F. B. Behr's Development of the Lartigue Monorail: From Country Crawler To Electric Express

by

PROFESSOR D. G. TUCKER, D.Sc., C.Eng., F.I.E.E., F.S.A. (Vice President)

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INTRODUCTION

The two personal names in the title are those of the two most important people in the story of the straddle-type of monorail. The name of Charles François Marie-Thérèse Lartigue was applied to the system because he developed, and patented in 1882, a design which led to wider commercial use than any other monorail system. This design had, however, been anticipated in all essential features over 60 years earlier by Henry Robinson Palmer. Lartigue, born in 1834, became a civil engineer in 1856, working in Spain and then Algeria, in the latter country becoming Engineer to a large farming firm which had extensive plantations of esparto, a large grass which was coming into use in paper making. Transport was a serious problem, and Lartigue devised an elevated monorail system, with pannier vehicles, which could be easily and quickly erected and dismantled, required no foundations, was cheap, suitable for animal traction, and free from blockage by blown sand. Then Lartigue developed the design and introduced locomotive traction and passenger carrying, and by late 1885 was promoting the Listowel and Ballybunion Railway, which became the best-known application of the system.

It was in 1885 that Fritz Bernhard Behr became in some way associated with Lartigue and effectively took over control of the Lartigue railway interests outside France and her territories, including acting as managing director of both the Lartigue Railway Co. Ltd. (together with its successors) and the Listowel and Ballybunion Railway. Behr was born in Berlin on 9 October 1842 of German parents. He was educated in Paris and had his engineering training in Britain, first as pupil to Wentworth Shields and Sir John Fowler, then in several railway engineering appointments. In 1876 he became a naturalised British subject. From 1885, for over 20 years, he devoted himself almost exclusively to developing and promoting the monorail system. He died on 25 February 1927, and had achieved sufficient distinction to be found in *Who Was Who*. While Lartigue is now thought, in some quarters at any rate, to have been something of a charlatan,[1] there seems little doubt that Behr was a very competent engineer and designer and open and honest in his dealings.

Behr became a real enthusiast for the Lartigue monorail, and saw it as having a much more important potential than merely providing cheap rural transport. He envisaged it in several urban and inter-urban roles, and most excitingly as the Lightning Express, a high-speed electric railway which he proposed first of all for the Manchester-Liverpool route to provide a train every 10 minutes, taking only 20 minutes for the journey (British Rail still took about 45 minutes in 1983). This railway got an Act of Parliament in 1901, but the Board of Trade effectively stopped it being built. But, in 1897, Behr had demonstrated the Lightning Express over a three-mile track near Brussels, where, even with hurriedly-constructed track and inadequate power supply, speeds of at least 75 m.p.h. were attained around curves of 1600 ft. radius. He was convinced that speeds in the range 100–150 m.p.h. could be safely achieved. It was disappointing that he never got a chance to prove it. The Lightning Express

Electric Monorail is the chief concern of this paper, and will be fully discussed after the earlier history of the Lartigue monorail has been summarised.

Part 1: Country Crawler

Before Behr's Lightning Express, all Lartigue monorails were operated by horse (or mule) traction, by very simple electric motors, or by double-boilered steam locomotives, and the speeds attained were quite low. Even on the Listowel & Ballybunion Railway the speed was only about 18 m.p.h., with a maximum of about 27. So it seems quite fair to refer to them as 'country crawlers'. The first of them, patented 13 years before Lartigue was born, was that of Palmer.

PALMER'S MONORAIL

The inventor of this monorail was Henry Robinson Palmer, born in 1795, associated with Thomas Telford for ten years 1816–26, then resident engineer at the London Docks, finally from 1835 a consulting engineer. He founded the Institution of Civil Engineers in 1818, became a F.R.S. in 1831, and died in 1844.[2]

He patented his monorail designs in 1821,[3] published a pamphlet in 1823 putting his monorail into context with ordinary railways on the basis of its lower measured resistance to traction and other advantages of the monorail,[4] and was able to see two short commercial lines in practical operation. These were at Cheshunt in Hertfordshire and at the Royal Victualling Yard at Deptford.[6] The basic design was for a single iron rail-strip, laid on the upper edge of a thick plank of wood fitted in slots in vertical posts of iron or wood. The vehicles comprised two panniers supported on a framework straddling the track and running on grooved wheels. Palmer gave attention to the proper shape of the wheel-treads and the corresponding profile of the rail, a matter apparently ignored by Lartigue 60 years later.

Palmer envisaged horse traction and kept his lines as level as possible by varying the height of the posts to suit the contours of the land. He had designs for points and level crossings which were in some ways superior to those of Lartigue. It is perhaps surprising that Palmer's monorail did not find extensive use.

HADDAN'S 'PIONEER RAILWAY'

John Lawton Haddan (1841–1880) had varied experience of railway engineering in undeveloped countries and in 1875 conceived his Pioneer Railway as a solution to their transport needs.[7] Like Palmer's system, it had a single carrying rail supported on posts; it differed, however, in using steam locomotives. These had two boilers, one slung on each side of the track, and the drive was not on to the carrying wheels, but instead, used horizontal wheels driving on to additional rails fixed on each side of the posts,[8] thus having much in common with the traction system developed by Fell for mountain railways.[9] Haddan's early death frustrated a practical demonstration actually started at the Crystal Palace,[10] and later refinements by F. J. Rowan[11] apparently led to no practical construction.

THE 'PEG-LEG' RAILWAY

This American system, contemporary with Haddan's Pioneer Railway and very similar except that it probably used the carrying wheels of the locomotive for driving, was actually built and operated commercially for a year or so over a 4-mile route between Bradford and Gilmore in Pennsylvania in 1878–79. There had previously been a demonstration at the Philadelphia Centennial Exposition in 1876. Technical details are sparse.[12]

LARTIGUE'S EARLY SYSTEMS

As has already been said, Lartigue's first patents[13] were taken out in 1882, and they covered a system of light, temporary, cheap and flexible monorail in which goods were carried in pannier wagons, the centre of gravity of which was well below rail level. It was a true monorail, for there were at this stage no side guide rails, although the patents did allow for side rollers on the wheel frames to run on the web of the rail; however, no indication has been found that such side rollers were ever used. When side rollers were introduced on the more sophisticated systems of 1885 onwards, they ran on special side rails fixed to the main rail supports. From the beginning the running rail was mounted at the top of a trestle frame, which needed much less foundation in the ground than the posts of the earlier systems. Horse or mule traction was intended in general, and on this basis some quite extensive systems, aggregating over 100 miles, were in use in the esparto plantations of North Africa.[14]

In demonstrations at the Agricultural Exhibition in Paris in February 1884, trains carrying passengers in adapted wagons were successfully hauled by small electric locomotives fed with electricity through the running rail as one conductor, and two side rails joined in parallel as the other. A similar demonstration was given at the Rouen Exhibition later the same year, but the arrangements were more advanced. It is believed that the side rails were used for vehicle-balance (by means of side rollers on the vehicles), as well as for conduction; and certainly specially-designed passenger carriages were provided. Following this, an electrically-operated Lartigue mineral line was built at the Ria copper mines in the eastern Pyrenees, with five hairpin bends of about 10 ft. radius and gradients up to 1 in 12, and with no generating station, the electricity for ascending trains being generated by those descending. How long this survived is not known, but it was certainly operating for two years at least.

ENTER BEHR: THE LISTOWEL AND BALLYBUNION RAILWAY

In 1885, following the small successes recounted above, Lartigue turned his attention to more ambitious monorail projects involving steam traction. It was at this time that Behr became associated with him, and largely took over the management of Lartigue business outside France. There had been plans for some time for a light railway from Listowel, a small market town in the west of Ireland, to Ballybunion, a small coastal resort with large supplies of good sea-sand. Little progress had been made in promoting the railway, and it apparently appealed to Lartigue and Behr as an opportunity for the monorail system. Around 10 miles in length and in fairly level terrain, with modest potential for both goods and passenger traffic, it must have appeared as a commercial possibility. They gave notice towards the end of 1885 of their intention to introduce a Bill in Parliament, and the Listowel and Ballybunion Railway Act, 1886 was duly passed. To finance their activities the Lartigue Railway Company Ltd. was formed, with Behr as Managing Director. This company set up in September 1886 a very interesting demonstration track in Westminster,[15] where both the original moveable Lartigue system and the newly-developed permanent type of monorail were shown in operation, with steep gradients, sharp curves, points and level crossings. On the permanent-type track a small steam locomotive with two vertical boilers hauled both passenger coaches and goods wagons; it also supplied steam to a small powered tender which had a cog-wheel which engaged a rack rail on the very steep gradients. The demonstration was successful. Its cost, and that of the Act, had, however, exhausted the capital of the company, and a new company, the Lartigue Railway Construction Company Ltd., was registered in November 1886, again with Behr as Managing Director and with enough capital to build the L. & B.R. The latter company had its own Board of Directors but was, it is believed, wholly owned by the L.R.C.Co. Behr was its Managing Director, with his office in London.

The railway was opened for public traffic on 5 March 1888. It had the original vertical-boilered locomotive used at Westminster, together with three new three-wheeled locomotives with twin horizontal boilers and powered tenders, built by the Hunslet Engine Co. of Leeds. All the locomotives were designed by Anatole Mallet, the French engineer who became well-known for his introduction of compounding and single-bogie articulation in locomotives; yet all the Lartigue engines were simple, and articulated only to the extent of having powered tenders.

The general nature of the L. & B.R. track and rolling stock is so well known that the photograph of Fig. 1 should be sufficient to recall it here. Of the numerous publications describing it, that by Newham [16] is probably the most useful; however, in the present author's opinion they all have errors, some of which he has tried to correct in a recent paper.[17] The straddle-type monorail led to some awkward operating problems. It was, of course, inconvenient to have to load both the 'panniers' of a passenger coach roughly equally when the passengers could only cross the trestle track by means of special staircases either fixed to the ends of the guard's vans or fitted on special small wagons. Points were of a special turntable type, effective but slow. Level crossings were a particular nuisance, awkward for the railway and insufferable to the farmers and others whose roadways they impeded.[18] There were, it is believed, 23 of them; three on public road crossings had a moveable section of track, operated by a crossing keeper, while the other 20 were of the bascule bridge type in which flaps were

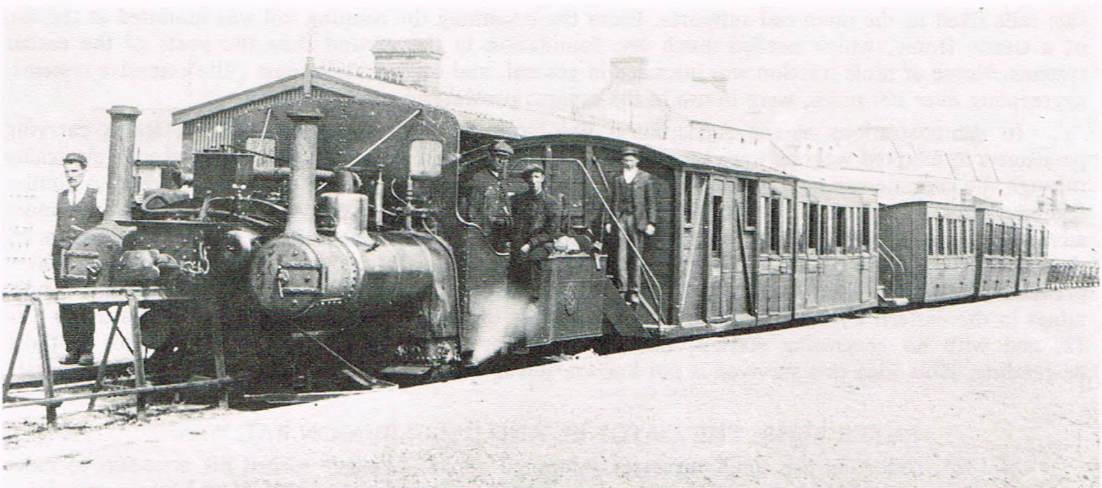


Fig. 1. Listowel and Ballybunion Railway. An early photograph of Locomotive No. 3 with train at Ballybunion. Note the staircases for crossing from one side of the train to the other, one fixed to the end of the guard's van and one (further down the train) on a special small wagon. *From R. A. Abbott collection, courtesy of D. H. Tew.*

let down to carry the road over the rail and which had to be raised again by the road user after he had passed over. It is significant that no other Lartigue railway, planned or built, was allowed to have level crossings.

During the late 1880s and early 1890s other Lartigue monorail lines were proposed and some were actually built,[19] but they do not affect our present story. The L. & B.R.Co. went bankrupt in 1897 (the L.R.C.Co. had done so the previous year) and Behr's control of it then ended. The railway continued in service, with many vicissitudes, until 1924. But by 1897 Behr was deeply engaged in much more adventurous projects.

Part 2: Electric Express

THE LIGHTNING EXPRESS ELECTRIC MONORAIL

The development of the Lartigue monorail into a high-speed electric system was entirely the product of F. B. Behr's drive, enthusiasm and initiative. Before the Select Committee of the House of Commons on 5 May 1900,[20] Behr said he had been considering the matter for 14 years, i.e., from 1886, about the time of the Westminster demonstration. Apparently experience with the Listowel and Ballybunion Railway did nothing to dampen his enthusiam; indeed there is perhaps no reason why it should have done, for however rough and noisy travel on that railway may have been, there seems never to have been a derailment except when the track was actually sabotaged.

Behr's first formal and considered proposal for a 'Lightning Express' railway service, operating at speeds of 120 to 150 miles an hour, was put forward in September 1893 in the form of a 34-page booklet with seven large sheets of drawings.[21] For some reason it was dedicated to H.M. King Leopold II of the Belgians. Although an acknowledgment was given to Lartigue and to a Louis Finet, there was no mention of the Lartigue Railway Construction Company Ltd. Possibly Behr produced this booklet as a private matter, although it was certainly the L.R.C.Co. which later went bankrupt over Behr's lightning express experiments. In the booklet Behr argued strongly that there could be no question of existing railways being used for high-speed trains; they were congested with miscellaneous traffic, they had level crossings and junctions, and they had too sharp curves. He calculated that for a railway of normal two-rail type with gauge of 4 ft. 8½ in., a super-elevation of 8 inches and a radius of curvature of 178 chains would just permit a speed of 150 m.p.h. with a 20-ton vehicle—or 120 m.p.h. for 112 chains. But 178 chains was nearly 2¼ miles, and clearly such requirements dictated a special railway system. The use of a guard-rail might, he thought, relieve these requirements to some extent.

As regards rolling stock, Behr concluded that electric traction was essential, with the traction motors on the passenger cars themselves. Electricity should be distributed from a central generating station. Automatically closing and opening doors should be provided, and brakes should be automatic and powerful. Behr suggested cars about 50 ft. long, carried on bogie-frames, with 600 h.p. of traction motors (or 'dynamos' as he called them) and streamlined front and rear ends. Trains could be lengthened, if necessary, by a system of articulation.

It is interesting that Behr's objection to the use of ordinary railway track for high-speed trains was based on the difficulties of negotiating curves and not on any inherent difficulty in attaining stability on a track comprising two rails required to be maintained at the same level to a high degree of precision. With the hindsight of the last part of the twentieth century, we now know that adequate stability for speeds of 125–150 m.p.h. **can** be attained on standard two-rail track, but there was no certainty of this nearly a century ago. In the same year that Behr produced his booklet, the *Railway World* published an article[32] which stated

> . . . it is a moot question not yet decided . . . as to whether trains of any form or shape will travel safely at 120 miles per hour upon a couple of rails.

It will come as no surprise to learn that Behr considered that there was one particular kind of track that was eminently suitable for his high-speed train: namely, the Lartigue single-rail system. Derailment was almost impossible; because of the guide rails relatively sharp curves could be taken at full speed, the trestles being tilted to correspond with super-elevation on an ordinary track. On this basis, Behr considered that curves of 25 chains radius would be satisfactory for 150 m.p.h. He made detailed calculations for the design of the track to give full stability and strength, allowing for extra stresses due to side winds. He calculated at first that an I-section running rail of 50 lb. per yard would safely carry twice the load to which it would be exposed; rather more slender guide rails would suffice, of 23 lb per yard. Later, however (in an Appendix), he increased these rail weights to 90 and 41 lb per yard respectively in view of his recommendation of a heavier articulated train.

As regards routes, existing railway routes could be utilised in various ways; the monorail could run alongside or over the existing railway and would certainly be carried over all stations, junctions, bridges, etc. Tunnels would remain a special problem. The high-speed monorail would have separate tracks for each direction which could have their gradients differently arranged, and they would be connected by closed loops at each end so that there would be no need for points in normal service. By avoiding points and level crossings, Behr had eliminated the two main operating headaches of the earlier Lartigue system.

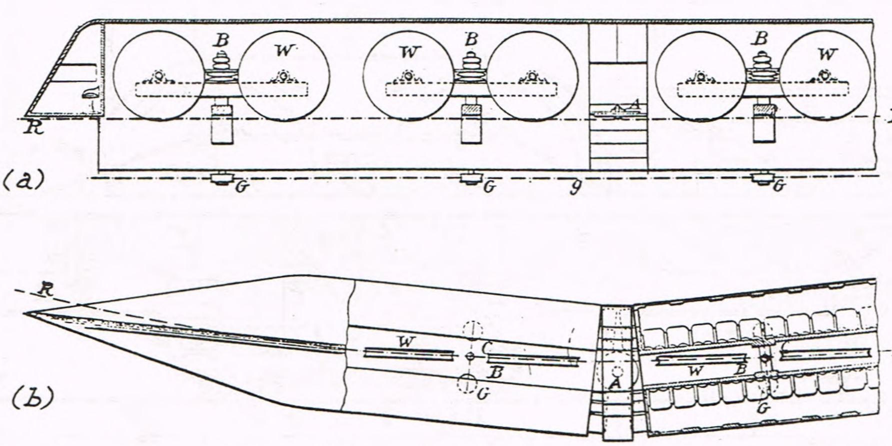


Fig. 2. Diagrams from Behr's British Patent No. 13,996 of 1893 showing bogie and articulation arrangement of his first proposal for a Lightning Express train.
(a) elevation, (b) plan.
A = coupling pin, B = bogie pivot, W = wheel, R = running rail, G = guide roller, g = guide rail.

At this stage Behr was envisaging vehicles which were technically very advanced.[23] They were articulated in the sense that individual sections were pivoted together rather than coupled in the normal way, as can be seen in Fig. 2, and entrance to the vehicle could be made at the flexible join. Each section was spring-mounted on two two-wheeled bogies pivoted at their centre-points, and each wheel had coils and a commutator fixed to it so that it formed the armature of an electric motor. Frames attached to each bogie carried one guide wheel on each side of each bogie. The guide wheels were pressed by springs to maintain steady contact on the guide rails; and the guide wheels were much more complicated than simple wheels: each was a rotating frame which carried a number of small wheels around its circumference which could run on the rail in turn. The idea of this was to avoid the overheating which might occur if a single small guide wheel took all the load. On sharp curves at high speed, of course, the guide wheels really would take a load, and Behr had allowed for this.

Behr's ideas were continually developing, and by 1895 he had apparently abandoned the idea of combining each driving wheel with the armature of an electric motor. In his patent of that year[24] he retained the concept of the articulated vehicles, but rather more specifically as a two-section arrangement, with each section having at its inner end (i.e., the end which is linked to the other section) a rigid driving wheelbase of two fairly large wheels, and at its outer end a pivoted bogie of two smaller wheels. The bogie carried its own guide wheels, see Fig. 3. The driving motors were mounted on the extension of the car body downwards below rail level at each side; by getting the weight of the motors so low, it became feasible to have the passenger compartment above rail level, with obvious convenience. Each motor drove the axle of one driving wheel by means of a coupling rod as shown in the diagram or by gearing or some other method. But, as the motors were carried on the sprung body frame, they were mounted on rollers ('G' in the diagram) to permit a fore-and-aft movement to keep the distance to the axle constant.

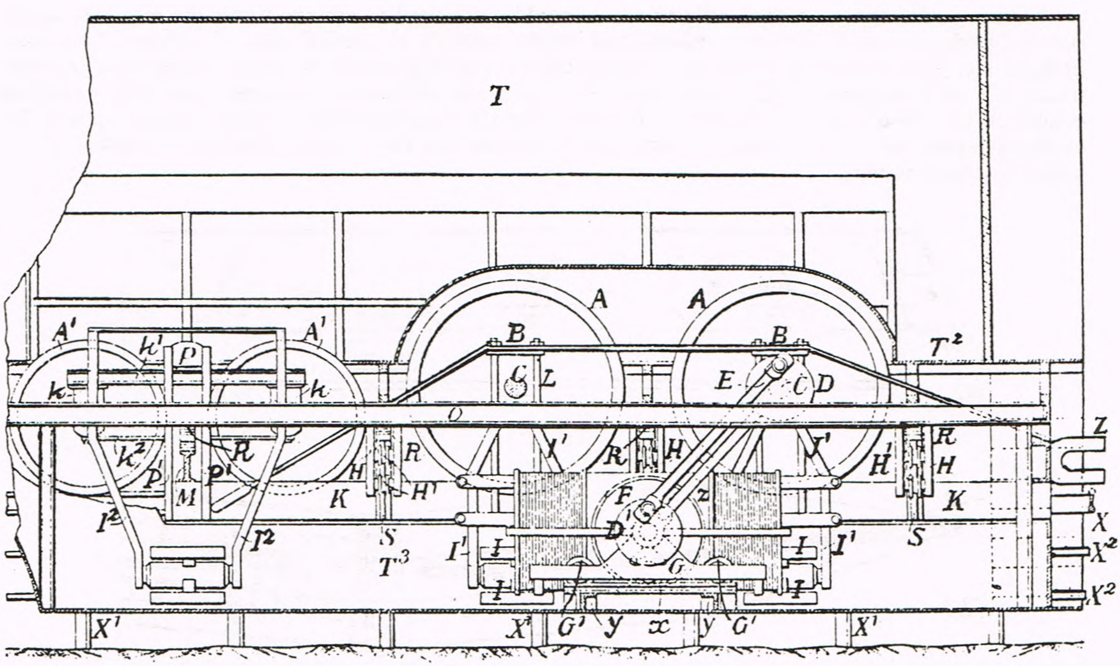


Fig. 3. Diagram from Behr's British Patent No. 16,643 of 1895 showing bogie and motordrive arrangement of his second design for a Lightning Express train.
T = carriage body, A = driving wheel, A^1 = bogie wheel, R = spring, F = motor, G = motor frame, G^1 = roller suspension for motor, E = connecting rod, X^2 = guide rail, I = guide roller.

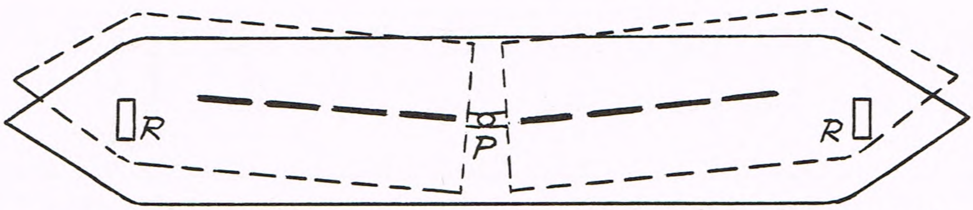


Fig. 4. Outline diagram by present author showing the bogie arrangement of Behr's 1897 Lightning Express car as demonstrated at Tervueren, 1897. P = pivot/hinge, R = roller.

Another change, which was destined to remain a permanent feature of all Behr's subsequent schemes, introduced in this patent of 1895, was the use of two guide rails on each side of the trestle, and two lines of guide wheels on each side of the vehicle. Each vertical pair of guide wheels was arranged on a short vertical arm pivoted between the wheels, so that guide-rail pressure could be evenly divided between the two wheels. Thus the so-called monorail had become a five-rail system and this led to some sarcasm at a later stage. It is hard to see what good two guide rails on each side could do that could not be done by one.

A third stage of development of ideas regarding the design of the lightning express vehicle can be seen in Behr's patent of 1896;[25] this was a very important stage because it represented the actual design of vehicle used in the practical demonstration of the lightning express monorail in Belgium in 1897 (see page 138). This time Behr abandoned the articulated body, using instead an articulated driving chassis with a long rigid passenger-carrying body supported on it. The four motors were mounted in the driving chassis at well below rail level, and as the chassis was sprung, provision had to be made to avoid a variable length of drive from motors to axles. In the patent specification, the drive was by connecting rod from a crank on the motor axle to another on the axle of the driving wheel; however, in the vehicle actually made in 1897 the drive was by chain. The guide wheels were now simple wheels.

The articulated driving chassis comprised two rigid four-wheeled units; each had wheels of equal size, but only the two centre wheels in each unit were driven, one by the motor on one side and the other by the motor on the other side. The two units were coupled by a universal joint or hinge, and the body also was supported on this joint, having rollers at each end to allow the driving chassis to swing laterally under it. (See Fig. 4) Such motion of the driving units relative to the body was permitted but also severely restrained by the method of springing used. Although the driving chassis were referred to as bogies, they evidently were not bogies in the usual sense, not being pivoted in the normal way.

Another important feature covered in the 1896 patent was the use of louvre brakes. Behr reasoned that the use of ordinary brakes would not be satisfactory in slowing the train from speeds in the range 120–150 m.p.h. Consequently in the pointed 'prow' of the vehicle he provided vertical slats, flaps, or 'louvres', which normally lay back flat against the vehicle, but which could be turned out to provide effective air brakes. The ordinary brakes could be brought in as the speed came down and their effectiveness would increase as that of the air brakes decreased at lower speeds.

The fourth and, it is believed, final design of the lightning express vehicle was made after obtaining experience of the vehicle described above at the demonstrations in Belgium in 1897. It was thought to be too big and heavy (it had seating for 100, was 58 ft. long by 11 ft. wide, and weighted 55 tons), and for the proposed Manchester and Liverpool Express Railway, a smaller and much lighter vehicle was designed,[26] as shown in Fig. 5. This had a rigid body carried on two pivoted bogies, each with one large driving wheel and a smaller idling wheel, as well as eight guiding wheels running on the guide rails. There were two electric motors on each bogie as before. The diagrams also show the wheels for picking up the electric supply from conductor rails. It was proposed to make extensive use of light alloys in the construction of these vehicles. By this time, the intended speed of the trains had come down to 110 m.p.h.

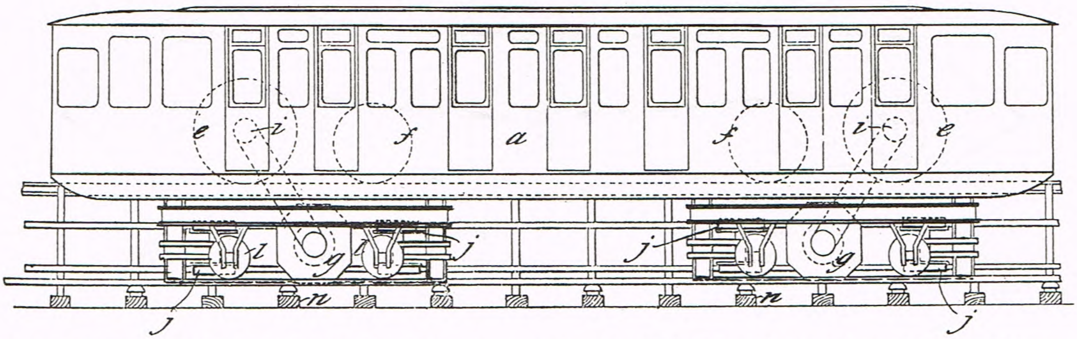


Fig. 5. Elevation of Behr's Lightning Express car as proposed for Manchester–Liverpool line; from British Patent No. 3610 of 1902.
e = driving wheel, f = trailing wheel, l = conducting wheel, g = electric motor, j = horizontal guide roller.

Of all the vehicles designed by Behr for his lightning express, only the third design materialised, and only one example was built of that. It did run in Belgium, as will be seen, and under bad conditions and with much bad luck, nevertheless attained speeds of around 80 m.p.h. without mishap, even on tight curves of 25 chains radius. Behr worked hard for his Lightning Express and it might have succeeded on the Manchester-Liverpool route if it had been given a chance. But the Board of Trade had no way of being certain it was safe; it was an enormous step into the unknown. So they killed it stone dead while appearing to approve it.

DEMONSTRATION AT TERVUEREN, BELGIUM, IN 1897

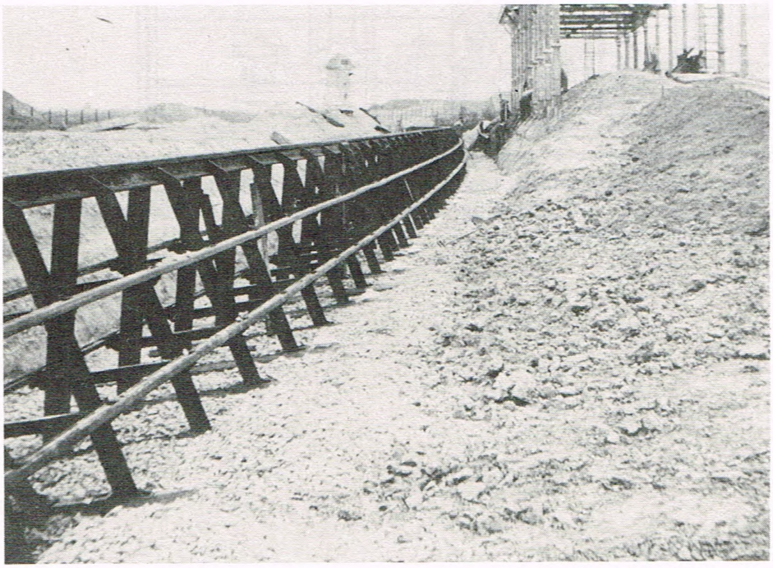
Behr's decision to build an experimental track at the Brussels International Exhibition in the summer of 1897 represented a necessary step in his promotion of the Lightning Express. The Westminster demonstration of the Lartigue system in 1886 (like its predecessors in Paris and Rouen) had no doubt been seen as a necessary step in the promotion of the simple Lartigue monorail and it must have been disappointing that so few commercial railways were built on this system. But the demonstration had cost only about £1,500 and it related to railways like the Listowel and Ballybunion which cost about £30,000. Now Behr was concerned with engineering undertakings of a different order (the Manchester-Liverpool Express Railway was a two-million-pound project) and the scale of the demonstration had to be correspondingly greater. It was said that it cost £30,000. Behr himself claimed that it cost £60,000.[27] The source of this money is not known.

The best source of information is an article in *Engineering*,[28] and we use it and quote from it extensively. The drawings in Figs. 7–9 (pages 140, 141) are taken from it. The vehicle itself was made to Behr's design by the Gloucester Railway Carriage and Wagon Co., and not only are some of their official photographs reproduced here, (Figs. 10–11 (pages 142, 143)) but also a view of the track taken by their engineers who assembled the vehicle at Tervueren. *Engineering* said:

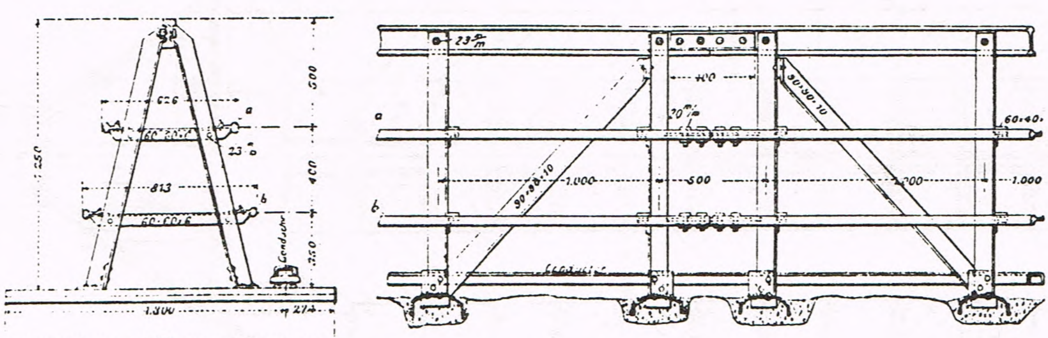
> Whatever may be the doubts of many, Mr. Behr certainly commands the admiration of all, for the remarkable enterprise he has shown in the construction and equipment of a railway wholly experimental and enormously costly. Only a profound belief in the soundness of his invention, and its future application on a large scale, could have brought him through the continuous difficulties he has had to encounter.
>
> The monorail exhibit consists of three parts . . . these are the permanent way, the carriage, and the power station . . . The length of the line is about three miles, and consists of two parallel straight portions connected by curves at each end cf about 1600 ft. radius; these arcs of circles are joined to the straight lengths by transition curves. The line is not level throughout, one-half the distance, including a part of the curves, being laid with a grade of 1 in 100. The great ring fence inclosing this ellipse does not lie within the limits of Tervueren Park, but extends from one end of it, so that the entrance to the exhibit is situated on the boundary of the park. The right of way for a period of 18 months was obtained only after great delays and expenditure . . . Owing to the minute subdivision of land, Mr. Behr had to conclude no fewer than 200 contracts, which have been followed by some 20 or 30 lawsuits . . . Near the entrance to the inclosure is erected the single station on the line; it is placed on a curve . . .

Fig. 6 shows details of the track design. The running surface of the rail is 1.25 m above the sleeper, the rail weighs 82 lb. per yard. Trestles are spaced at 1 m except at joints, where, as shown, the spacing is halved. The guide rails weigh 19 lb. per yard, except on the inside of curves, where the load is greater and a heavier rail of 24 lb. per yard is provided. As stated earlier, four guide rails are used. It is understood that the trackwork was made by the Thames Iron Works and Shipbuilding Co. Ltd., to whom the Lartigue Railway Construction Co. Ltd. was in debt in 1896. However, this was never explicitly stated and the matter is not clear.

Figs. 7–11 (pages 140–143) give details of the Lightning Express car. The general principles have been described on pages 135–138. The car was not provided with opening windows, but had a ventilating system based on roof ventilators circulating air through baffles in the roof space before admitting it at a comfortable velocity into the passenger space. Lighting was by incandescent lamps supplied from the main traction circuit. The car was luxuriously fitted out and one compartment prepared for royalty.



(a) photograph of track before conductor rails affixed. *Courtesy of Gloucester Railway Carriage and Wagon Co. Ltd.,*



(b) drawing of basic track structure.

Fig. 6. Behr's track at Tervueren, 1897:

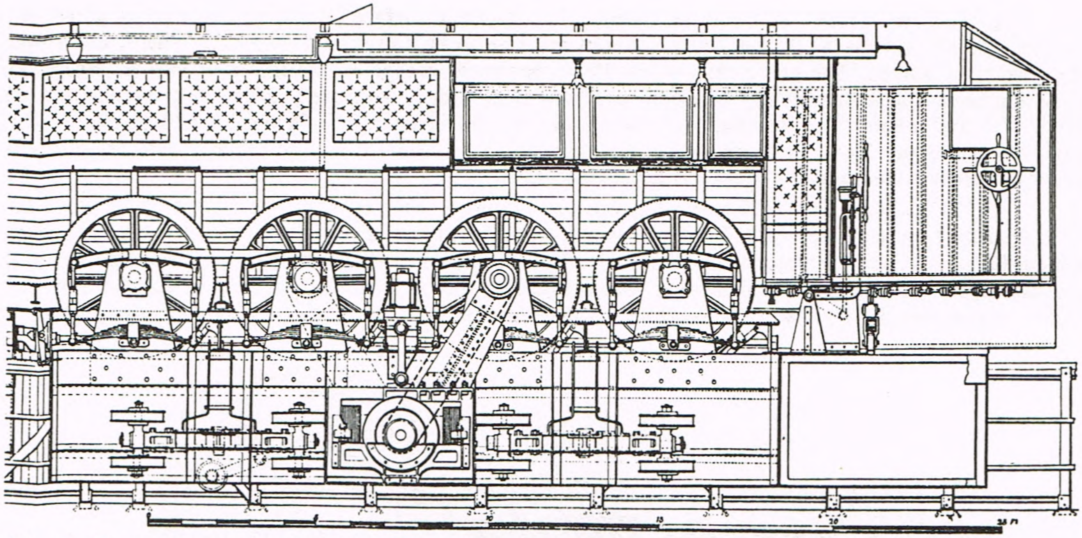


Fig. 7. Composite vertical longitudinal section of one half of Lightning Express car as made for demonstration at Tervueren, 1897, showing suspension, guide wheels, and motor-drive arrangements. From *Engineering,* Vol. **63** (1897).

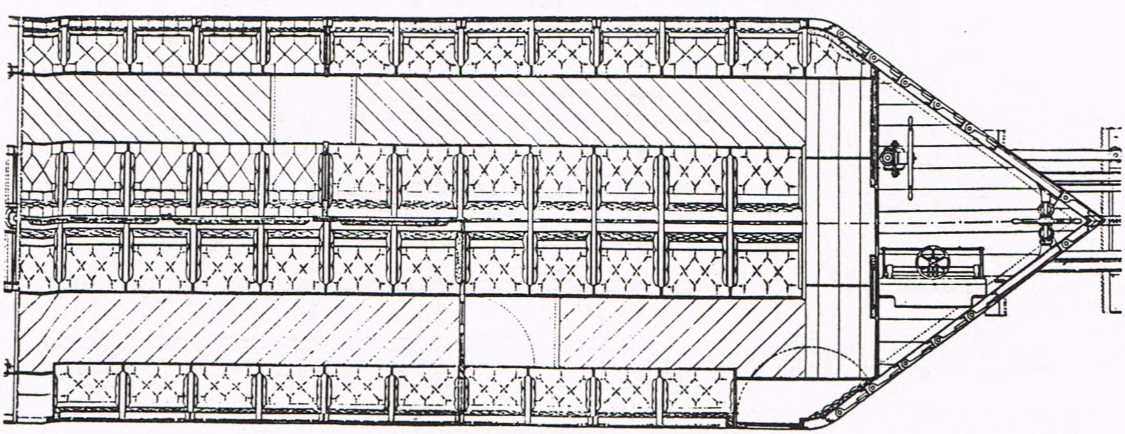


Fig. 8. Horizontal section of one half of Lightning Express car, showing arrangement of seats in longitudinal compartments on each side of running rail. From *Engineering,* Vol. **63** (1897).

Power transmission from the four motors to the wheels was by steel chain made by Renolds. The electrical equipment was manufactured by Thos. Parker Ltd. of Wolverhampton. Each motor was of four-pole type rated at 150 h.p. at 600 rev/min. Details of the electrical control system were published.[29] At starting, the four motors were connected as two parallel groups in series, with a resistance in series. This resistance was gradually reduced, and at a suitable speed the motors were all connected in parallel, with the resistance in series with them. The resistance was then again reduced to zero, as normal full speed was attained. For still higher speed, the series field windings of the motors were shunted by resistances. A double-pole automatic magnetic cut-out was fixed above the controlling switch, and the circuit was made and broken entirely by this, either automatically if too much current was demanded for any reason, or by the driver if he wished to stop the train. A reversing arrangement was provided for giving slow speed in reverse, but the car was not driven backwards in service.

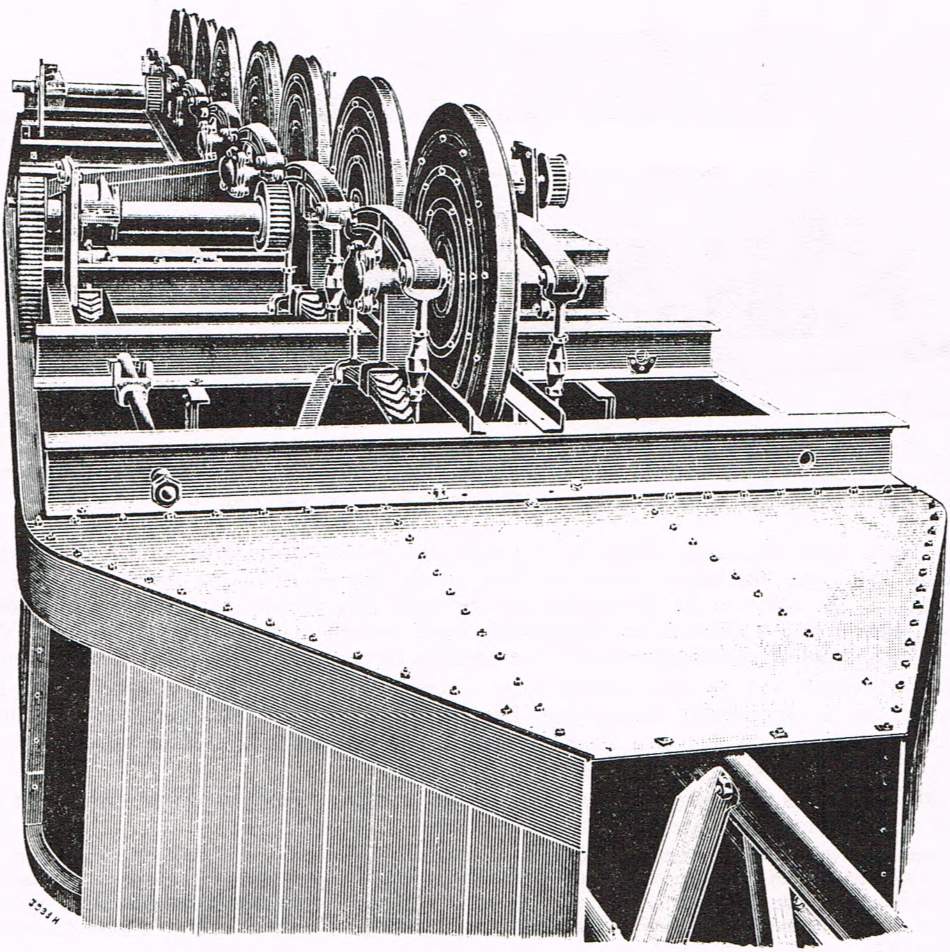


Fig. 9. View of the two bogies (or driving carriages) of the Lightning Express car; From *Engineering*, Vol. **63** (1897).

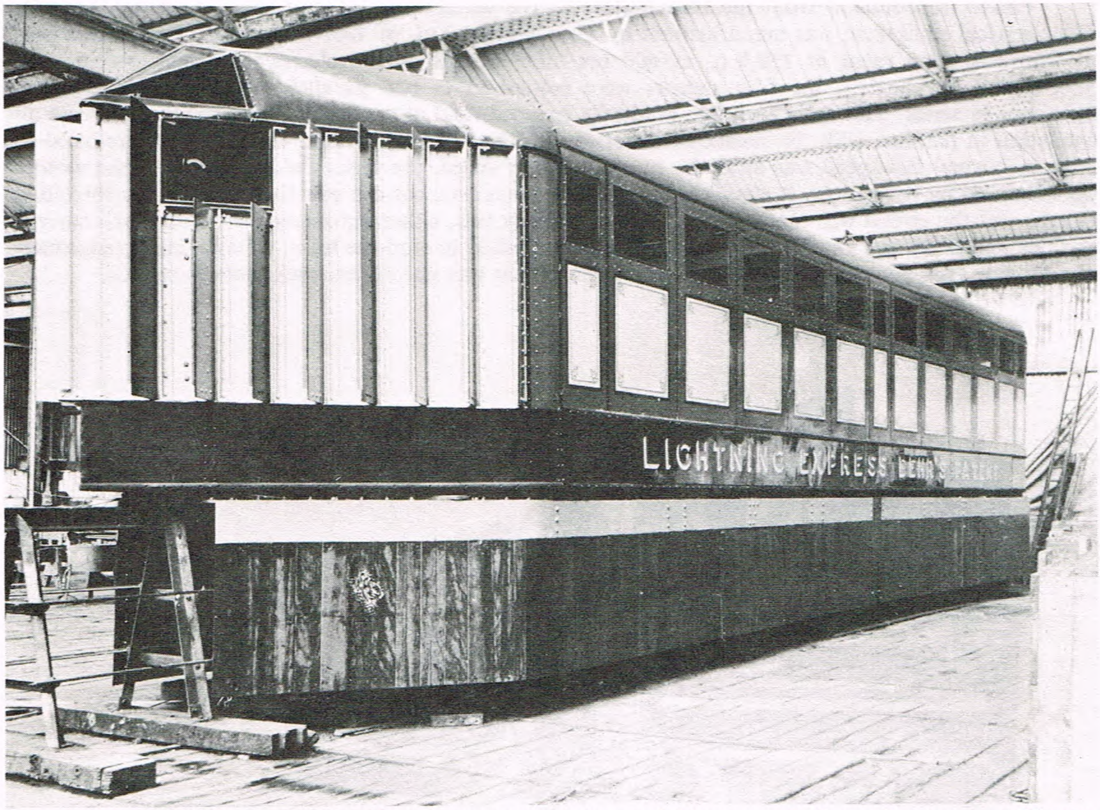


Fig. 10. Photograph of Lightning Express car at workshops of Gloucester Railway Carriage and Wagon Co. Ltd., 1897, showing the louvre brake flaps opened in the braking position. For normal running they fold back against the body. *Courtesy of Gloucester R.C.&W. Co. Ltd.*

Behr was very unfortunate in that he was badly let down by the exhibition authorities, who had undertaken to provide the power station for him. It was not ready in time for the opening of the exhibition, nor for some weeks afterwards, and never at full power; moreover it broke down on occasions. Behr found it difficult to make proper trials. Indeed, it was said he lost a great deal of money as he had hoped to recoup much of his expense in fares paid by visitors for rides in the train.

The trackwork had involved making some cuttings and embankments in order to be able to demonstrate the performance of the Lightning Express car on gradients. This had been done hurriedly with loose sandy soil, and Behr had some initial difficulty with his track shifting under the stress of the train taking the curve on the embankment at 70 m.p.h.[30]

Although speeds of 83 m.p.h. were claimed years after the event, the highest the present author can find recorded at the time was 'over 75 m.p.h.', thus:[31]

> Yesterday week, Count Adrien d'Oultremont, Commissioner-General of the [Belgian] Government, and his family, had a very successful run on this line, and the Count expressed himself very pleased with the same. The speed at one time on the most difficult part of the line, at which a sharp curve over a very bad embankment had to negotiated, was, according to Count d'Oultremont's timing, over 75 m.p.h. . . .

No contemporary critical appraisal of the demonstrations seems to have been published, nor is it known exactly what conclusions Behr himself reached. The only guides to his conclusions are the plans he subsequently made for the Manchester-Liverpool Express Railway. The track for that was to be generally similar to that used at Tervueren, so he must have thought it had behaved satisfactorily. He

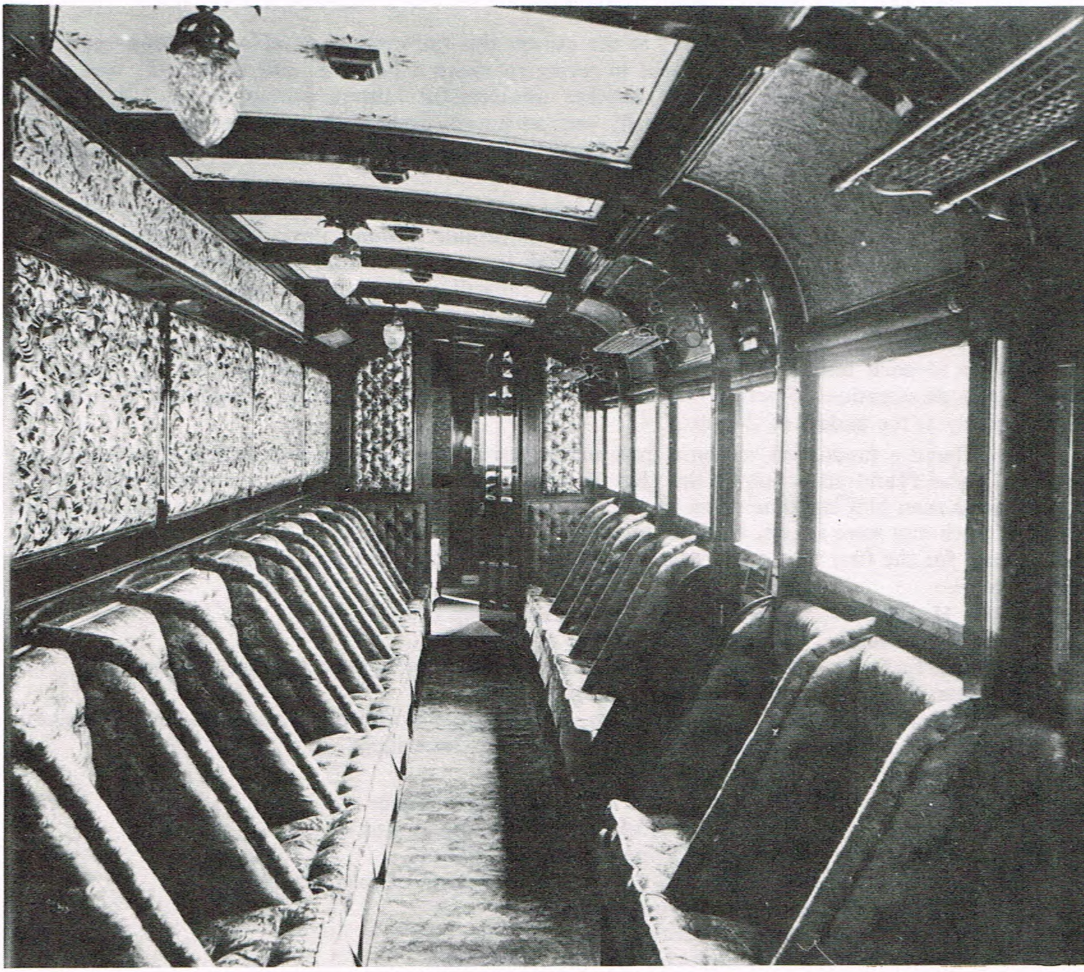


Fig. 11. Interior of one longitudinal compartment of Lightning Express car, 1897. *Courtesy of Gloucester R.C.&W. Co. Ltd.*

clearly concluded that the power-to-weight ratio of the vehicle was inadequate, for the planned new vehicles were to be of light alloy where possible, were to have roughly double the total horse-power for roughly half the number of passengers, and that was only for 110 m.p.h., not the original 150 m.p.h. Also he may have found his rather unusual bogie system too stiff, for the proposed new vehicles had a more conventional bogie system, and only two instead of four wheels per bogie. The louvre air-braking system could not have worked too well, for it was not proposed for the Manchester-Liverpool vehicles.

The press had never been very enthusiastic about the Lightning Express. The Belgian government had been interested in it as a possible means to a high-speed link between Antwerp and Brussels, and although their representatives spoke favourably about the demonstrations, the government authorities decided against adopting the system. However, Behr was apparently not discouraged, and pressed ahead with plans for the Manchester-Liverpool line. Before that scheme failed, he was also pushing a plan for a London-Brighton high-speed monorail link, but it came to nothing.[32] He continued promoting schemes at home and overseas for some years into the twentieth century.

THE MANCHESTER AND LIVERPOOL ELECTRIC EXPRESS RAILWAY

Getting the Act. Let it be repeated at the outset: this railway was never built. However, a very great deal of effort and money was spent in trying to make it possible, and F. B. Behr was at the centre of the activity. It was not just another unsuccessful railway promotion; it was to be a revolutionary railway, imaginative, technically very advanced, perhaps much before its time. It got the support of important people, it got an Act of Parliament. It got the opposition of the existing railways and it got the kiss of death from the Board of Trade.

Behr proposed a 34½-mile double line with one terminus in Deansgate, Manchester, and the other in Church Street, Liverpool. There were to be no intermediate stations. From Deansgate the line went to Barton, then just north of the Ship Canal, through Irlam to Glazebrook; then for most of its route it followed the line of the Cheshire Lines Committee railway to Garston, and finally to Church Street. Its one intermediate divergence from the CLC line was at Warrington, where it made a slight northwards loop round the town.[33] The line was to be generally more-or-less level, but there were to be steep gradients up to each terminus—1 in 25 at Manchester and 1 in 31 at Liverpool—this would help braking and acceleration. Traction was to be electric, with the generating station at Warrington, approximately at the middle of the route.

Behr found a favourable response from many business and professional men in Manchester and Liverpool, who found attraction in the idea of a train every ten minutes with a journey time of 20 minutes—less than half the time taken by the existing trains then or now. Committees under the Lord Mayor of each city were set up, and met together as a Joint Committee to consider detailed proposals and costings for the first time on 22 March 1899. The list of members is most impressive, including at Manchester:—

Sir W. H. Bailey	Director of the Manchester Ship Canal.
Sir J. J. Harwood	Lately Vice-President of the M.S.C.
I. Levenstein	Chemical manufacturer and Director of the Chamber of Commerce.

W. (later Sir W.) Mather of Mather & Platt Ltd.

The Deputy Lord Mayor and 3 Aldermen, Merchants, a stockbroker, a solicitor, an accountant, an engineer, numerous manufacturers, several Town Councillors

and at Liverpool:—

F. C. Danson	President of the Chamber of Commerce.
A. L. Jones	Chairman, Elder Dempster Shipping Ltd.
D. Cunningham	President of the Cotton Association.

The Chairmen of the Electrical and Tramway Committees of the Corporation.

The Electrical Engineer to the Corporation.

The Engineer to the Overhead Railway.

Other business men, a civil engineer, and the Town Clerk.

They set up a Joint Sub-Committee to make detailed studies, and met finally on 31 May 1899. The report of that meeting was printed and included the financial estimates.[34] These were effectively those produced by Behr and were detailed, but a summary is as follows:—

	£
Iron work and permanent way	406,237
Land and buildings	394,750
Bridges, culverts, earthworks	63,000
Laying line and fencing	20,659
Stations	40,000
Rolling stock—8 trains at £4,000 each incl. electrical equip.	32,000
Contingencies 10%	95,665
Engineering & admin. expenses	60,000
Patent dues, etc.	60,000
Interest during construction	45,000
Parliamentary expenses	50,000
Generating station and cables	220,000
Total	1,487,311

In the estimates of working expenses and receipts, it was clear that a profit was to be made. It was assumed that electricity could be generated and distributed for three-farthings (about £0.003) per unit and that 9.87 million units per annum would be consumed, making an annual cost for electricity of £32,000. The costs per train mile were estimated at 8.4d (£0.035), compared with 31 to 41d (£0.13 to 0.17) for ordinary railways.

Since the patent cover related mainly to the design of the 'trains' (which were, of course, single vehicles as now conceived), 'dues' of £60,000 for the patents covering trains costing a total of £32,000 seem at least adequate. Mr. Mather, presenting the sub-committee's report to the main committee, assured everyone that no member of the committee had any personal interest in the project, which was enthusiastically approved.

Evidently the next step was to form a company to push the project forward and get an Act of Parliament. The Manchester and Liverpool Electric Railway Syndicate Ltd. was registered on 18 October 1899 with an authorised capital of £40,000 in shares of £100. [35] The capital was increased to £60,000 in February 1902. The seven directors included three men who had served on the Joint Committee, among them W. Mather. Behr was Engineer to the Company.

This company promoted a Bill in the 1900 session of Parliament, and it came before the Select Committee of the House of Commons in May 1900. [36] Behr was supported by Ernest Gerard, engineer-in-chief of the Belgian State Railways, who thought the scheme was technically excellent and that 100–110 mph should be easily and safely attained (but the Belgian Government was not proposing to adopt the system); by S. B. Cotrell, engineer and general manager of the Liverpool Overhead Railway; by H. F. Parshall, designer of electrical plant for the Central London Railway; by W. Mather; and by no less a person than Dr. Edward Hopkinson, a well-known electrical engineer and consultant and brother of the famed John Hopkinson. Objectors were the District Council of Irlam, the Borough of Salford, the Garston District Council, the Mersey Docks and Harbour Board—all on environmental or land-utilisation grounds—and the Great Northern, Midland, Great Central, Lancashire and Yorkshire, and London and North Western Railways—on grounds of injury to their interests or danger to the passengers. The Committee decided it was a good scheme in principle, but were not satisfied that the proposals for braking from high speed were satisfactory, and considered that insufficient attention had been given to the interests of Salford and the Mersey Docks & Harbour Board. They therefore ruled that, 'the preamble of the Bill was not proved', i.e., the Bill was sent back for reconsideration. It was later stated that the promotion of this Bill in 1900 had cost the company £10,000.

Following this defeat, surely not unexpected, the company strengthened its technical support by enlisting Sir William Preece[37] as a consulting electrical engineer to the company. Preece was one of the best-known electrical engineers of the day, and supported the project by presenting a paper on it at the British Association meeting in September 1900.[38] Behr accompanied this paper by another on brakes and signals,[39] in which he proposed that a special block system of signalling be used, with signals controlled automatically by the trains.[40] The line would be divided into eight sections of 4.3 miles each. Each train leaving a terminus would set the signal to danger behind it, then another to danger at 4.3 miles as it passed, then another at 8.6 miles; as it passed this point it cleared the signal at the terminus. The next train would thus be at least 8.6 miles behind it, and normal operating timetables would be arranged to keep a spacing of 17.2 miles. Even in case of one train breaking down, the train behind it could not approach more closely than 4.6 miles without knowing it had to be prepared to stop. Cab signals were to be given so that operation would be possible in fog.

With this technical provision, and with small diversions to appease Salford and meet the docks requirements at Liverpool, a revised Bill was lodged at the end of 1900. The cost of construction, at £1,776,821, was slightly higher than before and considerably higher than the estimate of 1899. The capital of the proposed railway company was to be £2.1 million.

The Bill came before the Committee of the House of Lords in May 1901. Behr stated that there would be no goods traffic, the carriages were designed to seat 52, the weight of each motor was $3\frac{1}{2}$ tons, and 1500 hp could be used without slipping. Dr. E. Hopkinson had no doubts about the proposal. With 1500 hp, a speed of 110 mph could be attained in two minutes from starting, covering almost two miles. The retardation of 3 ft/sec^2 would bring the train to rest in 54 seconds and under one mile. The generating station at Warrington would supply at 10–15 kV, reduced to 1,000 V for the train. Major Cardew (Preece's consulting colleague) supported the proposal, explaining that there were two stages of braking, the first by using the motors as generators, the second mechanical. Other supporters were E. Gerard and A. Degraux of the Belgian State Railways, S. B. Cottrell of the Liverpool Overhead Railway, Sir W. H. Preece, Sir F. Bramwell (another eminent consulting electrical engineer) and Sir W. H. Bailey. Opposers included representatives of the railway companies and the local authorities *en route,* and the opposition was generally on a trivial level, typified by the Borough Engineer of Salford who 'regarded the mechanical details of the invention as absurd'.

With the assurance of the promoters that the centre of gravity of the cars would be at least 12 inches below the top rail, the Chairman (Viscount Falkland) announced that the Committee passed the preamble of the Bill and that the Bill should be reported to the House. The Bill came before the Select Committee of the House of Commons in July 1901, with Sir Lewis M'Iver in the Chair. Much of the discussion was as before, but a much stronger opposition was mounted, including an American, two Belgians, and a consulting engineer to the Paris Metro; representatives of the Cheshire Lines Committee, GNR, GCR, L & YR, and LNWR; W. P. O'Neill, Chief Engineer of the Midland Great Western of Ireland who had experience of the Listowel and Ballybunion Railway; and others. Littler, the K.C. for the CLC, raised malicious objections to Behr's past work, and asked: 'Do you know that the united capital of the five companies you are attacking is £150 million? If they were to run at half your rates, what would become of you?' The opposition was certainly strong in numbers, but it was weak in argument.

The Chairman said he regarded the scheme as something of an experiment. If it took traffic from the other lines, it deserved to and would benefit the public. If it did not, then the CLC would not be harmed. But it would be necessary to provide for Board of Trade approval of the plans and details of construction and maintenance, and for the conduct of experiments at the company's expense as the B.O.T. required. The K.C. for the promoters readily agreed to this, seeing the provision as eminently reasonable, and the Committee approved by a majority that the preamble of the Bill should be passed. Thus the company got its Manchester and Liverpool Electric Express Railway Act 1901, but with the clause giving the B.O.T. power to require experiments. It was a hollow victory for the clause was to prove lethal. A further Act in 1902 provided for a deviation at Salford.

Triumph turns sour. Behr and his co-engineer, R. Elliott Cooper, had much correspondence[41] with the B.O.T. officials during the months following the passing of the main Act in August 1901. They submitted drawings of the vehicles, stations, earthworks, signalling arrangements, etc. They intended to build the vehicles of a light alloy:

> Magnalium is an alloy of Aluminium patented in Germany . . . its specific gravity is not greater than pure Aluminium, though its tensile strength is more than three times greater, it is very tough, in fact very nearly as tough as steel.

The electric traction system was specified:

> Each car will be fitted with four continuous current traction motors, arranged in pairs, and working on two driving axles. Each motor will have a normal capacity of 160 HP at full speed of 720 rpm, but will be capable of giving at least 320 HP for short periods. Each motor will weigh $2\frac{3}{4}$ tons. The driving axles will carry the driving wheels of about 4 ft 4 in diameter, the speed of rotation being about 720 rpm, corresponding to 110 mph
>
> The average normal power required for running a 10 minute service is 2,000 kW at the car axles. . . .

On 13 January 1902 the B.O.T. wrote:

> we think that the B.O.T. need not raise any objection to the general type of permanent way, although, as the structural details require further consideration, the plans cannot yet be approved . . . *it is desirable that a section of the line be constructed in accordance with the plans . . . so that experiments may be made* . . . [present author's italics].

The company apparently agreed that a 7-mile section of line near Warrington should be built as soon as possible to satisfy the B.O.T. The *Liverpool Journal of Commerce*[42] saw the implications clearly:—

> It will be necessary to complete practically the construction of the generating station at Warrington, because the full electric current will be required, for it is intended to run trains on this section of the line at speeds up to 120 mph. The difficulties in the way of the promoters have been accentuated by the fact that the House of Commons Committee which passed the bill imposed the condition that

before the line was constructed the Board of Trade should give its approval to the plans of the promoters. The plans have practically been approved, but before the last word can be said on this matter, the officials declare that they require to be satisfied that the plans are more than theoretically correct. This situation absolutely prevents the promoters from issuing a prospectus and getting the capital for their undertaking. . . .

And when in July 1903 a prospectus **was** issued inviting applications for a capital of £2.1 million, so few applications for shares were received that no issue was made.[43] Evidently investors were not interested in a project which required a third to half a million pounds to be spent before knowing whether the B.O.T. would give their approval. Although the promoters and Behr did not give up, this was effectively the end. Whether the B.O.T. had killed the scheme by accident or design is not clear, but killed it certainly was.

The companies concerned. We have already mentioned the Manchester and Liverpool Electric Railway Syndicate Ltd., which was formed in October 1899 to get the Act of Parliament. As we have seen, it succeeded in this, and thus the Statutory Company, the Manchester and Liverpool Electric Express Railway Company, was created. The latter failed to attract any capital for reasons explained above, and virtually ceased to exist. The Syndicate had expended all its capital on promoting the Bills and by 1903 was bankrupt. It virtually sold its property—which consisted of agreements with F. B. Behr regarding the use of his patents—for £30,000 in shares in a new company, the Mono Rail Construction Company Ltd., which was registered on 23 May 1903 under a completely new management, with a nominal capital of £60,000.[44] The M.R.C.C. Ltd. also raised £20,000 in cash in 1903, and some more after the issue of a prospectus in December 1904, and it is thought that all, or most, of this money went to Behr in respect of his patent rights.

In July 1908, the Registrar of Joint Stock Companies was trying to find out the position of the Syndicate. The reply[45] of the former Secretary to the Company, T. Dundas Pillans, dated 30 July 1908, was very illuminating, and portions are quoted below:

The whole capital of the Syndicate was exhausted in the enormous expense of promoting the Bill in two successive sessions of Parliament, in the face of strenuous opposition of powerful railway companies, such as the London and North Western, the Lancashire and Yorkshire & the Cheshire Lines. Double fees to solicitors, counsel, engineers & other expert witnesses, absorbed the whole resources of the Syndicate, and left it in debt to the extent of some £5,000 besides. I may add that, besides this entire loss of capital, the Directors and some of the shareholders lost an additional sum of over £20,000 in connection with the Parliamentary deposit of Consols & in the payment of nearly £6,000 duty on the capital of the Statutory Company, which the government insisted on exacting in spite of the fact that not one penny of that capital was ever raised.

I have never received from the Syndicate any remuneration as Secretary, nor have the Directors ever received any fees. On the contrary they have incurred considerable expense in attending Board meetings, besides their loss as shareholders & guarantors of the Parliamentary Deposit.

The Syndicate and the Mono Rail Construction Company were both wound up about this time.

BEHR'S FINAL EFFORTS

Behr was a fighter, and after the failure of the Manchester—Liverpool scheme, tried hard to get the system adopted on various routes, particularly in America. Sadly he had no success there either, and it is believed that he retired from the struggle around 1907 when he was about 65; he lived another 20 years, long enough to see the demise of the Listowel and Ballybunion Railway of which he had been the first Managing Director.

Some general thoughts and questions. If the Board of Trade had given Behr a chance, would the era of high-speed rail transport have started 60 years or more earlier than it did and would Behr have then been regarded as the latter-day George Stephenson? One cannot answer this question, of course. Numerous business men and technical experts of the highest reputation supported Behr and no valid technical objection was ever raised to his plans. Similar ideas have since arisen from time to time. There was the Monorail Transporter for industrial sites in the 1940s,[46] with some resemblance to the early Lartigue system. Then in the 1950s there was the development of the Alweg system,[47] usually called a monorail but strictly a 'monobeam' system in which the train straddled a reinforced concrete beam on which it ran with pneumatic-tyred wheels and was guided by similar wheels at the sides of the beam. It has been generally recognised as a modern version of the Lartigue/Behr system. Its history is much the same—successful demonstrations, a few short commercial lines, ambitious large developments cancelled only at the last moment.

Clearly the straddle-type monorail concept is long-lived; 150 years so far. Yet it has never been successful. Is its persistence due to some inherent merit which either fails to be achieved or fails to command confidence? One can put technological developments into many classes including: *mainstream* (e.g. ordinary railways, telephones, turbines), *transient* (e.g. rigid airships), *rearguard* (e.g. steam locomotive development in the diesel era); is there also a class of *persistent unsuccessful?* Are there cases of such persistence being ultimately rewarded with success?

ACKNOWLEDGEMENTS

Several people have helped in my research by supplying references, photographs and other information. I would particularly like to mention Mr. D. A. Boreham, the Rev. E. Boston, Mr. D. H. Tew, and the Gloucester Railway Carriage and Wagon Co. Ltd. (per Mr. Simon Marshall). I would also like to acknowledge the facilities and staff of the Public Record Office, the House of Lords Record Office, and the Libraries of the Institution of Civil Engineers, of the Science Museum, and of the University of Birmingham.

REFERENCES

Abbreviation: PRO = Public Record Office

1. P.-H. Chauffourt et J.-L. Largier, 'Le monorail de Feurs à Panissières ou l'étonnante histoire du plus éphèmère des chemins de fer secondaires Français', *Chemins de Fer Regionaux et Urbains,* No. 164 (1981), pp.3–46. I am grateful to Mr. D. A. Boreham for letting me have a copy of his English translation of this work.
2. *Proceedings of the Institution of Civil Engineers,* Vol. **4** (1845), pp.6–8.
3. British Patent No. 4618 of A.D. 1821.
4. H. R. Palmer, *Description of a Railway on a New Principle. . .,* (London, 1823). 2nd edition, almost unchanged, 1824.
5. 'Suspension railway', *Mechanics Magazine,* Vol. **4** (1825), p.287.
6. M. J. T. Lewis, *Early Wooden Railways,* (London, 1970), pp.304–6.
7. J. L. Haddan, 'A pioneer railway for undeveloped countries', *Iron,* Vol. **9** (1877), pp.290, 325–6, and 388–9.
8. British Patents Nos. 1198 of A.D. 1875 and 2040 of A.D. 1879.
9. See, e.g., 'The Mont Cenis Railway', *Engineering,* Vol. **1** (1866), pp.7–8; Vol. **3** (1867), pp.284–6; and Vol. **5** (1868), pp. 598–600 and 620–1.
10. J. W. Wilson in discussion on paper by F. B. Behr, *Transactions of the Society of Engineers,* (1888), p.187.
11. F. J. Rowan, 'A one-rail or trestle system of light railway', *Transactions of the Federated Institution of Mining Engineers,* Vol. **19** (1898), pp.2–10 plus Plate 17.
12. A. G. Wells, 'American monorail', *Journal of the Irish Railway Record Society,* Vol. **4** (1956), pp.135–6; and J. R. Day, *More Unusual Railways,* (Muller, London, 1960), pp.96–99.
13. French Patent No. 149, 301 dated 31 May 1882; British Patent No. 2764 dated 12 June 1882.
14. F. B. Behr and G. Petit, *The Lartigue Elevated Single Rail Railway,* (London, 1886); reprinted as *The Compleat Lartigue* by the Merioneth Railway Society, 1982.
15. Described in Ref. 14; also in 'The Lartigue railway', *The Engineer,* Vol. **62** (1886), pp. 223 and 225; and F. B. Behr, 'The Lartigue single-rail railway', paper presented on 4 Oct. 1886, printed in *Transactions of the Society of Engineers,* (1888), pp.163–192.
16. A. T. Newham, *The Listowel and Ballybunnion Railway,* (Oakwood Press, Lingfield, 1967).
17. D. G. Tucker, 'The Listowel and Ballybunion Railway: some revisions and additions to its story', *Journal of the Railway and Canal Historical Society,* Vol. **28** (1984), pp.2–13.
18. For the angry reaction against level crossings when the L.&B.R. first opened, see correspondence in PRO, ref. MT6/476/2.
19. The main proposal in Britain was for the Lynton Railway, and the Lynton Railway Act of 1886 provided for the railway from Filleigh (on what was effectively the G.WR.) to Lynton to be built on the Lartigue system; it was, however, not proceeded with. A 17-km Lartigue line was actually built in France in 1894–5 but it was a failure; Behr had had nothing to do with it (see ref. 1). An interesting mountain railway of

44 km with a maximum gradient of 33%, using rack rails, was built on the Lartigue system from Chilecito to Famatina in the Argentine, but little is known of it (see 'The mono-rail or elevated single-rail railway', *The Indian Engineer,* Vol. **20,** Special supplement, 2 June 1894).

20. Report in *The Electrician,* Vol. **45** (1900), p.147.
21. F. B. Behr, *Lightning Express Railway Service: 120 to 150 miles per hour,* (London, Sept. 1893). Copy in Library of Institution of Civil Engineers, Tract 4to, Vol. **122,** item 10.
22. F. B. Lea, 'The possibilities of high-speed electric traction', *Railway World,* Vol. **2** (1893), pp. 649–51.
23. Described more fully in British Patent No. 13, 996 of A.D. 1893.
24. British Patent No. 16, 643 of A.D. 1895.
25. British Patent No. 27, 549 of A.D. 1896.
26. British Patent No. 3610 of A.D. 1902.
27. Evidence to Select Committee of House of Commons, 5 May 1900; reported in *The Electrician,* Vol. **45** (1900), p.147.
28. 'The Behr monorail system', *Engineering,* Vol. **63** (1897), pp.784, 788, 808–9, 815, 849, 854, plus a two-page plate.
29. 'The Behr monorail railway at the Brussels Exhibition', *Engineering,* Vol. **64** (1897), pp.40–41.
30. E. K. Scott, 'Brussels International Exhibition', *Electrical Engineer,* Vol. **20** (1897), pp.262–4.
31. *Electrical Engineer,* Vol. **20** (1897), p.257.
32. *The Electrician,* Vol. **48** (1901–2), pp. 29 and 991; Vol. **49** (1902), p.1018; Vol. **50** (1902–3), pp.203 and 500. Also *The Railway Engineer,* Vol. **23** (1902), pp.129–130.
33. Deposited plans, Manchester and Liverpool Electric Express Railway Bill, 1901.
34. 'Proposed Electric Express Railway between Manchester and Liverpool', *Proceedings of the Joint Committee formed for the purpose of Investigating and Reporting,* Liverpool, 1899. Copy in Library of the Institution of Civil Engineers, Tract 4to, Vol. **126,** item 2.
35. PRO, ref. BT31/8733/63881.
36. Minutes of Evidence on Opposed Bills, House of Lords Record Office; an adequate record of all the Committee proceedings was published in *The Electrician* for the dates concerned.
37. See D. G. Tucker, 'Sir William Preece (1834–1913)', *Transactions of the Newcomen Society,* Vol. **53,** (1981–82) pp.119–138.
38. Sir W. H. Preece, 'The Manchester and Liverpool Express Railway', reprinted in *Electrical Engineer,* Vol. **26** (1900), pp.381–2.
39. F. J. (sic) Behr, 'Manchester and Liverpool Railway: Brakes and signals', ibid., p.382.
40. British Patent No. 16, 117 of A.D. 1900.
41. PRO, ref. MT6/1882/2.
42. *Liverpool Journal of Commerce,* 3 Nov. 1902.
43. *The Electrician,* Vol. **51** (1903), p.605.
44. PRO, ref. BT31/10307/77484.
45. PRO, ref. BT31/8733/63881.
46. *The Engineer,* 9 Dec. 1949; 29 May 1959.
47. *The Engineer,* Vol. **194** (1952), pp.871–2; *Railway Magazine,* Vol. **103** (1957), pp.148 and 663–4; Vol. **104** (1958), p.262; *Railway Gazette,* Vol. **106** (1957), pp.62 and 68–9; Vol. **110** (1959), p.125; Vol. **113** (1960), p.589; Vol. **115** (1961), p.461; Vol. **116** (1962), pp.216 and 304; Vol. **119** (1963), p.258; Vol. **121** (1965), pp.187–9 (8-mile system at Tokyo); Vol. **126** (1970), p.502; *Modern Transport,* 29 Oct. 1960, p.3.

DISCUSSION

Mr. E. F. Clark opened the Discussion by raising a point regarding the vertically boilered locomotive first used on the demonstration line in Westminster; with the boilers slung well down on either side of the track what arrangements were made to ensure that the water level was the same in each? Regarding H. R. Palmer's railway, Mr. Clark had realized that the line at the Deptford Victualling Yard had been built just before the period he was studying for a forthcoming paper on the London Dock extension works; he had accordingly extracted from G. P. Bidder's diary the entries which appear to relate to the project commencing May 1826:

2nd Rose at seven. Went to Deptford and waited for the arrival of the goods until Mr. Palmer came down when I returned to Town with him and dined with Miss and the Messrs Hawkins and attended the Society.

6th Went to Deptford with Mr. Palmer and made arrangements for commencing operations at the yard

8th Rose at six. Breakfasted at Deptford. Levelled and marked out the line of Railway.

9th Rose at four. Went to Deptford Setting up posts.

10th Do Do Do.

11th Do Do Do. Came to Town in the afternoon and dined at the London Coffee House with the Institution and got queer.

16th — finished setting up the posts.

17th — commenced ramming and grouting.

20th — concluded the grouting.

22nd Rose at five. Commenced the ramming of the holes.

23rd Do Do Do got very queer with Merritt.

24th Rose at four. Finished ramming the posts.

25th Do Do engaged on fitting the planks and commenced the Gate Posts.

26th Do Do fitted a Gate.

29th Rose at five. Went to Deptford Poured with Rain got leave of Captain Hill to allow them work through the afternoon. Slept at Deptford.

30th Rose at six. Fixing Gate Posts.

31st Rose at four finished setting up the Gate Posts and placed the Carriage in its birth.

June 1st Rose at four commenced fixing the Rails and finishing the Gates.

2nd Rose at four fixing the Rails and Chipping also finishing the Gates.

3rd Rose at four. Finished the Rails, completed the Wedgings, commenced chipping the Rails also securing them and fixing the Gates.

10th —finished scouring and worked the Carrier.

12th Rose at four. Went to Deptford and worked the Carriage also got the stage completed.

13th Rose at four. Working the carriage.

14th Do and commenced making a Platform for the upper end of the line.

15th Do and completed the Platform.

16th Rose at Seven. Capt Hill treated me with great indignity and took the carriage into his own hands and worked the Carriage with five men against ten on his skids and although it was worked in the most imperfect manner yet in taking up forty Casks from the Pickle Yard to the Wharf including loading and unloading and also in Bringing the same Back they took 29 min. and our men only took 8 min. more. At twelve General Stapleton when having two men to load also two to unload and three to work the Carriage, we took to the Wharf 104 Casks in 35 min. while seven men on the Skids required 57½ min. Our men were fresh to go on theirs were worn out—after paying the men returned to Town in Mr. Palmer's Gig dined with him and got queer.

21st Rose at six. Went to Cheshunt and examined Railway there.

Clearly Bidder did most of the work on site. This must have been because Palmer was starting work at the London Docks and had no time to do so himself. The line cannot have been a very long one; it only took a short time to build, while the brief descriptions of the trials imply something quite short. The illustrations made it look as if the posts were cast iron. It was not surprising to find Palmer paying attention to wheel and rail profiles. It should be remembered that he was appearing about this time before the Parliamentary Committee considering the second Liverpool & Manchester Railway Bill. He gave evidence (against the Bill) on the resistance to motion with various modes of transport. He had conducted special experiments for the purpose and Bidder noted in his diary 'making measurements on the City Canal for him'. Another earlier diary entry showed that Bidder had made a perspective drawing of a carriage. An entry for 2 November 1824 '. . . visited Mr. Palmer's railway and Mr. De Ville's collection of busts. . .' implies that the Cheshunt line was already built by then unless Palmer had built a short demonstration line somewhere in the London area.

Prof. Tucker replied that in the Westminster locomotive there was a pipe linking the two boilers to ensure that the water levels were the same. Mr. Clark's extract showed that the Palmer monorail was a very efficient way of moving goods. The Bidder diary suggests that the Cheshunt railway was in operation in November 1824. Previous accounts mention 1825 and this was the only published date for the Cheshunt line.

Mr. J. D. Blyth gave some information about the French Lartigue railway of 1894–95 some 16 km long, of which slides had been shown by Prof. Tucker. The two locomotives were built by a local firm, F. Beatrix, of St Etienne and as far as Mr. Blyth knew this may have been a source of trouble. The locomotives were larger than the Listowel-Ballybunion ones but they did not have a tender; the coal and water were probably carried on the locomotive. They were four wheeled locomotives and probably all four wheels were driven. The Listowel-Ballybunion locomotives had three driven wheels on the locomotive and two on the tender so they were almost 0-5-0s. It is surprising that a line which was such a complete disaster (it was closed before it could open) should have attracted commercial photographers. The test running on the line is stated to have gone on for a period of at least 2½ years and it was only after this that they ran a train on a continuous journey from one end of the line to the other. The line is not completely unrecorded in this country for P. B. Whitehouse's 'Narrow-gauge Railways in Europe' has a copy of one of the photographs and a short paragraph in one chapter. The German tests on the Alweg system outside Cologne (which Mr. Blyth travelled on in a test train in 1959) had rubber tyred wheels running on a concrete beam giving very impressive accelerating and braking. As Prof. Tucker said, it did not catch on except at Sao Paulo and the only one still in existence is the half-sized one in the Disneyland Amusement Park in California.

Dr. D. de Cogan said that he believed that the Listowel-Ballybunion monorail closed immediately after it had carried away the last parts of the Marconi radio station at Ballybunion. Prof. Tucker believed that the literature had not mentioned that story and Dr. de Cogan said that his source was the Curator of the Dublin Broadcasting Museum.

Col K. Cantlie said that when he was a child he went on the Brennan monorail in 1910. The track was very much cheaper than the Lartigue one yet Brennan never managed to get his proposal accepted. This suggests that it is unlikely that Lartigue could have done so. Prof. Tucker replied that the reason for the lack of success of the Brennan proposal was probably that the public distrusted the gyroscopic principle. The only monorails that seem to have had as much success as the Lartigue one have been suspended ones. Proposals for new monorails appear every year or so; **Mr. N. New** had sent Prof. Tucker particulars of the Pendair system; this was an air suspended system which used rubber tyred wheels running on a concrete beam to provide traction—why should it then have been air suspended?

The President asked whether there were any comments about the curvature that the High Speed Train could negotiate? **Mr. Carpenter** thought that 125 mph could be maintained over a curve of not less than one mile radius. Prof Tucker said that Behr was hoping to get his monorail trains round 35 chain radii and he did run them round a 25 chain curve at more than 75 mph. A visitor asked whether the effects of centrifugal force on the passengers' wellbeing would have been uppermost in the official mind? Prof. Tucker doubted whether that had ever been questioned by the Board of Trade, certainly not according to the published literature.

Mr M. T. Tucker said that some years ago a development scheme had been studied in Cambridge using massive concrete beams and linear motors. It appeared that one difficulty would have been in making everything to a sufficiently small tolerance. This brought him back to the fact that the massive structure supporting the train was the prime objection. Were there any proposals which had the track on the ground? Prof Tucker replied that he did not know of any. He thought that the Cambridge project did not fail because of technical reasons but because the Government would not put any more money into it.

Mr. J. A. Williams said that the plans for the generating station must have been well advanced because when he was a pupil at Newton Chambers they used to generate electricity from blast furnace gas and the generators were D.C. because they could never rely on a constant supply of gas. The generating station had National gas engines driving D.C. generators and just before Mr. Williams arrived they had changed their works manager. The previous works manager had acquired a large 12 cylinder gas engine and he was looking for a cheap generator for it to drive. There was a generator not connected to the gas engine in the power station and Mr. Williams was told that it had been intended for a high speed electric line between Liverpool and Manchester. Prof. Tucker interjected that the power station was to have provided an A.C. supply and there were to have been rotary converters at the sub-station and D.C. motors on the trains. Mr. Williams commented that the generator he had mentioned might have been a generator for one of the sub-stations.

Mr N. D. New said that some years ago he had constructed a switchback for a local Scout group which used a similar rail system to prevent derailment.

The President called on **Mr. D. H. Tew** who said that the Meeting was extremely indebted to Prof. Tucker for a most interesting Paper. He had once read an article by a man who had been on the Listowel-Ballybunion railway who had met there a French family who looked as if they were going to the seaside and they said that they were going to Ballybunion Plage! Mr. Tew proposed that the Meeting should give Prof. D. G. Tucker a hearty Vote of Thanks for his Paper and this was passed by acclamation.

CORRESPONDENCE

Mr. D. R. Carling subsequently wrote; From memory I think that there was a short Palmer monorail from a quarry to the River Ouse at Offam, just north of Lewes, the first railway in Sussex. The use of the term bogie for the undercarriage of a vehicle was regular tramway practice even when there was no pivot at all as on a four-wheeled tramcar. Certainly most of the so called monorails had more rails than a normal railway. Beside the suspended type, of which the German Wuppertal line is the best known example, and the Brennan experimental gyroscopic line, there was another experimental gyroscopic line at Tsarskoe-Selo in Russia, but the financial crisis of 1922–3 prevented more than 7 of the proposed 20 miles being completed. (*The Gyroscope: Its Practical Construction and Application.* E & F. N. Spon, London 1924). There were also the Patiala State Monorail in India, on which the vehicles were stabilized by a single road wheel on an outrigger on one side, and the Lisbon Tramways, on which they had an outrigger with a road wheel on each side. Both these last two were in service for many years working at low speed.