JUNE

THE UNDERGROUND ELECTRIC TRAIN

by Piers Connor

24 – BACK TO THE FUTURE II

2009 TUBE STOCK

Perhaps readers will remember that, some months ago, I interrupted my historical account of the development of the Underground train and went "back to the future" to write an article called "T-Cups and Longer Trains" [1] when I described the proposals for the new sub-surface stock, the S Stock. In the best traditions of the media industry, I now present the sequel, a sort of "Back to the Future II", for the other new stock coming to the Underground, the 2009 Tube Stock for the Victoria Line. With the imminent delivery of the first train, it is a good excuse to take a look at the stock that will appear on the Victoria Line in the next year or so.

The 2009 Stock doesn't look particularly revolutionary, more evolutionary *(see centre page drawing).* It has a traditional London Underground air about it, not surprising when you think of the very restricted tunnel shape it has to fit in. The body and door configuration is traditional, the make-up is traditional – eight cars comprising 2 x 4-car sets arranged back to back – and the traction system is the now usual (for the last 10 years anyway) 3-phase AC package, not dissimilar to that provided on main line Electrostars and supplied by the same company, Bombardier, from their Derby factory[2]. The train has a mix of six motor cars and two trailers giving 75% axles motored compared with 50% on the 1967 Tube Stock. There is, of course, a "designer" front end, mostly to give the train a modern look and convince the stakeholders that this really is a new train, and there are a few technical variations but, otherwise it's "more of the same".

To be fair to LU, for a time they had some radical designs on the drawing board. A concept known as "Space Train" was offered to the technical press in 1999 and it showed an articulated body, with small wheels and a low floor designed to give more height inside the cars, and with wide gangways to allow free circulation between vehicles. There were some serious technical problems to solve, like where to put all the equipment, how to supply traction current, how small wheels would perform on LUL track, how to fit the motors in and, most important, who was going to pay for the considerable amount of development work required to get it to a stage where metal could be cut and a prototype built. Not surprisingly, it fell at the first fence because the PPP (Public Private Partnership) financial mechanism doesn't allow for speculative development work. The idea is not entirely dead, as various options around the idea of wide gangways for tube cars are being considered for the Piccadilly Line replacement stock, planned for delivery beginning around 2012-ish (at the moment they're calling it 2012 Tube Stock) but radical designs are risky and expensive and, I for one, can't see it happening.

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1 Article 12, *Underground News* No.534, June 2006.

2 The same factory produced the 1992 Tube Stock but one hopes the quality will be better.

When the PPP bidding got underway, the manufacturers worked hard to design a train which maximised capacity and speed in order to get the best “Journey Time Capability” (JTC) score, as required by the invitation to tender. The JTC score is a number, to two decimal places, representing the average journey time, in minutes, of a passenger on the line. Each line has its own score. It takes into account waiting time at stations, crowding on trains, speed between stations, loading and unloading times, the effects of signalling on throughput, the types of termini, train capacity and all sorts of peripheral issues like the number and location of reversing points along the line and how far the toilets are away from the driver’s cab at terminal stations[3]. Part of the PPP process is to make the score better by improving line performance.

For the Victoria Line, over 60 iterations of seating and door layouts were tested to see which solution would give the best JTC score. The resulting design is actually what any competent metro car designer would have recommended if he went to look at the Victoria Line one morning in the peak. The final design has lots of standing space with no transverse seats and some of the seats that are left are tip-up because LU is forced to provide spaces for wheelchairs under the DVAR (Disabled Vehicle Accessibility Regulations).

FORMATION, EQUIPMENT & NUMBERING

Cars are given letters in the style of the 1992 Stock on the Central Line. The two 4-car units are treated separately, even though they are very similar. The formation is, from the north, A–B–C–D + D1–C–B–A1, numbered as shown below.

'A'-end North 'D'-end South

A DM	–	B Trailer	–	C NDM	–	D UNDM	+	D1 UNDM	–	C NDM	–	B Trailer	–	A1 DM
11002	–	12002	–	13002	–	14002	+	14001	–	13001	–	12001	–	11001
11004	–	12004	–	13004	–	14004	+	14003	–	13003	–	12003	–	11003

.... and so on up to

11094	–	12094	–	13094	–	14094	+	14093	–	13093	–	12093	–	11093

The numbering sequence is interesting[4]. The number series starts at 1 instead of 0 as is traditional. Of course, starting at 1 is more logical and it aids calculation of car totals. It also means that cars are numbered from the east end first so that odd numbers are at the ‘D’ end and even numbers at the A end, according to the Underground’s long-standing convention. People will have to be careful with identification though. Now we have the A1 DM (which is actually a ‘D’ DM) at the ‘D’ end with the ‘A’ DM (which really *is* an ‘A’ DM) at the ‘A’ end. Mmm – you might need to read that again! The reason for the addition of the number 1 to the south end unit’s DM and UNDM cars seems to be more to do with wiring and orientation during manufacture rather than any operational need. I think it will be dropped when the units leave the factory.

A total of 47 trains are being provided. This is four more than the current Victoria Line fleet. To make room for the extra trains, they are building four additional sidings

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3 Don’t ask! Well OK, do ask. Yes, it is a valid issue. If the toilet is a 15-minute walk away from the platform, it could seriously delay a train with a 7-minute turnround if the driver needed to use it!

4 The system was devised by our esteemed editor some years ago during his former employment with the Underground.

in Northumberland Park Depot. It is planned to have 43 trains in service at peak times. Quite how they will all fit on a line originally designed for a 34 train service remains to be seen. There will be some improvement to the line's capability with the new train's go-faster traction kit plus the Westinghouse "distance-to-go" signalling now being installed but, on the day, the achieved performance will really be down to the dwell times. With some of them currently running over 50 seconds at places like Victoria and Kings Cross in the morning peak, it will make the projected 109 second headway[5] impossible to reach unless a radical and sustained effort is made to get dwell times down.

In order to make use of the additional throughput capability of the new signalling, the 2009 Stock has a higher performance than the current stock. The existing 1967 Tube Stock draws about 2,700 amps maximum, while the 2009 Tube Stock will draw 3,500 and is capable of drawing up to 4,500 amps. The extra current draw will need a power system upgrade to allow it to happen. LU is anxious to avoid a repeat of the embarrassment of Railtrack when they were rushed into a hurried upgrade of the 750 volt system on the Southern and South Eastern areas because they had forgotten that the new Electrostar trains being delivered would double the current requirements. The present Underground power upgrade plan involves, amongst other things, raising the Underground's voltage from 630 to 750.

The original intention for the 2009 Tube Stock was for an all-motor-car train but, after a lot of soul searching, Bombardier decided they could meet the performance requirements even if they saved themselves the cost of two traction packages per train. As a result, the train has the DM – T – NDM – UNDM + UNDM – NDM – T – DM formation described above.

5 Headway = the elapsed time between the passing of the head of one train and the passing of the head of the next – put simply, the planned interval between trains, currently 126 seconds on the Victoria Line.

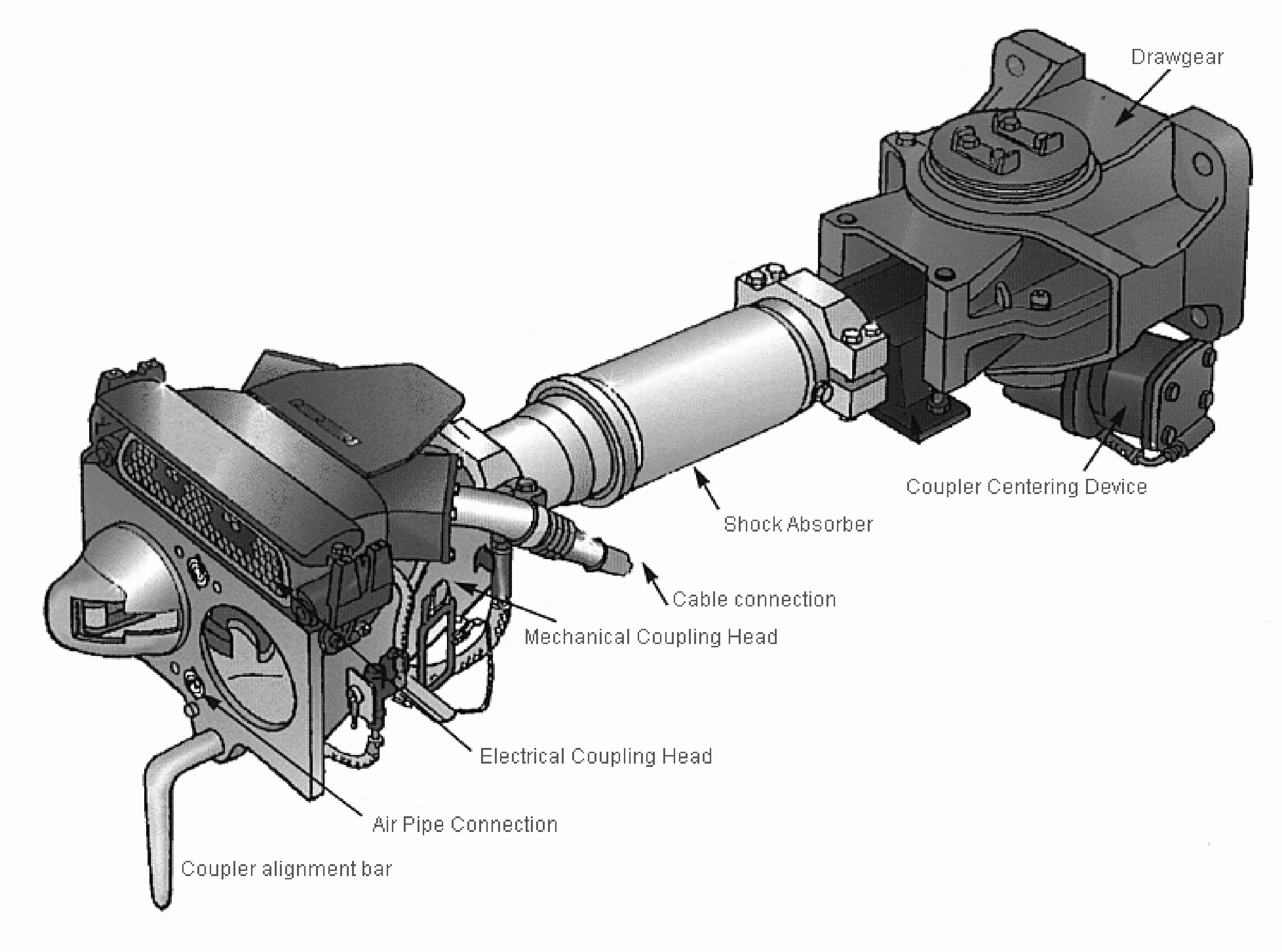

Fig. 2: Scharfenberg coupler of the type to be supplied for the 2009 Tube Stock. The electrical connection box over the coupler proper will not be provided as the coupler will only be used for push-outs and in depots. Some sort of plug-in cable will be provided for communications between trains during push-outs.

An interesting aspect of the new stock is the coupler system. Gone are the traditional Underground Wedgelock couplers and gone is any pretence of automation. The train is basically an 8-car block set. The traditional uncoupling system fitted in the middle of the train, where two Wedgelock couplers provided all the mechanical, pneumatic and electrical links in one system, has gone. Now we are back to jumpers, hoses and staff having to get down and dirty. The middle coupler is basically a semi-permanent arrangement which can only be uncoupled from a pit under the train. It has two mating faces which need to be unbolted. It is referred to as a “muff coupler”. Air and electrical connections are through jumpers at just below waist level, which have to be released and pulled manually to disconnect the units. One must assume that the jumpers, which are to be positioned at this level between all cars, are somehow vandal proof.

Readers may remember that I am not a fan of fully automatic couplers but the system that eventually evolved on the Underground, which allowed a simple semi-automatic system to be used in depots or on the road if necessary in emergency, was a good compromise between everyday requirements and reliability. The new system isn't. Even if uncoupling trains in service isn't required any more, it is certainly needed in depots on a regular basis because only one of LU's lifting shops is long enough to take a full length train (Neasden) and the wheel lathes (see adjacent box) require a double length track to allow all the wheels on the train access to the machine.

Not only that, but the Victoria Line's Northumberland Park Depot has single-ended stabling and shed roads so, any train needing to be split will have to be shunted over a pit road first to be uncoupled. With a depot which is already quite tight for space, this will only cause trouble.

The end couplers on the 2009 Tube Stock are also alien to the Underground. The couplers provided on the outer ends of the driving cars are akin to main line and European practice and are basically a Scharfenberg design *(Fig. 2 above).* The company which sells them is called Voith and they are well known for drive and transmission systems used on road vehicles and diesel trains. It seems that, with the car floor of the new stock being lower than the LU norm for tube trains and with the PPP effectively removing any possibility of trains being moved from line to line, compatibility with existing systems was pointless. If you can get a cheap standard design, why not? So, the 2009 Tube Stock will have a coupler on the outer ends which resembles a modern main line coupler. It will only be required for shunting and push-out purposes[6].

DRIVE PACKAGE

The new trains have the usual (these days) 3-phase AC traction package. Each motor car will have four motors, one for each axle, fixed to the bogie frame and driving the axle through a flexible coupling. The traction power is controlled through the proprietary Bombardier train control system called Mitrac. It was developed by their Swedish designers, formerly well known in the industry as the electrical equipment suppliers ASEA. Mitrac takes the demand signal from the traction/brake controller or ATO command and uses it to control the power supplied to the motors. The power is fed to the motors through an inverter. The inverter

WHEEL LATHES

Train wheels are made of steel and, as they run on steel rails, they wear down. The wear tends to change the tyre profile, and this reduces the ride quality and it will eventually lead to derailment if the wear is allowed to go too far. To fix this, the tyres are reprofiled or "turned" in a lathe so that the profile is returned to its optimum shape. Each cut will take 5mm or more off the diameter of the wheel so eventually you will have to replace the wheels.

In the meantime, you can "turn" wheels in one of two ways. You can take the wheels off the train and do it on a dedicated machine somewhere or you can use what is called a "ground wheel lathe".

A ground wheel lathe is a lathe mounted below rail level in the floor of a depot so the train can be moved over it and the wheels turned without their having to be removed from the train. LU installed ground wheel lathes in various depots around the system in the 1950s but they were taken out in the 1980s because they were worn out and there was no money to replace them. This meant that wheel turning required each car to be lifted, the wheelsets to be removed and then sent away for reprofiling.

Now, they have realised that the time and expense of doing this is a waste and that the old system was better, so they have gone back to it. However, it does require a track dedicated to the lathe, a system for moving the unit (you can't drive it under power on the lathe road – where would you put the juice rails?) and space either side of the lathe to allow all the wheels on the unit to access the lathe. So, if you have an 8-car train, it needs 16 cars space. If you can split the train, it can halve the space required. Hence my view that splitting the train should be easy.

[6] Coupling adaptors will have to be provided during the changeover period while old and new trains are running together.

converts the DC from the current rails into 3 phase AC for the motors. It uses IGBTs (Integrated Gated Bipolar Transistors), the latest form of heavy duty power electronic switching devices. On the 2009 Tube Stock, most of the traction control kit is contained in a box called a Motor Control Module (MCM).

HSCB

On modern stocks (1992 Tube Stock onwards), the complete 630 volt electrical package on each pair of cars is protected by a High Speed Circuit Breaker (HSCB). A feature of modern stocks is that they have air-operated HSCBs. When open, they will leave the train without any power except what is available from the batteries. This is OK, except that they need air pressure to close them again so, if the air leaks away during a prolonged power failure, there is no way to close them and therefore no way to get the train going once the power comes back on. A couple of incidents over the last few years have resulted in long delays while a man with a bicycle pump went to the train to “pump it up” to get the HSCB closed. The result is that the 2009 Tube Stock will have all-electric HSCBs.

You might ask why this doesn’t happen on older trains. Well, PCM traction equipment does require a minimum air pressure to operate – the P in PCM stands for pneumatic and it needs 70psi[7] – so how do you get the train going after a long power outage? You separate the individual 630 volt systems and you keep auxiliary equipment contactors closed. If you ensure that the auxiliary power is fed through a mechanically latched contactor, it always stays in the position you last left it, so if you get the power back on after a long lapse, the motor alternator (MA) restarts immediately without any action by the crew. The MA provides current to recharge the battery and supplies all the train control circuits, including the compressor. Once the compressor control gets current, the compressor starts and the air supply is restored. Now you have air to close the line breakers and start the motors.

AC TRACTION

Perhaps a word about AC motors will be useful here. For the last 10 years or so, new trains in the UK have been provided with AC motors instead of the traditional DC type. I have described bits and pieces of the DC traction system before in various of these articles but a little recap here will help us understand the rather different concepts involved with modern traction kit. I should add a health warning for the purists and electrical experts amongst you; this is a very simple version of the concept. The reality, as you know, is rather more complex.

Both AC and DC motors have two main parts, the stator and the rotor. The stator (from “static”) is the fixed part, while the rotor (from “rotating”, as you might expect) is the moving part. The rotor is often described as the armature and it spins to provide the driving force. The stator is really a steel case built around the armature that is lined with insulation and tightly backed coils of wire called “the field”. The rotor (the armature) is also made up of coils of wire in DC motors or metal laminations in AC motors.

To get the motor to work, you have to apply electric current to both parts by placing them in a suitable circuit. When you do, the magnetic reaction between the current in the field coils and the current in the armature coils will cause the armature to rotate. To get this to work in a DC motor, you must physically connect the supply to

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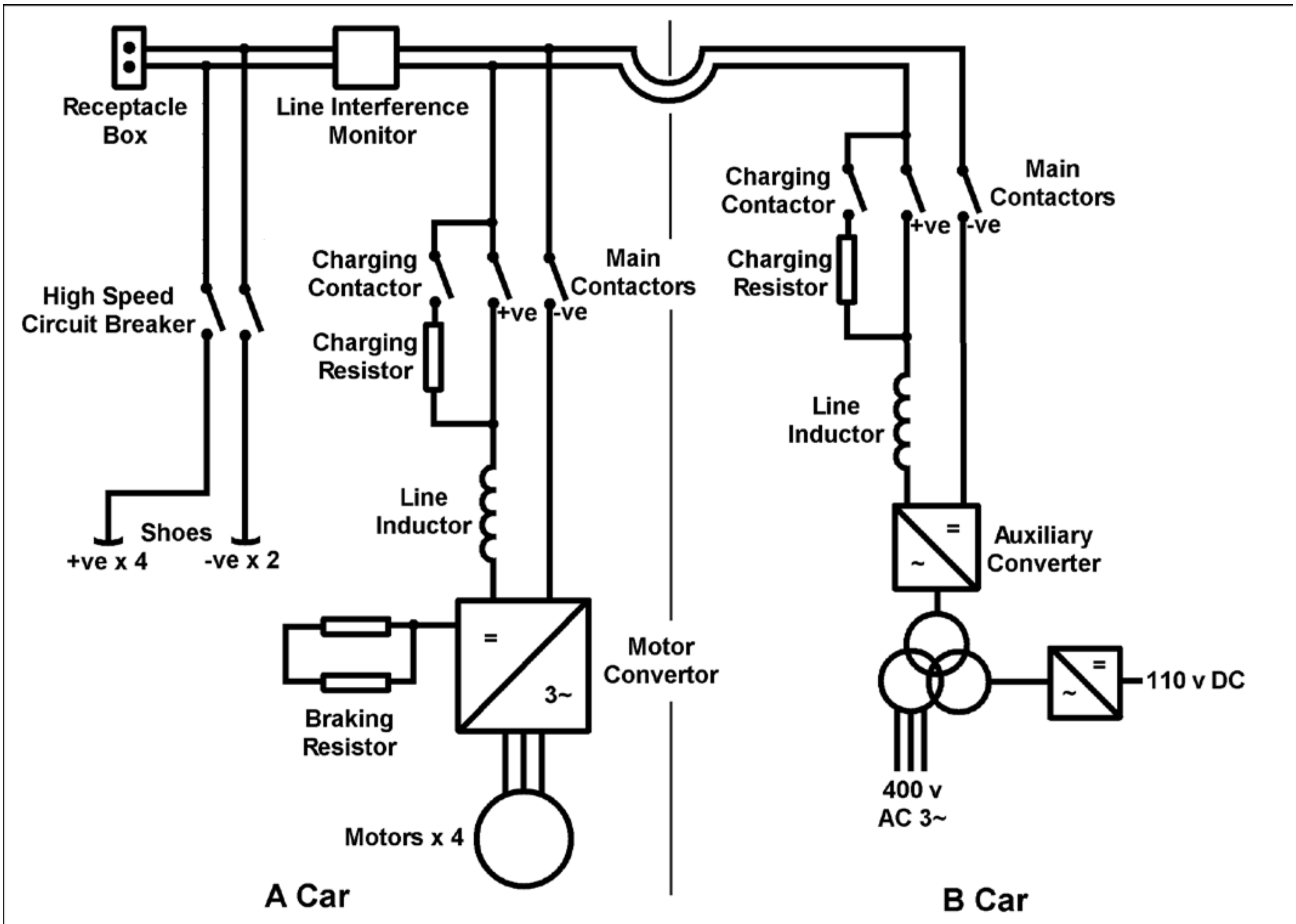
7 An “equipment governor” prevents trains from starting unless the air supply is sufficient to operate the equipment properly.

both the field coils and the armature. Usually, for railway traction, the DC motor has the armature and field connected one after the other in series – the "series motor". With a 3-phase AC motor, you don't have to connect the field and the armature. The current in the AC armature is "induced" by its proximity to the current circulating in its field – hence the "induction motor" title often used.

The fact that you don't have to physically connect the armature to the field in the AC motor provides one of the reasons why it is now so popular. Trying to design and maintain a good electrical connection between the rotating armature of the DC motor and its field coils caused a lot of grief in the early days and still causes some trouble to this day. The design solution required the armature coils to be connected individually to segments at the end of the armature called the commutator. Contact between this and the field coils was achieved by "brushes", so called since they tried wire brushes in the early experiments on electric motors but soon, spring-loaded carbon brushes became a reasonably successful standard type and they survive to this day.

Nevertheless, arcing, wear, vibration, water and even "the wrong kind of snow" has caused endless trouble for the DC motor and its commutator/brush system over the last 100 years or so of electric traction. The AC motor removes most of these problems but, as we shall see, creates a few of its own.

With either motor, to control the motor power and speed, you must vary the circuit. You daren't apply all the power at once to a motor driving a heavy object like a train – it will just overheat and "go bang". You have to start it gently – the electrical equivalent of first gear. For a DC motor, you do this by reducing the voltage available at start up. The circuit is connected to a set of resistors which "burn off" the excess current so that the motor only gets what it can take. As the motor speeds up, it can take more current, so you gradually give it more by switching the resistance out of the circuit in steps – the "click, click, click" you hear under a motor car on pre-1992 Underground stocks. On the 1992 Stock, they use power electronic control for



the DC motors instead and we will look at it next month.

Fig. 3: Power and auxiliary schematic for two cars of 2009 Tube Stock. The A car (above left) and D cars (not shown) have a similar equipment arrangement, the B car (above right) has the auxiliary converter and the C car (not shown) has a full set of traction equipment but is fed from the adjacent D car. Only A and D cars have current collection.

The 3-phase AC motor is controlled in a different way. It doesn't use resistors. Modern power control technology and electronic switching devices allow the motor to draw only the current it needs from the line. This saves around 30% of the energy used during the acceleration phase.

As I mentioned above, the 3 phase motor creates a few problems of its own. The motor control is complex. The AC motor needs both voltage and frequency control to work together to provide the correct power. This is known as VVVF – Variable Voltage, Variable Frequency control. It is necessary to vary the voltage to control the starting current and to vary the frequency so it will actually produce power. Put another way, because an AC motor naturally synchronises with the supply frequency is has to be forced not to if it is to provide power. If the motor is allowed to rotate at its synchronous speed, it will not provide any torque. This will make it useless in driving anything, let alone a 200 tonne train. To get torque, you have to let the motor try to get to its synchronous speed but never let it actually reach it. This means that you must vary the frequency to something less than the motor's natural frequency. The motor therefore "slips" electrically behind its field frequency and becomes "asynchronous". At the same time, you must get the right voltage input to match the power required for the torque.

To obtain the necessary AC to do all this on a DC railway like the Underground, you have to have an inverter. This "inverts" the DC from the current rails and produces three phase AC. There are other bits and pieces too – a control system to reduce the interference, a large and rather heavy smoothing choke and provision for dynamic braking. The 2009 Stock traction package includes regenerative braking where, as we have seen[8], the motors become generators and convert the kinetic energy contained in the moving train into current. This is fed back into the current rails in the hope that it can be absorbed by other trains needing the energy for their drives. If the line can't accept the current and the potential rises to over 800 volts, the current is diverted into an on-board resistor mounted under the car and the brake becomes rheostatic.

AUXILIARY SYSTEM

As we have seen, the 2009 Tube Stock train has underfloor packages for the traction equipment known as MCMs under each motor car but it also has two ACMs, one on each trailer (B) car. ACMs are Auxiliary Converter Modules. These convert the traction current supply into two different voltages for various pieces of auxiliary kit on the train. This is the current system for what is sometimes known as "hotel power". We looked at this on older trains in an earlier article[9].

For the 2009 Stock, the output voltage is 400 volt AC 3-phase. A connection from this output to an inverter provides a 110 volt DC supply for control circuits and battery charging. The 110 volt supply system is a departure from the Underground's

8 Article No 7, *Underground News* No.529, January 2006.
9 Article 10, *Underground News* No.532, April 2006.

traditional 50 volt system. There was some consternation within LU when this was first offered but it is the European norm and it does allow standard equipment to be supplied with all the benefits which that gives. The other output, the 400 volt supply, is used to drive the ventilation fans provided for car ventilation and motor cooling[10]. There is also a fan for the on-board braking resistor.

A cautionary tale about fans is worth recounting here. The 1973 Tube Stock also has a fan-cooled resistor. When the trains first entered service in 1975, there were a number of instances where the resistor grids overheated and caught fire. It transpired that the fans were collecting tunnel dust and blowing it into the resistors. Eventually they became blocked with dust and overheated. What was also discovered was that the dust was being drawn from places inside the tunnels where it had lain undisturbed for many years. The 1973 Stock had a slightly different profile from the 1959 Stock, which had worked on the line for the previous 12 years or so, and its new shape caused new vortexes inside the tunnels. The changing air flows raised the dormant dust and caused it to get drawn into the underfloor resistor grids. What lesson might be learned from this? You should clean your tunnels before you introduce new trains.

The 2009 Stock train batteries are mounted under the B cars. There isn't room for them under the end cars because of all the ATO and ATP equipment that has to be fitted to these cars. In order to provide tail light power if the last car becomes uncoupled[11], a small emergency battery is expected to be provided on the 'A' and 'D' cars. Batteries are supposed to last for 2 hours, but history proves that this is a forlorn hope. It's a bit like expecting your mobile phone or laptop battery to last for the 3 hours or whatever time the manufacturer says it will. With constant recharging and "memory loss" effect, no chance! After a few weeks use, the life expectancy drops sharply. It's not much different on a train.

AIR SUPPLY

The compressor set-up for the 2009 Tube Stock is a new type, mounted under the trailer car in an air supply module. The module consists of a compressor, aftercooler and air dryer with the compressor using a 400 volt, 3 phase motor, supplied from the auxiliary converter module. This is a departure from the usual method of supplying the compressor from the 630 volt DC traction supply. As usual, the 8-car train will have two compressors, synchronised to ensure they start and stop at the same time to share the load. . A single air supply module is capable of supplying sufficient cool, clean, dry air for an 8 car train to continue in service.

Of course, air on modern trains doesn't get used up the way it used to. Dynamic braking, using the traction motors instead of air braking for most of the brake sequence, has reduced air consumption considerably and now, with the electric doors being fitted on the 2009 Stock, the demand for compressed air will fall dramatically compared with older stocks. So, a main reservoir is provided only on the B cars. Brake reservoirs will be provided on all cars. Air is distributed along the train by a single main line air pipe, except between cars where a pair of hoses will be provided, each one protected by the usual flow cut-off valves to prevent a burst hose disabling the train.

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10 The motors will work hard on this stock and need cooling fans to prevent overheating.

11 In Article No 10, *Underground News* No.532, I describe the logic for needing batteries on the rear car and how it was almost defeated until the intervention of the Camden Town accident of 19 October 2003.