THE CITY & SOUTH LONDON RAILWAY ELECTRIC TRAIN
3 – LOCOMOTIVE DEVELOPMENT

by Piers Connor
with Printz Holman

SLOW PROGRESS

After months of trials and experiments on the City & South London Railway (C&SLR), things moved very gradually towards the opening. The company, with technical assistance from Grindle, Spagnoletti and the Hopkinsons, had been through more than a year of prototyping between placing the order for locomotives with Mather & Platt in January 1889 and making the final decision on the design for the production locomotives in February 1890. The production run (locomotives Nos.3-14), were all built and delivered to London during 1890. There was no rush for them, since the railway wasn't ready but the company was feeling confident enough to arrange several visits during March 1890 with trips along the line for various worthies, including the Mayor of London[1]. Eventually, once construction was substantially complete, the line was opened officially by the Prince of Wales (later to become King Edward VII) on 4 November 1890. After some further prevarication, it opened to the public on the 18 December 1890 with a planned 10-minute service up to 08.00 and at 5-minute intervals from then onwards.

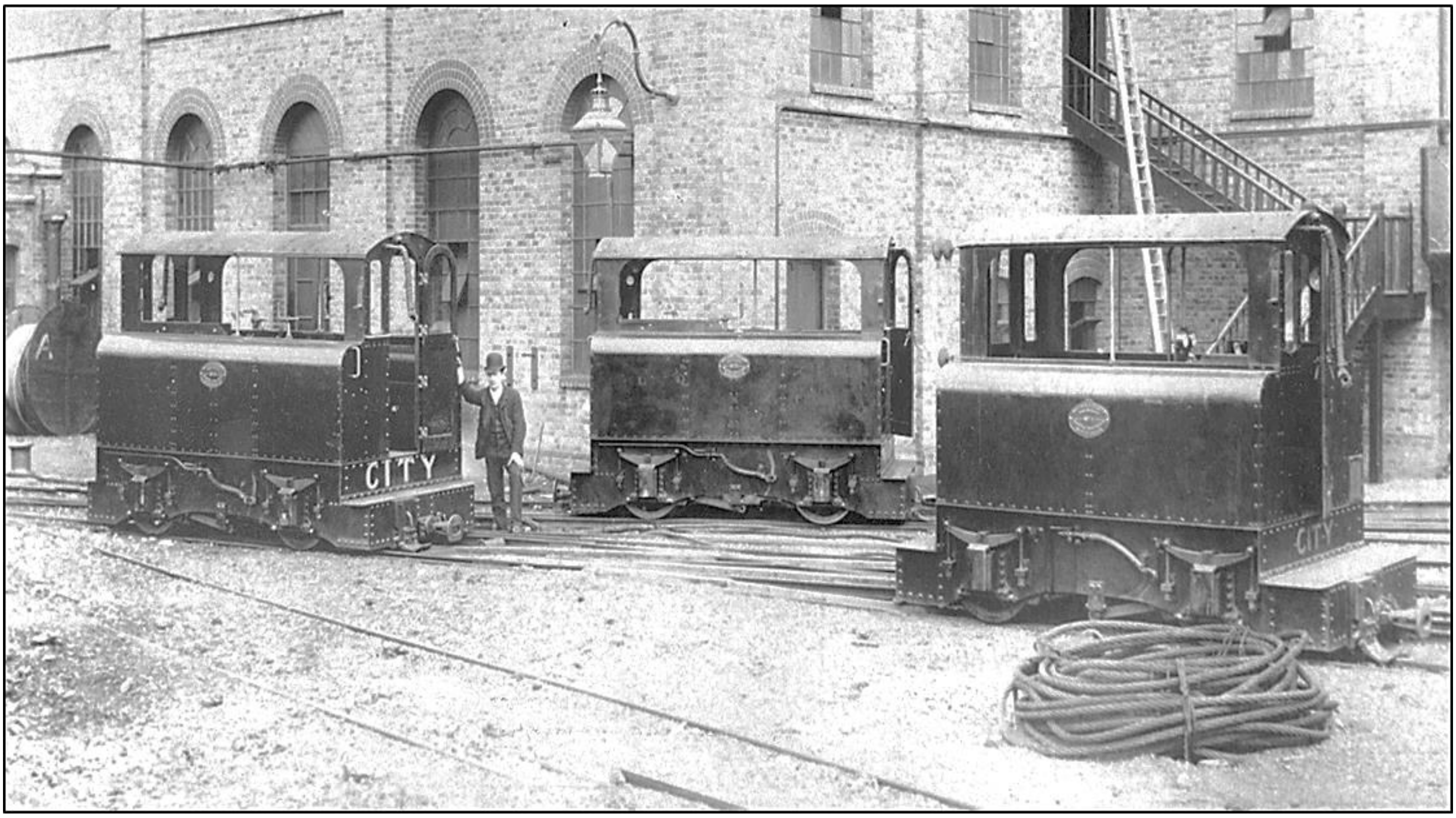

Figure 1: Three of the Mather & Platt locomotives in the yard at Stockwell, from left to right, Nos. 6, 11 and 1. Nos. 6 and 11 were part of the main production run but No. 1 had a shorter body than standard. This can be seen because of the longer step plate over the headstock at each end and the ends of the body relative to the axlebox suspension springs. No. 1 wasn't used regularly in service largely because it was too short to allow the crew to work effectively. Photo: LT Museum

There were immediately considerable difficulties. From day one they were almost overwhelmed by both the volume of passengers and a number of technical issues. The technical troubles started with the carriages being overweight. They came in at 7 tons each, way over their specified weight of 4.25 tons and this caused problems with the performance of the locomotives.

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1 T.S. Lascelles records that the Mayor's trip was seriously disrupted when the power supply was shut down because someone turned off the water supply to the generating set. This was the temporary generator at Borough.

The situation was aggravated further by the inadequate power supply. The locos met the specification but, because of the excessive train weight they appeared to be underpowered. Also, as the trains were not expected to carry more than 100 persons each, they were somewhat embarrassed by finding that loads regularly reached 200 passengers. The line was quickly becoming a victim of its own success.

During early tests, it was discovered that Loco No.1 was too light so the production locomotives were designed to be around two tons heavier to improve adhesion[2]. This change was rendered ineffective by the overloading of the trains, causing the locomotives to suffer wheelslip, which led to the armatures overheating and their insulation getting damaged[3]. It was also reported that the original windings were too small and that the armatures sometimes shifted on the axles. T.S. Lascelles, in his book[4], suggests that changes to the armature windings helped reduce the motor problems. I suspect this solution provided some increase in power too.

The current supply issue was already a known problem and, in order to reduce the load on the generators at Stockwell, stations had been equipped with gas lighting instead of the originally proposed electric lighting. As we noted last month, within two years of the opening, an additional generator had been installed at Stockwell to try to overcome the power shortage at peak times.

DEVELOPMENT

Being a pioneer in the field of electric traction and needing to improve its efficiency and reliability, the C&SLR quickly realised that work was needed to develop the system technically. To help them, they took on one of Mather & Platt's engineers after they had installed the electrical equipment and delivered the locomotives. His name was Peter McMahon, an Irish born electrical engineer (see box).

McMahon was initially appointed as the C&SLR's Assistant Engineer with responsibility for electrical equipment and he spent much of the first ten years of the line's operation trying various ways of improving the power supply and locomotive performance, and of reducing failures. Looking at how he did this and how the line's locomotives were improved over the years, provides us with an interesting insight into the way electric traction evolved during the late 19th Century.

PETER VALENTINE McMAHON

Mr. Peter Valentine McMahon, to whom we owe much for the information about the C&SLR electrical systems he described in his two papers to the Institution of Electrical Engineers (IEE, now the IET), was born in Ireland in 1868. After an apprenticeship there, he came to London and studied electrical engineering. After short spells in jobs in London and Ireland, in 1890 he became resident engineer for Mather and Platt during the equipping of the C&SLR. When the line opened, he got the job as assistant engineer to the C&SLR and in 1896, when Basil Mott retired, McMahon succeeded him as company engineer.

His two papers to the IEE were "Electric Locomotives in Practice, and Tractive Resistance in Tunnels" (Journal I.E.E., 28, p.508) 1899, and "City and South London Railway; Working Results of the Three-Wire System applied to Traction" (Journal I.E.E., 33, p. 100) 1904. Both provide much interesting information about the railway and the development of its electrical systems on the trains and the power supply.

When the C&SLR was absorbed into the Underground group in 1913, he took command of the Lots Road power station and in 1927 he became Assistant Chief Electrical Engineer to the Underground group. He retired in 1933 and died in 1940, aged 72 years. *Source: IEE Obit.*

DESIGN ISSUES

A big issue for the M&P locomotives was mechanical problems with the motors. According to McMahon[5], "The chief source of trouble in service was the failure of the armature winding due to its shifting on the core, thereby causing short-circuiting and burning-out". Preventing this would have required some sort of modification to secure the armature, probably by fitting collars round the axles, as was done on some American designs, although not always successfully. We don't know if this was done for the M&P locos but the answer eventually proved to be longer armatures with built-in end shields. We also know that the original armature windings themselves were not entirely suitable

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2 *Electrical Engineer* 12 December 1890 p.523
3 Reckenzaun, A. (1892), 'Electric Traction on Railways and Tramways', London: Biggs and Co., p.133.
4 Lascelles, T.S. (1955), The City & South London Railway, Oakwood Press.
5 McMahon P.V. (1904) "*Working Results of the Three-Wire System applied to Traction*" (Journal I.E.E., 33, p.100).

for the work they were expected to do and the motors were rewound to improve performance as well reliability[6].

Experience in service eventually showed that it was necessary to remove the armatures on each locomotive once a month so they could be inspected and re-varnished if necessary. Gradually, with these regular inspections, things began to settle down and eventually it was found that rewinding could be done at intervals of 100,000 miles or two years running. As a comparison we can note that, in the 1950s, motors that had been built in the mid-1920s for the Underground's Standard tube stock were running for over 25 years without rewinding[7].

CONTINUOUS IMPROVEMENT

Loco. No.	Built	Builder	Body	Electrical Equipment	Developments
1	1898	M&P	Beyer-Peacock	M&P	Short body. Not normally used in service. Weight about 8.4 tons. No side windows.
2	1890	M&P	Beyer-Peacock	M&P	Geared motors. Not normally used in service. Had the standard 10ft body length used on all subsequent batches.
3-14	1890	M&P	Beyer-Peacock	M&P	First production batch; weight 10.35 tons. Body width 6ft 2ins. No side windows. Gearless Gramme wound motors. Nos.3-12 rebuilt with new geared motors 1904-07. Side windows added to rebuilt locos.
15-16	1891	Siemens	Hunslet	Siemens	Drum wound motors, weight increased to 13.5 tons. First locos with curved sides, width now 6ft 9½ins.
17	1893-1896	C&SLR	Hunslet?	?	Built at Stockwell. Modified Gramme wound motors, 11.6 tons. Side windows provided. Body width 6ft 3ins.
18	1897	Crompton	?	Crompton.	Body narrower than underframe. Wheel diameter increased from 27" to 31" and wheelbase probably 5'-6". New design off compact motors. Low floor. Compressor. Series-parallel motor control.
19	1898	Electric Construction Co.	Hunslet?	Electric Construction Co.	31" wheels and wheelbase probably 5'-6". 4-pole motors with slotted armatures, drum wound. Series parallel control and compressor. Weight 12.25 tons.
20	1898	Thames Ironworks	Thames Ironworks	?	As No.19 but with some improvements to the motors.
21	1898-1899	C&SLR	Hunslet	C&SLR?	Built at Stockwell. Flat floor, 31" wheels, confirmed 5ft 6in wheelbase, body width 6ft 10ins. 4-pole motor with field windings on side poles only. Series parallel control. Weight 12.25 tons.

[6] In a board report of February 1892, the chairman reported that they were getting 20,000 miles between locomotive failures in service, a record that some of our railways today would be pleased to get with their brand new trains. (Street Railway Journal, March 1892, p.130).

[7] Bruce, J.G., (1955). The overhaul and maintenance of direct-current traction motors. *Journal of the Institution of Locomotive Engineers*, *45* (243), pp.98-135.

22	1900	C&SLR	Hunslet	C&SLR?	As No.21.
23-32	1899-1900	Crompton	Hunslet	Crompton	Design similar to Nos.21 & 22.
33-42	1900-1901	Crompton	Hunslet	Crompton	Curved lower sideframe profile, otherwise as Nos.23-32.
43-52	1901	Crompton	Hunslet	Crompton	Last batch.

Before describing the C&SLR's locomotive development in detail, it is worth looking first at a summary of the locomotives the railway acquired following the delivery of the Mather & Platt (M&P) order and at what changes took place as each batch arrived. Including the original batch of 14 M&P locos, the C&SLR eventually had a total of 52 locomotives. The various batches are listed in Table 1 below, together with a brief summary of the known developments.

Table 1: Electric Locomotives of the C&SLR 1890 – 1923.

Shortly after opening to the public in December 1890, the C&SLR realised they had to improve the service and get better reliability, so it was decided to buy two additional trains. Six carriages were ordered from G.F. Milnes in March 1891 and a couple of months later, two locomotives from Siemens. It is possible that Siemens were chosen because the C&SLR's relationship with M&P had deteriorated somewhat since the opening of the line. The guaranteed cost of operation that M&P had signed up to as part of their original contract had not always been met and it became the subject of contention between them and the C&SLR, along with the problem of armature failures. It's possible that these last two facts are the reason why M&P never built any more locomotives for the company. Siemens are reported as offering some advice on the armature failures around this time. Perhaps their knowledge of the issues encouraged them to offer a good price together with technically improved motors. We don't know for sure but the order was confirmed in May 1891[8] and the locomotives, Nos.15 and 16, entered service in August and September 1891 respectively. They had two 2-pole traction motors that were similar to those provided for the original Mather & Platt machines but the improved armatures differed in that they were 'drum wound' rather than 'Gramme wound'.

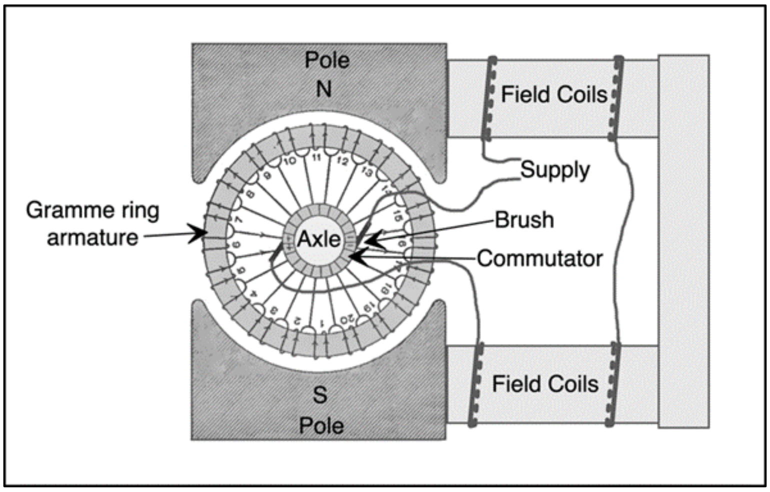

Figure 2: A simplified schematic of a Gramme motor with a ring armature. The armature is built round the axle but insulated from it. The insulated wires wound round the armature ring are each connected to the commutator. The brushes (two in this case) rubbing against the rotating commutator, connect the armature wire loops with the field coils. In this way, the armature is connected to the field 'in series', giving us the 'series wound motor'. The field coils magnetise the poles. The motor shape forms a resemblance to the traditional horseshoe magnet. Drawing adapted by author from 'Armature Windings of Electrical machines' Parshall & Hobart, D. Van Nostrand Company, New York, 1895.

The difference between the two methods of armature winding was important. The Gramme name came from Zénobe Gramme, a Belgian electrical engineer who is today regarded as the inventor of the first viable dynamo and who also discovered that his design could be used as a motor as well as a generator. His motor had an armature built in the form of a large ring that rotated between the magnetic poles (Figure 2). It worked but the winding of the wires round the rings prevented the full efficiency of the motor from being achieved and an alternative method of armature construction, developed by Siemens, used a drum as the core with the wires wound lengthwise along the drum (Figure 3). The Gramme system was used on the Mather & Platt locomotives but the new Siemens locos had the drum wound system.

8 BTHR, CSL 1/2, p.137.

In December 1891, just a year after opening, the C&SLR ordered 6 new armatures from M&P, doubtless to augment their existing spares holding in the light of the failures and the need for regular rewinds. From early on, McMahon saw the need to upgrade the electrical performance of the railway and, amongst other things, he looked for ways to improve the design of the locomotives. He was also experimenting with alternative windings on the original armatures to try to get better performance and reliability.

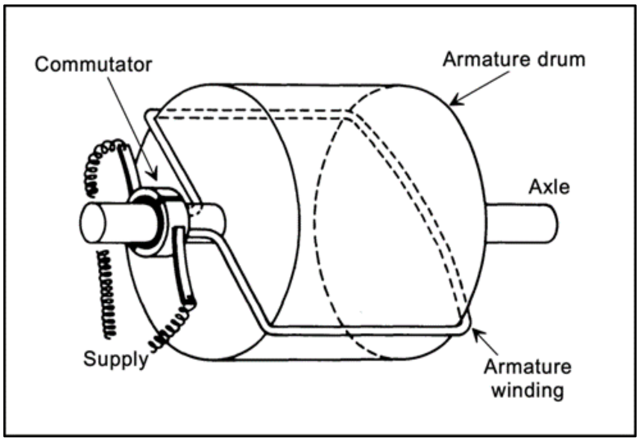

Figure 3: A schematic of a drum-wound electric motor. The main difference between this and the Gramme design was that the windings were all on the outside of the armature core, instead of being wrapped around a ring. Only one armature winding is shown here but there were actually lots of them. The drum proved to be a more efficient design electrically and soon became the standard for most electric motors. The poles and field coils are not included in the diagram but the brushes and commutator are shown. Drawing adapted by the author from Milne, A.G., (1971), January. IEE Power Division: Chairman's address. Let there be light. Proceedings of the Institution of Electrical Engineers (Vol. 118, No.1, pp.89-98). IET.

The two new Siemens locos (Figure 4) were the first to be built with the curved bodysides, which increased the body width from 6 ft 2 ins to 6 ft. 9½ ins. However, they were not entirely satisfactory. They were over 30% heavier than the M&P locos and, despite their more modern, drum wound motors, their performance was not as good as the original Gramme equipped machines[9]. McMahon wanted something better and, in April 1893, he persuaded the board to let him get started on building a new loco[10] in the C&SLR workshop. He took his time, largely I suspect because he was otherwise occupied both with the fire-fighting needed to keep the existing service going and, the following year, with a new project, the development of a motor car train.

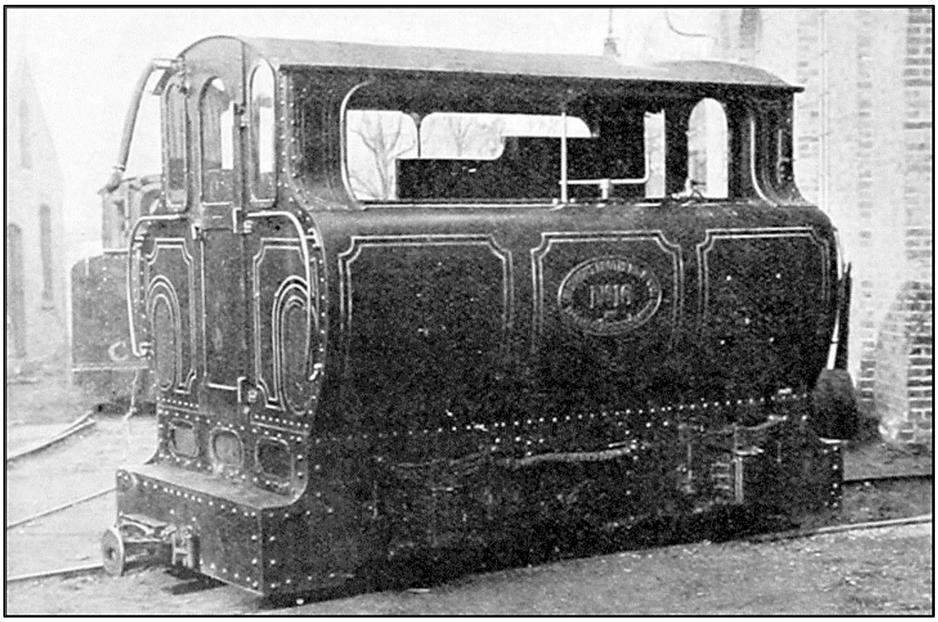

Figure 4: The next stage in the development of the C&SLR locomotive. This is a photo of Siemens Loco No.16, one of two the company supplied in 1891. This was the first example of the curved sides that were adopted on all subsequent builds. The Siemens locos were also unique in having the double lining for the decorative panels. Note also the ventilation grills in the body end both sides of the doorway and in the underframe over the headstock. Motors tended to get very hot in those days. Note the high control board in the cab, which seems to have been unique for these two locos.

Photo: LT Museum

A CHANGE OF DIRECTION

As I described in Article 1 in this series, when electric traction was first considered for the C&SLR, it was intended to operate 4-car trains with electric motors mounted on the leading and rear bogies. Space for traction equipment and a driving cab was to be provided at each end of the train. The rest of the train would be available for passengers. The motor car concept was most likely based on the vehicle used on the Bessbrook and Newry Tramway in Ireland.

Mather & Platt, in their proposal of May 1888, considered this too difficult and offered a locomotive hauled three-car train instead. Eventually, their suggestion was accepted but the idea that a motor-

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9 McMahon, P.V., 1899. 'Electric locomotives in practice, and tractive resistance in tunnels, with notes on electric locomotive design.' *Journal of the Institution of Electrical Engineers*, *28* (141), pp.508-607.

10 BTHR, CSL 1/3. m. 138.

car train would be better never really went away and, in February 1894, McMahon offered the board a set of drawings showing a design for a "new motor car and train"[11]. McMahon was allowed to proceed with the idea and, as we will see in a future article, considerable effort was put into building and testing it. However, in the end, it wasn't thought to work well enough to be adopted for the future and, sometime during late 1895, the project was abandoned.

The motor coach train work diverted resources away from other development work and the new locomotive authorised by the board in 1893 actually took three years to appear in service. I doubt much was done on it until late in 1895. It was to become No.17. Although I have no firm evidence, it is possible that the motors came from M&P, especially as they were recorded as Gramme wound[12], and it is probable that the body was supplied by Hunslet. It finally entered service in 1896. One feature of this loco that was different from the Siemens locos was that, although it had the curved bodysides, the width was only 6 ft. 3 ins. compared with the Siemens width of 6 ft. 9½ ins. Otherwise we have little to tell us what other improvements were made.

TRIALS

In October 1896, civil engineering work started on the northern extension of the line to Moorgate. This included by-passing the original, cramped City terminus at King William Street. Further extensions to Clapham and Islington were in planning. To provide services on the lengthened railway, the company would need more trains and it planned to increase their lengths from 3-cars to 4-cars as well, so it needed more efficient locomotives to haul them. McMahon prepared for this by conducting a series of trials and experiments.

The trials were carried out between mid-1896 and early 1899, starting with Locos Nos.12, 15 and the newly completed No.17. Towards the end of this period, Loco No.3 was drawn in to the testing too. McMahon recorded the details of the locomotives used and the results of his trials in a paper to the IEE in May 1899[13].

In his paper, McMahon records that the standard arrangement on the line's locomotives was to have the two motors wired permanently in series. This somewhat restricted the top speed and the possible power but the benefits of series-parallel control that most electric traction systems adopted in later years was already understood. It had been patented as early as 1881 by Dr. John Hopkinson, who was then working as consulting electrical engineer to Mather & Platt, but it was not used on the C&SLR for their early machines largely, I suspect, because of the low speeds expected and the additional complication needed for the power controller. However, McMahon thought that it would prove beneficial for the more powerful locomotives required for the upgraded service, so he decided to try it first on Loco No. 3.

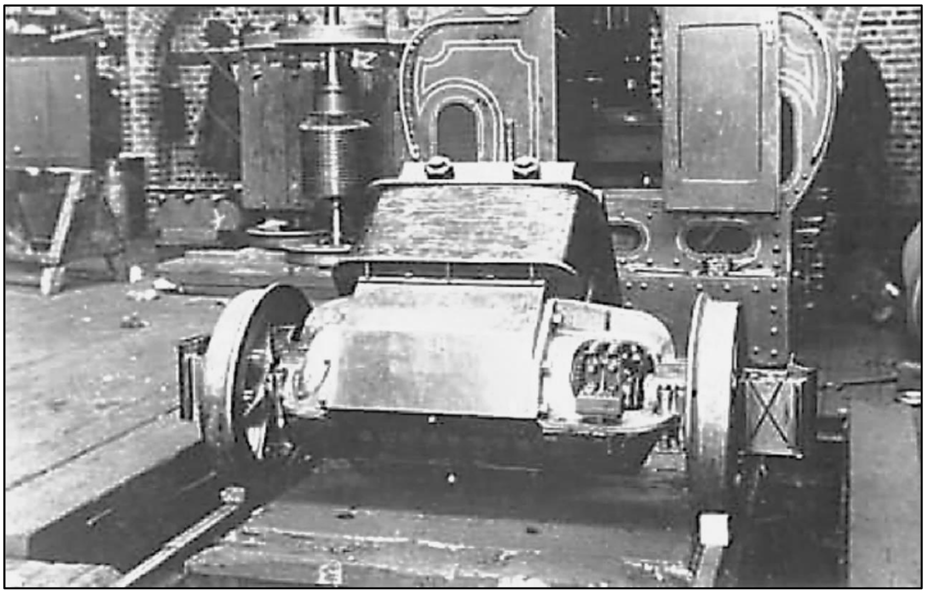

Figure 5: A traction motor and its wheelset from one of the two Siemens locomotives (Nos.15 & 16), showing the locomotive behind. The curved sides provided on locomotives built from this time onwards can be seen, together with the double lining on the body end of the locomotive that is believed to be unique to the Siemens locomotives. The motor has the armature wound on the axle and the exposed brushes are visible on the right hand side. The upper pole magnet is plainly visible, hiding the armature, and the huge pole winding can be seen above the magnet. Photo: LT Museum.

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11 BTHR, CSL 1/3. m. 374.

12 McMahon, P.V., 1899. 'Electric locomotives in practice, and tractive resistance in tunnels, with notes on electric locomotive design.' *Journal of the Institution of Electrical Engineers*, *28* (141), pp.508-607.

13 McMahon, P.V., 1899. 'Electric locomotives in practice, and tractive resistance in tunnels, with notes on electric locomotive design.' *Journal of the Institution of Electrical Engineers*, *28* (141), pp.508-607.

For the trial, the armatures on Loco 3 were rewound to increase the number of windings by 50% while the traction control was redesigned to allow series-parallel control. A number of test runs were made with a 3-car train and these were compared with similar runs using Loco 12 in its original condition. The results showed that the series-parallel configuration gave a 15% increase in top speed between stations with only a 3% loss in efficiency. A number of other tests were conducted showing, amongst other things, that the Siemens locos were less efficient than the M&P ones. Both the Siemens locos and the C&SLR-built No.17 were taken out of use about 1914.

Enough information was gained from McMahon's tests to guide the specification for a new locomotive design and, early in 1897, a number of suppliers were invited to tender for two new locomotives. Siemens and M&P were included, along with Westinghouse, BTH, Thomas Parker Ltd., Easton Anderson (who made lifts), Thames Ironworks (who made ships), The Electric Construction Co. and Crompton & Co[14]. The tenders were returned in April 1897 and, after a few weeks of deliberation, the Electric Construction Co. and Crompton & Co were each asked to supply one locomotive[15]. These became Locos 18 (by Crompton) and 19 (Electric Construction Co.). No.18 was delivered in 1897 and No.19 arrived in mid-1898. Another locomotive, No.20 also arrived in 1898. This was built by Thames Ironworks. Apart from No.20, it is probable that the bodies were built by Hunslet, who seemed by now to have become the go-to manufacturer for them, while the electrical equipment came from the suppliers.

McMahon records that Nos.19 and 20 were provided with larger 31-inch wheels, 4-pole motors, series-parallel control and an on-board air compressor. He doesn't mention No.18 but we can be pretty sure from a photo of it that it had the same improvements as the other two machines. We will discuss this in more detail in next month's article. The new features were all beneficial for locomotive operation but there was also an improvement for the crew in that the new, 4-pole traction motors were compact enough to fit below the cab floor, giving them a more comfortable, level working space. And, importantly, the new motors allowed a shorter wheelbase.

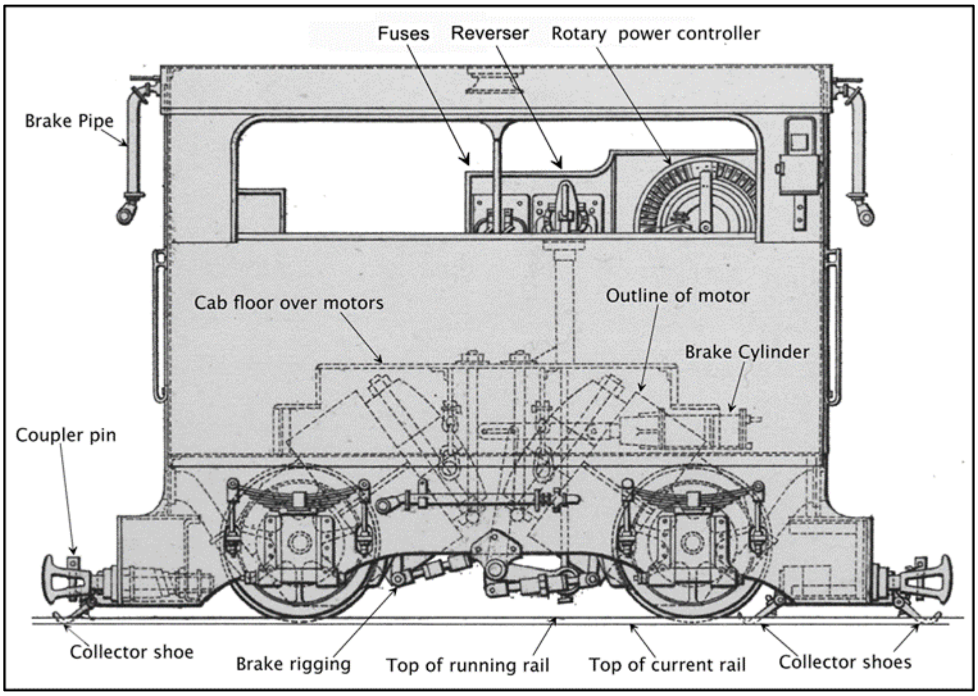

Figure 6: Drawing of a Siemens locomotive (Nos.15 & 16) showing the main parts. These were the first locomotives to have the curved sides in place of the flat sides of the M&P locos. The two vertical links seen in outline under the floor support the traction motor fields. Drawing modified by author from Greathead, J.H., 1896. The City and South London Railway: With Some Remarks Upon Subaqueous Tunnelling by Shield and Compressed Air. Minutes of the Proceedings of the Institution of Civil Engineers (Vol. 123, No.1896, pp. 39-73).

The wheelbase of the original M&P locomotives was 6 feet. It couldn't be any longer because of the sharp curves on the line. The rigid wheelbase meant that the wheels struggled with some of the severe curves, particularly at the King William Street end. Wheel and rail wear rates would have been high. The limited wheelbase was the reason why the motors were angled and had to protrude through the cab floor. The arrangement was a bit of compromise. Reducing the wheelbase would reduce the wheel and rail wear on the curves so, once the more compact motors became available,

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14 BTHR, CSL 1/4. m. 322.
15 BTHR, CSL 1/4. m. 874.

it was a logical step to reduce the wheelbase for the new locomotives. The new design had a 5 ft. 6 in. wheelbase.

In his 1899 paper, McMahon describes how Locos 19 and 20 were tested against the performance of the older locomotives and, although both of them showed improvements, No.20 proved to have a faster average speed when compared with No.19. McMahon commented on this by saying "… it may be mentioned here that when this locomotive was ordered [No.20] the author was in a better position to specify the requirements, than when the order for No.19 locomotive was placed. The latter locomotive was nearing completion before the former was required, and when the plans of No.19 were prepared, the author had not gone so far into the question of locomotive design."[16] This suggests that each new version of the locomotive ordered had some improvements and McMahon was still testing ideas when Loco No.20 was ordered. Even then, No.20 underwent a number of alterations during 1899. Unfortunately, McMahon doesn't describe the changes.

To be continued …

[16] McMahon, P.V., 1899. 'Electric locomotives in practice, and tractive resistance in tunnels, with notes on electric locomotive design.' *Journal of the Institution of Electrical Engineers*, *28* (141), p.577.