—MANAGING—
ELECTRA

GEC
Transportation
Projects

Roger Ford

Previous page:
Pictured on 12 February, as the first Class 91 made its public debut, are Director InterCity, Dr John Prideaux (in cab door); and (left to right, foreground) Mike Newman, Project Manager, Class 91, GEC Transportation Projects; David Rollin, Project Director, InterCity 225, British Rail; Andrew Higton, Project Engineer, InterCity 225, British Rail. *Brian Morrison*

Roger Ford

AS THE pre-production Advanced Passenger Train (APT-P) raced north from Euston on the evening of 12 February 1984, its record-breaking run was the defiant last hurrah of a cause already long lost.

Throughout 1983, the APT project had petered-out in an alphabet of P-train derivatives, culminating in APT-U which was an Advanced Passenger Train only in acronym. But already, the formation of the business sectors was giving InterCity's next generation of traction and rolling stock a new focus and a revived sense of urgency.

In place of APT came InterCity 225. In essence, this was a 140mph electric locomotive based on the APT power car — generally seen as a more-successful part of the APT project. Given a cab and a streamlined nose, the power car became a locomotive which could haul non-articulated tilting coaches.

By mid-1984, this combination, plus associated driving van trailers, was the preferred option for the West Coast main line (WCML) from 1990 onward. Potential builders in Britain, France, Germany and Sweden were invited to prequalify for the design and construction of the 25 locomotives needed for the WCML.

Revolutionary at the time, though standard BR practice today, was the intention to award a single contract covering the design, development and construction of the locomotive. The possibility of one contractor taking responsibility for the complete locomotive/Mk 4 coach package was also on offer.

It must be remembered that IC225 was a replacement for existing WCML traction which would become life expired around 1990. To make the investment case, it had to offer a similar dual capability — express passenger by day, sleepers and freight by night.

From this came a daunting combination of technical parameters. Low vertical and lateral track forces essential for 140mph running and curving at 9° cant-deficiency resulted in a maximum unsprung mass of 1.7 tonnes on a 20kN axle load. Restarting the specified 750-tonne trailing load (equivalent to 15 Mk 3 sleepers) on Shap would require a peak power rating of 6,300hp on a Bo-Bo wheel arrangement.

Meanwhile, in July 1984, electrification of the East Coast main line (ECML) had been approved. Years of obsession with the technology to overcome the physical constraints of the WCML left engineers and operators with little time to consider traction and rolling stock for the electrified ECML.

The successful submission was based on 125mph Class 89 Co-Co locomotives hauling new Mk 3 coaches. But with InterCity 225 rising Phoenix-like out of the ashes of APT, it soon became apparent to InterCity Sector Director Cyril Bleasdale that a common traction policy for the West and East coast routes made sense. The concept acquired project status, and the title IC225 was extended to cover both locomotives and coaches.

IC225 was now the InterCity flagship, BR's first attempt at true procurement from a main contractor, an investment of £100 million at 1984 money and vital to the future survival of the InterCity business. If it was to succeed, BR would have to run the project as a BR project had never been run before.

On board APT on that December night were the two men whose task this would be. And both were surprising appointments in an organisation where seniority had tended to determine the position in the engineering hierarchy.

Newly appointed Project Director InterCity 225 was David Rollin, then 40 years old. A dark, intense man, Rollin joined BR from school and worked in all the craft shops. A scholarship from evening technical college followed and he became a professional engineer.

In the 1970s, at BREL, he was associated with the development for the P-trains of body construction using seam-welded long aluminium extrusions. Unashamedly ambitious, he became a rising star in BREL when Philip Norman took over as Managing Director, becoming New Product Development Manager. But despite the obvious drive and presence, it seemed at the time a substantial jump from planning BREL's future products to running IC225.

Under BR's new procurement policy, IC225 would have its own Project Engineer — Andrew Higton. Aged 36, but looking even younger, Higton had trained as an engineer with a private-sector engineering company. His BR career included a period with BREL as a Sales & Contracts Engineer before becoming Bogie & Suspension Engineer in the Mechanical & Electrical Engineering (M&EE) Department. He was then InterCity Engineer for only a short while, before being elevated to the IC225 job.

This pair of untypical BR engineers was plunged straight into the deep end. When Rollin walked into his new Marylebone Road office on 5 February 1985, there was a note on his desk from Cyril Bleasdale. It read:

'The Project Director's life is a lonely one. You have the difficult and important task of writing the conversion case from the Class 89 to the Class 91 for the ECML in three weeks. Good luck, Cyril Bleasdale.'

There was a PS. 'Perhaps you would like to use your initiative to find a telephone, a chair etc.'

AT DERBY, Higton had the even harder task of converting the 30 page business specification for the Class 91 into a technical specification, ready to go out to tender, by 28 February. He had the advantage of an 'awful lot of ground-work' which had been done on APT-U and Derby's conceptual Class 91. As a result 'we knew what we wanted', although Higton had no fixed ideas, not having been associated with locomotive design before.

By dint of working seven days a week, the deadline was met. He admits now that a lot of his colleagues thought it an impossible task. It was achieved by a small team built round three engineers — two electrical and one mechanical — as the core. The technical spec occupied about 200 pages.

This unrelenting pressure of deadline after deadline dominates the project. Acceptance of the ECML IC225 fleet by the Department of Transport merely tightened the screw. IC225 now had to be ready for the start of electrified services to Leeds in October 1989.

By now, the decision had been taken to procure traction and rolling stock separately. Clearly, the locomotive, now publicly named *Electra* after a press interview with Cyril Bleasdale, was the critical component.

After HST and APT, BR was determined to have adequate testing before the entry into service. This meant delivery in 1988. The coaches would then follow on.

Working backwards from that inviolable date established all the interim targets for the Class 91. The specification had to go out to tender in April 1985. Competing firms would have until 1 July 1985 to submit their bids. After a period of evaluation, followed by submission to the BR investment Committee, the contract would be placed in October.

On 3 April 1985, three firms were invited to bid for Electra: ASEA of Sweden, Brush, and GEC-Transportation Projects (GEC-TPL). It soon came down to a straight fight between ASEA and GEC.

For the British firms, it was not just the first time they had bid as main contractors to BR since the 1955 Modernisation Plan, it was also the first time they had faced foreign competition in the home market.

This gave an added edge to the contest. If British industry lost the contract to build the national high-tech flagship, it would be tantamount to a vote of no confidence in UK technology by the domestic customer. In the vital export markets customers would be given the message — 'Even their own railway won't buy British equipment — why should you?'

At GEC-TPL, where commercial survival depended on export success, competition was a way of life. They recognised that the key to success with Electra lay in the ability to meet the dynamic criteria and the resulting low track forces. Radical solutions would be needed for the mechanical design, but electrically, the Class 91 was an extension of existing technology.

So GEC set out to win the track forces battle. This, they were well-placed to do, thanks to the most experienced locomotive designer in the business — John Dowling

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(see 'The Bogie Designer', *Modern Railways* September 1986).

He broke completely with concept of the Class 91 as a derivation of the APT-P power car. Removal of the traction motors from within the body to beneath the underframe was the master-stroke. Here, they occupied the space within the bogie normally taken up by the traction motors in a conventional locomotive like a Class 87.

GEC also moved the transformer from the body to between the bogies. Together, these features resulted in a shorter body which started a virtuous spiral.

Dynamically it produced a 'stiff' system and it also reduced the mass of a locomotive which had to pack 6,300hp into 80 tonnes. In fact, weight management has been a highlight of the Class 91. David Rollin instances the physical measurement by GEC of every steel sheet used, to ensure that the variations in the nominal thickness as received from the rolling mill were on the side of the angels.

The resulting design was commercially attractive and more than met BR's dynamic criteria. Its minimum ride standard was better than the average called for in the tender specification, under all conditions. This was achieved at the expense of some added complexity and innovation.

But GEC had misread BR's approach to competition. As Rollin puts it: 'They had defended their position by believing you got extra brownie points for being better than the specification. In fact, we didn't evaluate in that way. If you complied fully with the specification you got 10 out of 10.'

So GEC reverted to their earlier, simpler, but fully compliant, concept which won the day. However, this introduced what would be the critical component in the Class 91 design — the right-angle drive between the traction motors and the axles.

All these events took time. Instead of signing the contract in October 1985, it was not until the night of 5 February 1986, at a motorway service station, that the top men from GEC and BR met to sign the letter of intent. Rollin still recalls the delay as the only slippage in his carefully planned procurement timetable. It cut the time GEC now had to produce 91001 to two years.

Indicative of the passions raised by the fight for Electra was the immediate release of the roll-out date. On BR traction and rolling stock contracts, before and since, you would be lucky to get a firm delivery month: any request for a day would be met with blank incomprehension or point-blank refusal.

I believe that the public announcement of 14 February 1988 as roll-out day was a move to ensure that GEC would be seen to have failed by those within BR who were unhappy with the award of the contract and doubted GEC's ability to deliver the goods.

It was the time of the Nimrod fiasco and the parallel was not slow in being drawn. Time and again people would ask me: 'Do you really think GEC can do it?' The answer could only be: 'Electra must work and it will.'

FOR ITS Project Manager on Electra, GEC-TPL had chosen Mike Newman, a veteran in the management of advanced railway technology. After a spell away from the railway industry, he had joined GEC-TPL as Engineering Manager in mid-1984, just as the preliminary enquiry for IC225 had been released by BR. During tendering he had been responsible for overseeing the technical aspects of the GEC offer. Now, with the contract won, the Class 91 project was his.

There was a strong sense of deja vu. In December 1966, the young Mike Newman had joined the infant British Rail Research from the National Coal Board. His job title was Senior Project Engineer: the project was APT-E.

A colleague from that time recalls Newman as the real leader on the project, an inventor who produced new ideas every five minutes, solving problems with the sheer flood of invention.

By the time I first met him, APT had long gone from Research and Newman was about to leave BR. At that meeting, he recounted how Ian Campbell, then Board Member for Engineering and the man responsible for the P-train project, had described him as 'the piece of grit in the BR oyster which might one-day produce a pearl'. It was not meant kindly, but showed remarkable prescience, even if the pearl would eventually emerge from the GEC oyster.

Newman is frustratingly prosaic about the appointment, other than suggesting, with a laugh, that his career had come full circle from APT. What was his reaction when the job was mooted, I asked him?

'Well, it gave me the feeling of an opportunity to complete a piece of business' was his understated reply.

But he does concede that he had a unique set of qualifications — managerial and technical, plus knowledge of the customer and the principal sub-contractor, British Rail Engineering Ltd (BREL).

With characteristic modesty he adds that his technical qualifications did not mean that he would be doing the Project Engineer's job. This would be the responsibility of Gerry West, yet another of the APT team. He had been bogie engineer and had joined GEC in 1985.

As GEC-TPL Managing Director Brian McCann now says, Electra was a very difficult project. It combined a very high technical performance within a timescale half that of the best previous achievement. With wry understatement he adds: 'We don't usually rush around looking for challenges but we felt we couldn't walk away from this one and remain an international force.'

In fact, GEC-TPL was well prepared for the Class 91. Its project management skills had been honed on a series of turnkey export projects. Technically too, valuable groundwork had been laid.

Soon after joining, Newman had begun planning the transfer of BR's expertise in the computer simulation of vehicle dynamics from Derby Research to GEC's Stafford Mechanical Engineering Laboratory. This transfer was implemented immediately the Class 91 contract was signed.

Without this in-house dynamics computational ability, says Newman, GEC might have been in some trouble. Not that BR Research could not have provided the same service; but trying to handle something as complex as ride quality, stability of guidance and track loading at arm's length would have been 'exceedingly difficult'.

Instead GEC had 'real understanding', which was important because 'the guy who understands is doing the design'. The benefits soon emerged. GEC was able to present the dynamic requirements for the Class 91, such as spring and damper rates and component masses, to BREL within the first eight weeks of the project.

But for Newman and his team, the first task on 15 February 1986 was to work out a

Below:
Driving position of No 91001.
Colin J. Marsden


INTERCITY

Class 91 No 91001 at BREL Crewe on 12 February. *Brian Morrison*

detailed plan for the design, development and manufacture of 91001, counting down day by day. It contained around 9,000 elements and was produced by two men, Neil Thompson and Alan Schofield, in 28 days.

For a British Rail contract, GEC's project management philosophy was even more innovative than the locomotive itself. Figure 1 shows the internal organisation and how it interfaces with BR.

A point to note is the Technical Auditor. This role, fulfilled by the Manager of the Stafford Laboratories, was designed to provide a 'whistle-blower' in the event of something going wrong within the project. As Manager of the Central Laboratory, the Auditor was directly responsible to the parent GEC, by-passing Newman and GEC-TPL.

He examined all the design, analysis, development and test programmes, where necessary appointing independent consultants. Running audits were also made of specific parts of the locomotive such as body and bogie structures, the vehicle dynamics and the braking system.

With the Auditor concept, 'If we felt the pressure of time-scales and wanted to bypass what was acceptable, we knew at the end of the day we couldn't', explains Newman, adding dryly: 'I guess that by doing so we also knew we wouldn't. It was a self-regulating mechanism for what we would have done anyway.'

What the chart does not reveal is the nature of the relationship between contractor and customer on the Class 91 project.

Pre-dating 'Glasnost', GEC-TPL worked on a basis of being totally open with the customer to a degree which is 'uncommon'. As Newman puts it, 'As part of our internal auditing of the project, we endeavoured to place everything in front of the customer, warts and all, once a month.' In the early days the report stretched to 70 pages, later it grew to around 100.

This report provided the customer with full knowledge of progress, including all the difficulties GEC was experiencing. For Newman, the monthly report had two benefits. First, if you had problems, it was a way of saying, 'can you help us'. Second, 'openness is never being found out', as it becomes absolutely impossible to bull the customer.

For Higton, the first six months after the letter of intent were spent sorting out fine detail and the perennial loose ends in any agreement so that the formal contract could be signed. He also sat down with GEC to determine the format and content of the monthly progress reviews.

Higton confirms that GEC, 'to their credit', approached the reviews in a very open way. 'If they had a problem they would share it with us very quickly.' While openness worked in the best interests of the project, Higton thinks it made life quite difficult at times for GEC.

I suspect the aggravation was not limited to the contractor. If a hare got running within BR about some problem, the 'home' project team could also be distracted by having to justify its actions or response. Certainly I was surprised at times by the degree to which those with no 'need to know' were informed on the project's traumas.

Below:
Organisation chart. The GEC-TPL Project Manager is responsible to his board for all aspects of the project. Large arrows show the contractual interface between British Rail and GEC-TPL, but other delegated channels of communication are also shown. Black arrows show direction of managerial instruction, and thin lines show lines of functional responsibility. *GEC-TPL*

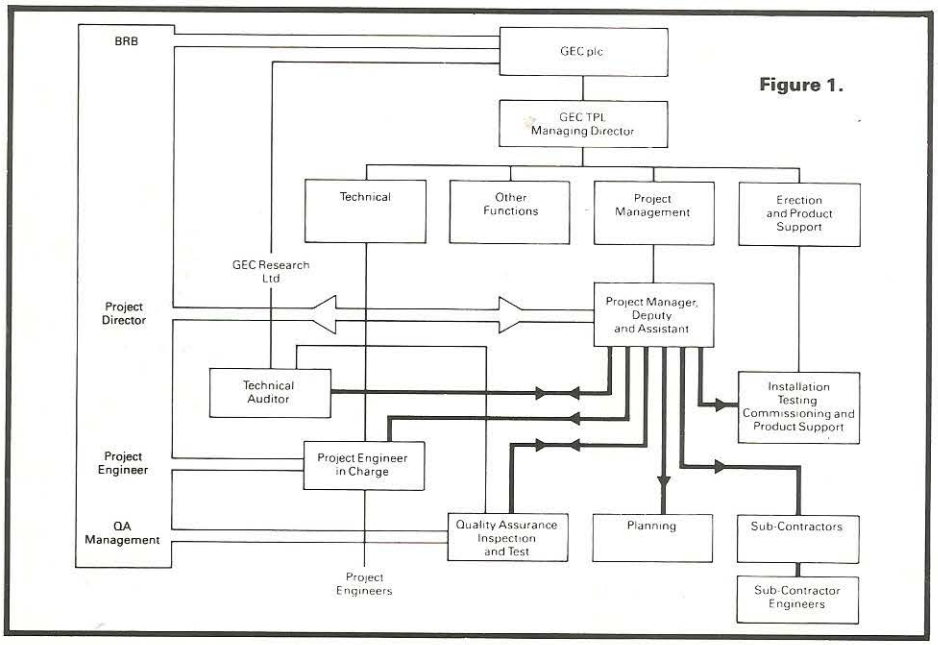


Figure 1.

FROM THE outset, the drive was seen as the highest risk area. The power to be transmitted, the space limitations, the life and reliability required were all unprecedented as far as railway technology was concerned.

In the Class 91, the traction motor is connected to the right-angle drive gearbox by a short cardan shaft. In the gearbox, the drive is turned through 90°, and then connected to the wheelset by a quill shaft with flexible couplings at each end.

Right:
Simplified diagram showing the body-mounted motors located in the bogie space. The disc brakes are also effectively body-mounted, thus minimising unsprung weight. *GEC-TPL*

The wheelset itself runs through the centre of the hollow quill and through the gearbox. It is this configuration which imposes the severe restraint on gear width. The quill and couplings have to deflect through 28mm as the axle rises and falls on its primary suspension relative to the bogie-mounted gearbox, another critical point.

At the formal contract signing in October 1986, Brian McCann explained how GEC was approaching this critical area. The Company had alternative designs for the vital transmission between gearbox and wheelset and was testing both the prime concept and its back-up on full-size test rigs. These tests took the components beyond their maximum service loads and speeds with deflections of 35mm. At that time he hoped that the back-up would be on the shelf by the end of 1986.

In fact GEC had built even more insurance into the mechanical transmission. While Voith of Germany had been the lead firm during tendering, David Brown had sought and been given a parallel sub-contract to design and manufacture a right-angle drive. As further insurance, David Brown were also encouraged to create a drive package incorporating an alternative make of cardan shaft.

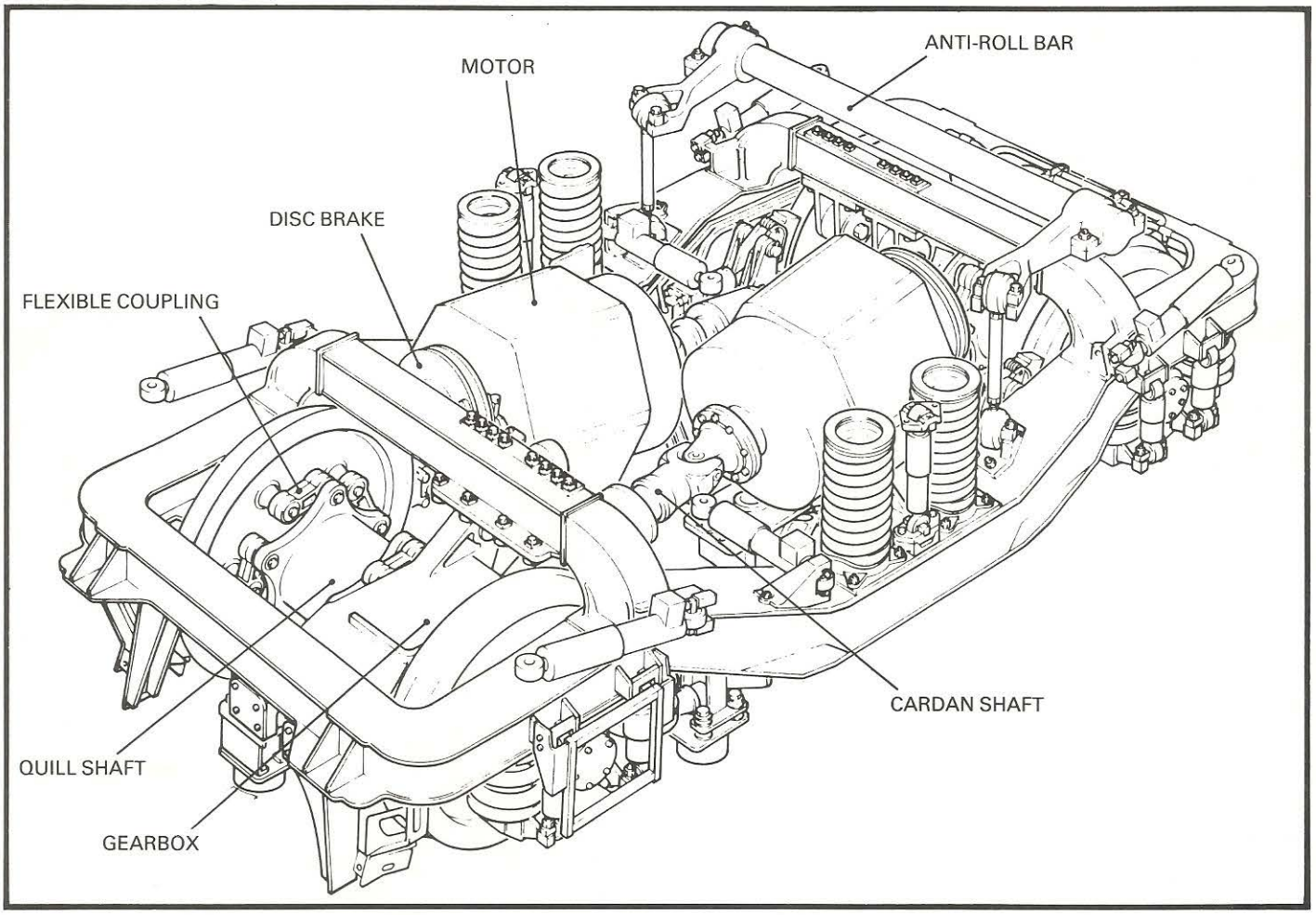
GEC also became deeply involved in the esoteric world of gear design, engaging their own consultants and creating mathematical models of the performance of gear teeth and their lubricant under extreme stress. In the vital contact area, square centimetres of carefully shaped and case hardened steel are transmitting megawatts of power.

At the signing, McCann also gave some advice to the project team: 'Start fast and vigorously. If you are going to fall out, do so in the first six months. Finish slowly and with care.' He also remarked, 'I'm not that lucky to get through the job without a major problem.'

Some of those present took this realism for pessimism and interpreted it as a cryptic warning of problems already emerging. Certainly, the gear manufacturers were encountering development snags, but much of the organisational sorting out was already over.

When I asked Andrew Higton if there had been any really black moments, when he thought the project was in dire trouble, he paused and said 'No'.

We carried on talking before he stopped, having remembered one black day about a month after the contract had been let. But for engineers depression is a transient thing. 'You go to bed and when you get up next morning, all you're concerned with is solving the problem.'



Rollin is more specific. He had a 'great concern' when the first rig tests with the right-angle drive revealed signs of emerging problems. But the darkest time for him had been when the placing of the order began to slip: 'I began to think "Here we go again".'

Those early days did involve considerable culture shock. BR engineers, who had been used to designing and specifying, were now restricted to scrutinising the main contractor's designs. Higton, who at BREL had already been associated with private party work, emphasised the need to make scrutiny constructive. BR also had their own external auditors, notably Richard Dain of Ford & Dain Research.

Perhaps the most dramatic cultural change concerned BREL. After years of doing what the Railway's engineers told it to do, BREL was put in the position of being a real sub-contractor — responsible technically and commercially for detail design and manufacture of the mechanical parts.

Pressed, Newman admits that there was some rough talk and table thumping as the GEC policy on sub-contractor responsibility was brought home. But the subsequent relationship with BREL gains the rare Newman accolade of 'Superb'. McCann says BREL did an 'exceptional job'.

Certainly, the Class 91 experience has been part of the transformation of Crewe Works, including completion of the first locomotive to a timescale that initially seemed impossible. On the roll-out day, one BR engineer with a close interest in Electra went ferreting among the drawings on the Class 91 production line as a check on the basic quality control. Not easily impressed, he came back positively beaming.

Above the project teams were two further levels of contact between the customer and contractor. Every three months, there were Level 2 review meetings between the Managing Director of the Group within GEC responsible for TPL and the BR Vice-Chairman. Then, at least twice a year, Lord Prior, the GEC Chairman, and Sir Robert Reid met for a Level 1 meeting.

By overall GEC Group standards, Electra is a fairly small contract. These high-level meetings indicated the importance the Company placed on the high-profile Class 91. By all accounts, the result has been a dramatic turnround in GEC's reputation within the BR Board.

A characteristic of GEC-TPL is a fierce loyalty to its sub-contractors. So when I asked Newman for an example of how problems were solved he spoke not about brakes or drives but about something in the suspension which the GEC dynamics experts discovered in March 1987 almost on the point of production.

The vibration would not have put the locomotive out of specification because the BR specification didn't cover that point. 'But', explained Newman, 'we did not wish the customer to be dissatisfied'.

So he stopped everything to 'sit on solving that problem'. It was a combined operation, bringing in BREL most notably, BR M&EE, BR Research and the GEC Stafford Laboratories, who worked 17-18 hours a day. As a result, not a day was lost to the programme.

At the end of the fortnight, he was presented with four solutions and had to choose one which fitted the project best. Modestly, Newman remarks, 'Actually, the one I chose turned out to be the best solution, but that was by coincidence. Not everyone thought so at the time'.

This latter remark hints at the top-down support which both project teams refer to. Both in BR and GEC the project managers and engineers were given both responsibility and authority.

Newman again: 'At all levels in GEC, they ask or suggest things but never tell you what to do'. On one critical issue, Newman was 'almost in a minority of one', but to the outside world the Company presented a united front. Newman was simply told 'Get on with it'.

Rollin has a similar view. Early on, there were occasions when he had to remind some BR executives, 'When I am reporting problems, their solution rests with me'. He too got top-down commitment without interference. He also makes the point that this became easier as it became apparent that the project management was working — success breeding success.

Equally important has been the approach to contractual matters. Rollin

sees the key factor as balancing the letter and the spirit of the contract. In fact, there have been about 100 variation orders.

The clever thing, according to Rollin, is to achieve a balanced judgement, offsetting rigid adherence on purely contractural considerations against the implications of a minor issue delaying the project. He puts this in terms of mice and elephants.

At conception there is not all that much difference between the two. Successful project management depends on stopping the elephants before they can grow. Such contractual realism can only come as both sides build up trust which comes from being on top of the job, monitoring variations, meeting timescales and managing risk out of the project.

He pays tribute to the way in which GEC addressed the management of an 'extraordinarily difficult' project under Mike Newman's leadership. Reflecting Newman's two years of 50-hour, often 70-hour, working weeks, Rollin talks of the GEC man 'throwing himself body and soul into the project', hastily adding, 'but not in an uncontrolled way, of course'.

Readers may have noted that little has been said about the electrical aspect of Electra. This is much more straightforward. The electronic control scheme was pioneered on the GEC locomotives for Taiwan and is now in service on a whole spread of locomotives and trains from South Africa to Docklands.

Engineers are finding that setting up these digital control systems is very different to previous equipment where you adjusted settings until you got the right response. A simile is the difference between setting an analogue watch, where you turn the hands to five past ten, and a digital watch where you adjust the reading to 22.05.00, exactly on the pip of the time signal. But once set, the digital watch is precise.

Similarly with digital traction controls. To help with the setting-up, GEC interfaced the Class 91 control system with an analogue computer, simulating the characteristics of the locomotive's traction equipment so that the electronics software could 'control' the locomotive.

GEC's electrical engineers are particularly proud of the G426 traction motor for the Class 91, which develops 30% more power for a similar weight to the GEC motor in the BR Class 87 locomotives. It first ran in mid-1987.

Newman calls the motor the 'quiet success'. Suggestions that it has already been rendered obsolete by three-phase drive do not go down well. 'It might be outdated', concedes Newman, then adds, 'but it won't be outdated on a price basis for a long time to come. It will only be beaten by ac where ac is specified.' In performance terms, 'there is absolutely nothing this motor isn't going to do that an ac motor could do.'

A reassuring feature of the motor is the closeness of its peak and continuous ratings (1,175kW/1,135kW). As a result there is no need for fancy thermal modelling or other systems to protect the motor against overloading. In Newman's words, 'It's bloody nigh impossible to make it do anything it doesn't like.'

All the electrical equipment first came together on the GEC-TPL combined test at Preston. Here the control system, transformer, rheostatic braking resistances and a bogie-set of traction motors could be tested under full load, simulating service operation over a variety of routes.

The main emphasis was on system development, for example studying stability, interaction and possible interference, rather than route simulation. The equipment was configured exactly as mounted on the locomotive, even to the correct lengths of cable and the 11° inclination of the motors.

With such a powerful installation, over 2¼MW, taking in power at 25kV single phase for the traction equipment and pushing out 415V three phase, Combined Test represented a potential disturbance to the local electricity supply.

During the second half of 1987 the engineers were visibly less tense as assembly progressed along the Crewe production line. It was, indeed, a case of finish with care. On 4 January 1988, 91001 turned its wheels for the first time as it left the assembly shop to be weighed.

But, with the interruption of the formal 'roll-out' ceremony on 12 January, it was not until around 22.00 on Sunday 14 February that 91001 was signed-off to BR. Back in February 1986 you would have found plenty of people willing to bet that Electra would not happen to time. Now, as with most challenges, once something has been achieved, its achievement is taken for granted.

This article is meant as a tribute to the hard work and long hours by the engineers in GEC, its subsidiaries and subcontractors, BR's IC225 project team, the M&EE Department and BR Research, not to mention the consultants and other outside specialists, who made the impossible happen.

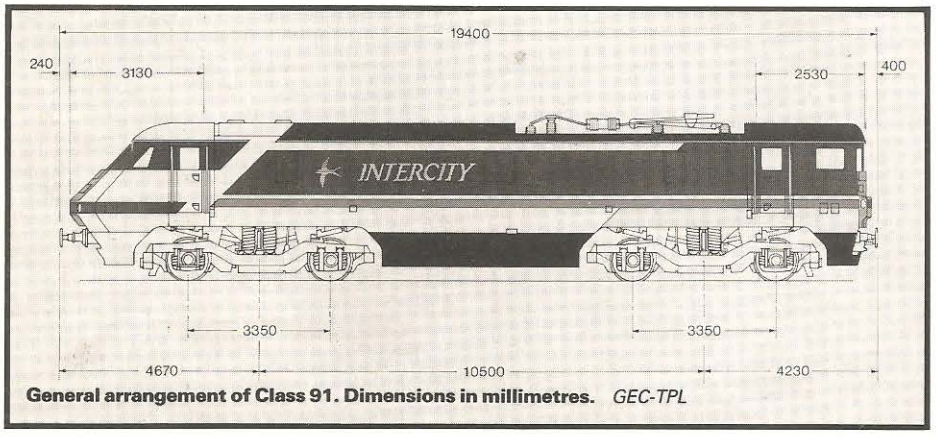
NOW, the scene shifts to the Railway Technical Centre for Type Approval testing and then to Bounds Green Inter-City Depot, as the first 10 Electras roll off the production line at fortnightly intervals. Getting Electra into service has received the same management attention as the rest of the project. For the first time in living memory, BR has got the maintenance handbooks *before* the locomotive, and depot staff have been undergoing training at Crewe.

But even in the celebration of the official roll-out, the project teams were not relaxing. The most extensive approval testing and development-running programme seen on BR has to be completed by August, plus the accumulation of 1 million locomotive miles on the track by the end of the year.

Apart from the pressure to get the first 10 Electras ready for the full electric service to Leeds in October — a year ahead of schedule — BR also has to decide by September whether the Class 91 is acceptable. BR can only exercise the option to cancel the outstanding contract by 1 September if the performance or reliability are below expectation. Otherwise the Crewe line starts rolling again, with 91011 delivered in February 1990.

And for Higton and Rollin, there are the additional pressures of taking the other part of IC225 — the Mk 4 coach — down the same road by 2 April 1989, with around five months lost because of the change in bogie.

No one is under any illusions that Newman's 'puffs of blue smoke' or one of Rollin's 'elephants' may not suddenly appear as Electra starts building up the miles. Brian McCann speaking at the roll-out ceremony set the tone: 'When you've done 90% of the work you're only halfway there.' But he did add, 'I'm looking forward to the next six months with optimism.'



General arrangement of Class 91. Dimensions in millimetres. *GEC-TPL*

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