goods-traffic which the line could carry would represent profit or dividends. The carrying-capacity of the Chilian Transandine Railway, even with the present arrangements, was considerable; and, owing to the safety appliances now in use, trains could follow one another at short-time intervals, as was done elsewhere, while additional sidings for crossing trains could be introduced when found to be necessary. He considered that from the addition of "high class" and "medium" goods-traffic the line would reap prosperity in the future.

[1] Minutes of Proceedings Inst. C.E., vol. clxxx, p. 81.