A 7 ¼" Gauge British Railways 2-8-2

Introduction

After completing the build of a 'converted' Royal Scot number 6115 *Scots Guardsman* in late 2008 – a 9-year project largely done before retirement – it was time to carry out a major overhaul on my *Flying Scotsman.* This was a task that was somewhat overdue after she had given me 40 years of excellent service. During this overhaul thoughts turned to what to do next. Building a 9F was top of the list of potential locomotives, as I had regularly seen them hauling heavy iron ore trains from Bidston Docks to the John Summers steelworks on the Wirral in the 1960's. I had been collecting data for some years on the full-size 9Fs and had a number of drawings covering the main frames, motionwork, the smokebox, pony truck etc.

Fig 1: *Scots Guardsman's* first run at Bentley Miniature Railway in May 2009

However, despite having collected all this information, I was unsure whether a 9F was what I really wanted to do, as many 9Fs had already been built. Many years ago, there was a photograph on the cover of 'Model Engineer' of a 5" gauge 2-8-2 version of the 9F and, as you may know, in the early days of British Railways Robert Riddles (the boss) was at odds with his assistants Cox and Bond about whether the proposed heavy freight loco should be a 2-10-0 which Riddles favoured or a 2-8-2 which the others preferred. After considerable debate, unsurprisingly the boss won and the 2-10-0 eventually appeared as the last of the standard designs to do so. However quite a lot of work had been done on the proposed design of the 2-8-2 which, as the work progressed, would have drawn heavily on many items from the Britannia class. It would, for example, have utilised the existing Britannia boiler, as there was obviously space for the firebox above the rear trailing truck and thus avoided the need for a new boiler design in which the firebox had to sit above the rear set of driving wheels. The driving wheels at 5' 3" diameter would have been slightly larger than the 2-10-0 (at 5'0") and similar to other standard designs in existence. This would have enabled it to operate freight trains at the higher speeds that were envisaged at the time, though the 9Fs were subsequently found to have a fairly spectacular turn of speed on occasions, with claims of 90mph being made. So, the idea grew that a 7 ¼" gauge 2-8-2 would make an attractive, powerful and fairly unusual model. In particular, from a modelling point of view there was more freedom do my own thing and enjoy the pleasant task of designing a new loco rather than using existing material.

Fig 2: *Flying Scotsman* at Bentley after completion of the major overhaul in May 2011

Design

I managed to acquire a very simple general arrangement drawing of the proposed new 2-8-2 locomotive from E.S.Cox's excellent book titled *British Railways Standard Steam Locomotives*, as well as the detailed background to the 2-8-2 and much useful information from the Railway Correspondence and Travel Society (RCTS) book on the *BR Standard Steam Locomotives (Volume 4)*. Armed with this information and the other data I had collected on both 9Fs and the Britannias, it was a fairly straightforward task to make a full size (for 7 ¼" gauge) general arrangement drawing of the 2-8-2, using 1.54" per foot. This was an important drawing as far as the model was concerned as, besides capturing the key dimensions of the prototype, it also had to deal with the many minor design issues associated with a working 7 ¼” gauge model. As usual, my copy of the *Highlander* drawings proved invaluable, providing inspiration when in a ‘tight corner’.

It was also essential to draw a plan view of the locomotive chassis at this stage to check the clearances, as from the outset it was a concern that getting the long fixed wheelbase round fairly tight curves could be a potential problem – as there were no flangeless centre driving wheels as the normal 9Fs had and the movement of the rear truck is constrained by the presence of the main frames. Considerable effort therefore went into ensuring that the two trucks and the four sets of driving wheels would negotiate at least a 50ft radius curve and perhaps a bit less. It was also important at this stage to ensure that there was sufficient clearance between the front coupling rod and the slidebars as the front driving wheel sits right behind the slidebars and crosshead and some side clearance had to be built into the design to allow for the movement of the wheelsets when negotiating corners. The rear section of

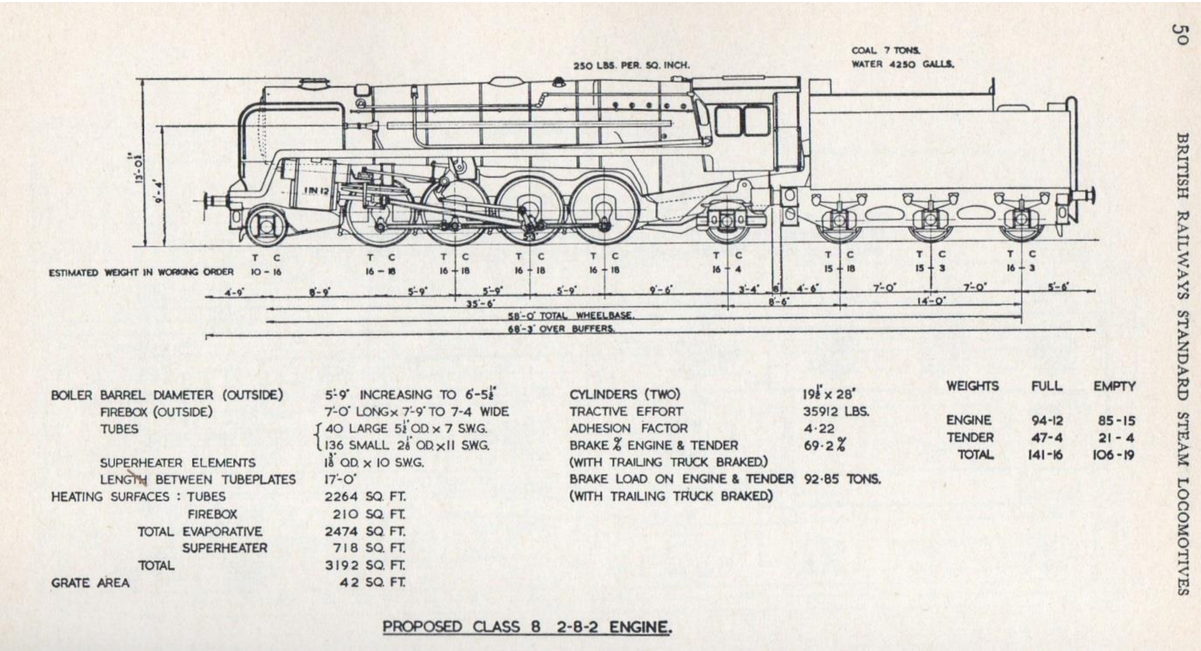

Fig 3: The drawing from E.S.Cox’s book that started the project – this shows a BR1G inset tender (often fitted to the Britannia class as well as the 9Fs) and the smokebox regulator. These engines were known as Class 8 initially but would have become Class 9 later when the power classification system was changed.

the main frames was angled inwards by ¼” on each side (after the rear set of driving wheels) to provide a little extra clearance for the rear truck. The design would now nominally handle a 45ft radius curve, which is considerably tighter than we have at Bentley Miniature Railway, so all was thought to be well. As the full-size locomotives would have been based on Britannia practice wherever possible, an early consideration was that the model should have a smokebox regulator (unlike the 9Fs which have the regulator in the dome). I initially considered using use a commercially available high temperature ball valve but the best I could find was only capable of operating at up to 250 degrees centigrade external temperature (which would have been fine if it had been located under the dome). I therefore concluded that as the temperature inside the smokebox could be much higher – possibly up to 450 degrees centigrade, when working hard – a cylindrical valve regulator would have to be designed. I was fortunate that Peter Southern had found a suitable regulator design for a 5” gauge American loco in a nice book titled *'So You Want to Build a Live Steam Locomotive*' by Joseph Foster Nelson, who lived in California and (unknown to me at the time) was a senior mechanical engineer working at ITT Gilfillan – a company I had cause to visit when I was involved in the procurement of a number of specialised radar antennae from them in the 1980s. This design was used as the basis of my smokebox regulator. The locomotive would also have a double chimney.

Whereas wheel castings were available for the pony and rear trucks (from the 9F/ Britannia sets from Horley Miniature Locomotives) I was unable to find any suitable ones for the driving wheels, so an early task was to draw and make a split pattern for these to be cast. The T H Dick iron foundry in Hull subsequently cast the driving wheels in a good grade of cast iron which should wear well (unlike some grades which machine easily but wear out easily too). Steel tyres for the driving wheels could, of course, also be fitted later if ever needed.

The boiler design was based closely on that previously done for *Flying Scotsman* a couple of years before with all the principal features being the same – only the shape of the firebox and some dimensions change. The boiler is of welded steel construction without superheaters. The boiler was drawn out full size and the finished drawings were then passed to the late Harry Holt for construction to full CE standards. Although the plan included the smokebox regulator, provision was made in the boiler design for a conventional regulator to be fitted beneath the dome with a cover plate on the backhead to allow a regulator bush and gland etc to be fitted should there ever be problems with it. In the event, this has not been needed.

The cylinders and valve gear were similar to those designed and built for *Scots Guardsman* making changes to cover the larger bore and stroke and external shape – they are 2 ½" bore by 3 ½" stroke. With a port size of ¼" and with 3/16" lap, this gives a cut-off of about 82% and therefore good starting capability. The exhaust passages were designed to be turned back into the cylinder blocks leading to a simple exhaust pipe arrangement.

Having cleared away the principal design features for the loco, there remained a decision to be made on which tender to model. As you may know, there was a range of BR tenders fitted to the Britannia's and 9Fs, ranging from the popular inset versions (BR1, BR1A and BR1G, 7 tons coal, 4250/5000 gallons) shown in Figure 3 to the full sided versions (BR1B,C,D,F and K). An inset tender was discounted for practical reasons as it is easier to sit on the wider versions which would allow more coal and water to be carried anyway. So a BR1C (9 tons coal, 4725 gallons) was initially chosen as it is a more substantial tender, similar to that provided for the LMS 'Duchesses' which better matches a large loco. However, in BR days there had been a proposal to build a stretched version of a standard BR1G tender to provide additional water capacity (7 tons coal, 6000 gallons) for those 9Fs to be used on the Southern Region of BR (where there were no water troughs). It turned out that the 9Fs were rarely used on the Southern and the tenders were not built. So, it seemed to make sense to me that if the locomotive never actually existed, it might as well have a tender that never existed too. So it is has a stretched version of the BR1C tender - about 1½" longer than normal.

Finally, I set about acquiring photographs and was pleasantly surprised to find a vast store of photographs on the internet, taken when *Britannia* was stripped down for its major overhaul at LNWR Crewe during the period from 2006 to 2010 – see: http://fraserker.com/britannia/. Further photographs were found covering the 9Fs on various websites (including Station Road Steam which featured a large number of photographs of a superb model 9F). A trip to the National Railway Museum in York to see 'The Great Gathering' of all six LNER A4 pacifics in 2013 provided the opportunity to photograph *Evening Star* which gave me the remaining items of detail needed. This event also convinced me that my new *Morning Star* (the name was chosen by an old friend shortly before he passed away) would look better in Brunswick Green livery than in plain black. I also decided that it would carry the number 91000. It is unclear whether this would have been the number series allocated had these locomotives actually been built – the first 9F was number 92000 and this could easily have been allocated to the 2-8-2 instead. However, as the austerities had already taken the 90xxx numbers, I decided in favour of 91000 on the hopeful basis that maybe there was a lingering desire in BR to eventually build the 2-8-2 anyway, in which case it had a number series already waiting. Finally, in memory of Bidston Shed where just three 9Fs were shedded for working the John Summer's iron ore trains, it would have a 6F shed code. One of these three (number 92203) was the locomotive in charge of the last steam hauled iron ore train to the steelworks in November 1967, and was then purchased straight from traffic and preserved by the late David Shepherd as *Black Prince*, by the way.

As with *Scots Guardsman*, metric materials and fixings were chosen wherever possible to take advantage of their relative cheapness and availability. The actual construction, however, is all in imperial sizes. It was important to ensure that the engine would be as heavy as possible to provide good tractive effort without compromising the external appearance. I had seen a model 9F some years ago which had not been built sufficiently heavily and was prone to excessive wheel slipping and an inability to use the power available. The opportunity was therefore taken to build in as much weight as possible by using substantial materials wherever it could be done. Consequently, the main frames have 25mm thick stretchers adjacent to the driving wheelsets with no lightening holes, of course. This, together with a heavy steel boiler and smokebox, plus taking every opportunity to add weight discretely wherever possible was thought to be satisfactory.

The rest of this article is not an attempt at detailing the construction but instead includes some of the areas of construction that I found to be a bit tricky, interesting or unusual and I hope that my experiences are of some value to others.

Tender Construction

Following the completion of the general arrangement drawings of both the engine and the tender, construction began with the tender, on the basis that if the engine was completed first I would be impatient to complete the whole locomotive and run it, so it's better to have the tender waiting for the engine to catch up – anyway it is something of a quick win which provides encouragement when faced with the somewhat daunting task of building a complete locomotive from scratch. I followed my usual plan of only producing detailed drawings where really necessary, accompanied by a lot of sketches to save time. The tender chassis is pretty conventional, though with coil springs hidden inside fabricated dummy leaf springs. As the chassis is fairly straightforward, I opted to 'drill and mill' the frames rather than have them laser cut – this was quite a simple task and probably just as quick as making another drawing, sending it off etc. The wheels were made from solid steel rather than cast iron as it would be almost impossible to see the spokes unless you are lying down pretty much at rail level. Some suitable blanks were obtained from M-Machine in Darlington who kindly chopped six thick pieces off a large piece of free-cutting mild steel . A pattern was made for the horns which our local non-ferous foundry (White Eagle) cast in gunmetal. The axleboxes are steel, housing twin ball-races in each box. Vacuum brakes are fitted to the tender, as well as a screw-down hand-brake, of course. The footrest for the driver is simply bolted on to the tender front ‘buffer beam’ and is thus easy to attach and remove and does not impact the locos overall appearance when in use.

The tender sides were interesting to make as they have curves at the bottom as well as the top and were specially rolled by a colleague who had access to a suitable bending machine. Vertical bars were milled to fit inside the tender sides and these were flush- riveted to the sides and then bolted to the various other angles inside the tender body. A separate welded stainless steel water tank was fitted, with twin filtered water feeds. The top of the tender has a suitable flat portion for the driver’s seat. Tender bodies are surprisingly tricky things to assemble when you have a separate water tank inside and I opted for fitting the tank to the

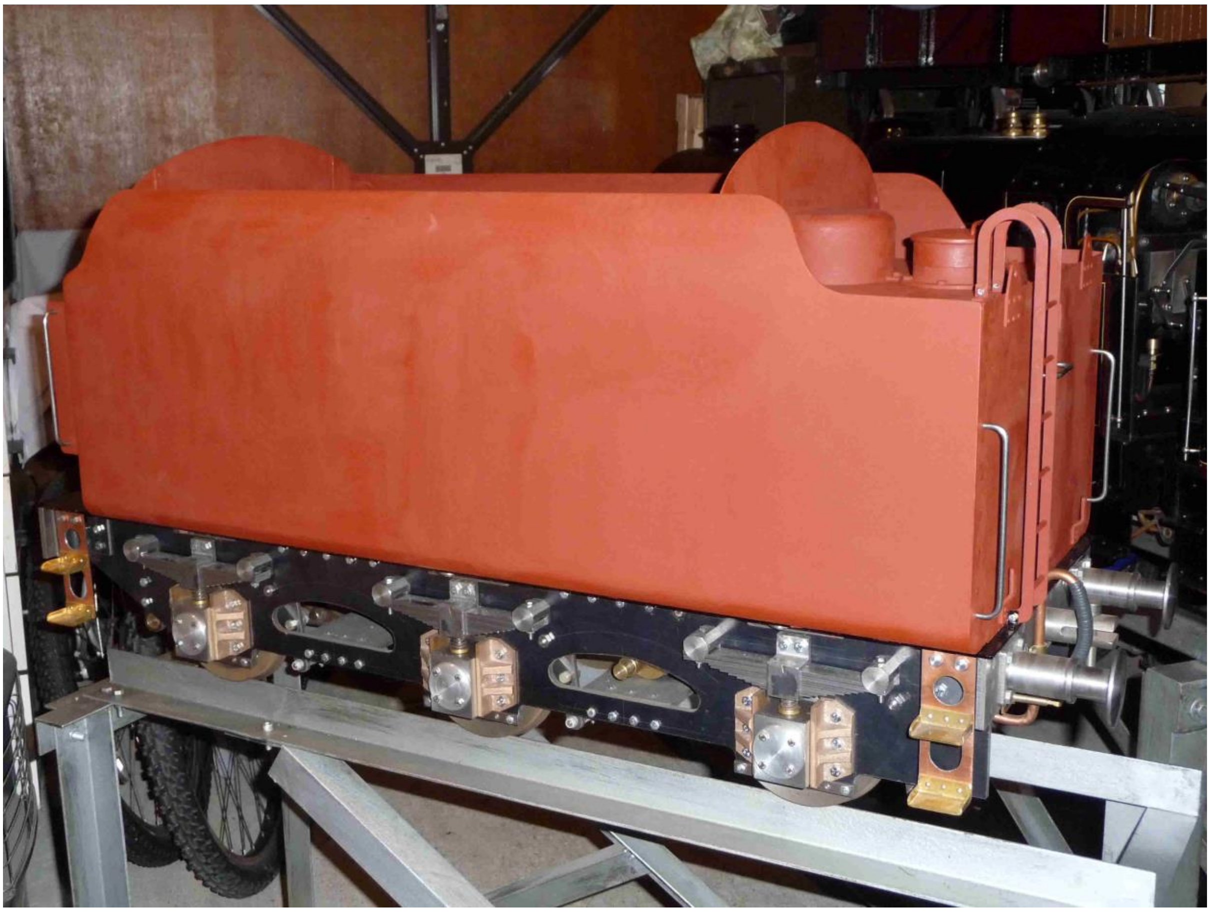

Fig 4: The completed tender awaiting final painting – it is about 1½” longer as a result of stretching than a normal BR1C tender. The vacuum release valve is just visible between the centre and rear axles.

soleplate and lowering the completed body over it. The alternative is to fit the tank through either the front or the back or even the top – all of these have disadvantages. Although a small amount of water capacity is lost compared with making the whole body a water tank, I find this a very convenient way of building tenders, as they don’t rust, they are a bit heavier (which helps stability) and you don’t have to make them watertight – in fact there are some large holes in the soleplate help to get rid of any water that happens to get down there.

Locomotive Construction
The locomotive construction began as usual with the main frames, buffer and drag beams and the stretchers. The frames were made from standard black steel and were initially kindly

skimmed along their long edges by Mike Carroll at the Bluebell Railway where they have a very large milling machine. I then continued the milling to their final to shape after chain drilling first to remove the larger amounts of metal – as with the tender frames, this approach was chosen rather than having them laser cut as there had been problems on the Royal Scot's frames previously with heat distortion and I didn't want to incur the expense of water jet cutting. Horns were made in steel this time, pre-machined and bolted through the frames using a jig, with the axleboxes in cast iron with steel axles running in the plain cast-iron bearings. Given that this is going to be quite a heavy engine, large axlebox bearing surfaces were designed in with three lubrication points (to hopefully avoid the horror of having a blocked feed hole) in a 'slot reservoir' in the top of each box. The slot (which is covered) is fed by a telescopic tube to allow for the vertical movement of the axlebox and this, in turn is fed from a dummy sandbox. It was pleasantly surprising to find that on assembly there was only a few thou variation between all four axle centres and well within the tolerances that you would normally have on the coupling rods.

The two trucks were a nice job to make – with side-control springing being at the heart of the designs. The front pony truck has plain cast iron axleboxes whilst the rear truck is very similar to the tender, using twin ball races on each side, again with hidden coil springs in the dummy leaf springs. About this time, the springing arrangements were considered in some detail using guesstimates of the sprung weight of the loco (including water in the boiler) and aiming to concentrate a large amount of the total weight on the driving wheels. This is much easier to do than on a 4-6-0 (where there is a tendency for too much weight to be on the leading coupled axle) as the 2-8-2 wheel arrangement makes the engine more balanced. So, the plan was to only load the front and rear trucks sufficiently for the side control to be effective without derailing the trucks at extremes of movement when the side-control spring force is at its greatest. The rest of the weight is then on the four main axles which should give good adhesion.

Driving Wheels

An early problem was always going to be machining the driving wheels as they are too big to easily fit into my Myford Super 7 for the first task of facing and boring whilst being held in a 4-jaw chuck. I looked at swopping the Myford for something larger, ranging from the new Far Eastern products to the second hand Colchester/ Harrison lathes. Despite getting close once or twice, the Myford was retained (but see later) and the kind offer of Peter Southern taken up to use his Harrison lathe for the facing and boring operations. My technique here was to hold the wheel casting in the 4-jaw chuck with the outer face of the wheel visible – opposite to normal practice - this enabled the facing to be done so that the spokes etc were at the correct distance from the outer edge of the rim and the visible side of the wheel running as true as possible. The wheel was then drilled and reamed. All the remaining machining was then done on the Myford, using a stub arbor in the headstock and the large 9" diameter faceplate which is now available.

For some time I had been thinking about the problem of quartering the driving wheels with various schemes using jigs, plates etc being considered. After a while, I found an interesting U-tube video by an American loco builder which gave me the perfect solution – the 45 degree method. See this link: http://www.youtube.com/watch?v=q0smMBVb-Fs . As you will see, this is a straightforward method of producing a keyway in each driving wheel with all eight wheels being identical and the other half of the keyway slots being machined in a straight line in each axle. For those who are not familiar with this simple way of quartering driving wheels, this is how it works. Machine all driving wheels through to completion, apart from the crankpin holes. Make up a jig to hold the bush from a standard broaching machine. Drill and ream the crankpin holes in the wheels (making sure that all of them are exactly the same using a fixture on the vertical milling machine with the milling table locked solidly) and similarly **make the equivalent hole in the jig at the same setting**. The broaching bush is clamped to the jig so that the bush slot can be set to exactly 45 degrees to the centreline between the crankpin and the axle. It would of course be possible to drill the broaching bush and bolt it solidly to the rest of the jig with two suitable bolts, but I preferred to clamp it on this occasion as I had to return it to its owner! The jig is then placed into the axle bore and is located by a pin which is a nice fit in the crankpin bore – see Figure 5. Cut a keyway in all driving wheels using the broaching machine, making them all exactly the same. Note that when the wheels are pressed on the axles the key will set the quartering position.

Fig 5: The Quartering Jig. The broaching bush goes into the axle bore and is held by the jig which is located by the pin in the crankpin bore (nearest the camera). The keyway is cut at 45°, with the angle of the broaching bush being set by the plate visible at the top, using a piece of the ¼" keyway steel (that will be used to make the keys) fitted into the broaching bush slot. A keyway in the jig is also cut at the same time as that in the first wheel (after this photograph was taken) which helps repeatability. The main part of the jig is made out of 12mm bright steel bar, by the way.

The left and right-hand keyways in the axles are accurately machined in a straight line in the milling machine, with both keyways on a given axle being machined at the same setting. As the wheels set out as being identical, when one of a pair of wheels is turned the correct way round and then rotated so that the keyways line up with that in the axle, the cranks are set to 90 degrees. Although the aim is to set the keyway at exactly 45 degrees, it is more important to ensure that all the wheels are identical, so the coupling rods fit and rotate easily. Although there is little chance of the broaching bush moving from one wheel to the next, the first time it is used the broach also cuts a ‘keyway’ in the jig and this then is a useful guide as each successive wheel is broached.

With wheels complete and the keyways cut, prior to pressing the wheels on the axles the balance weights were made – these are made up of steel plates riveted through with the centre filled with an epoxy loaded with atomised iron – this is a particularly useful material as when used it is almost ‘solid’ iron, making it surprisingly heavy . I am uncomfortable about using molten lead for balance weights and have found that loading normal epoxy resin with this

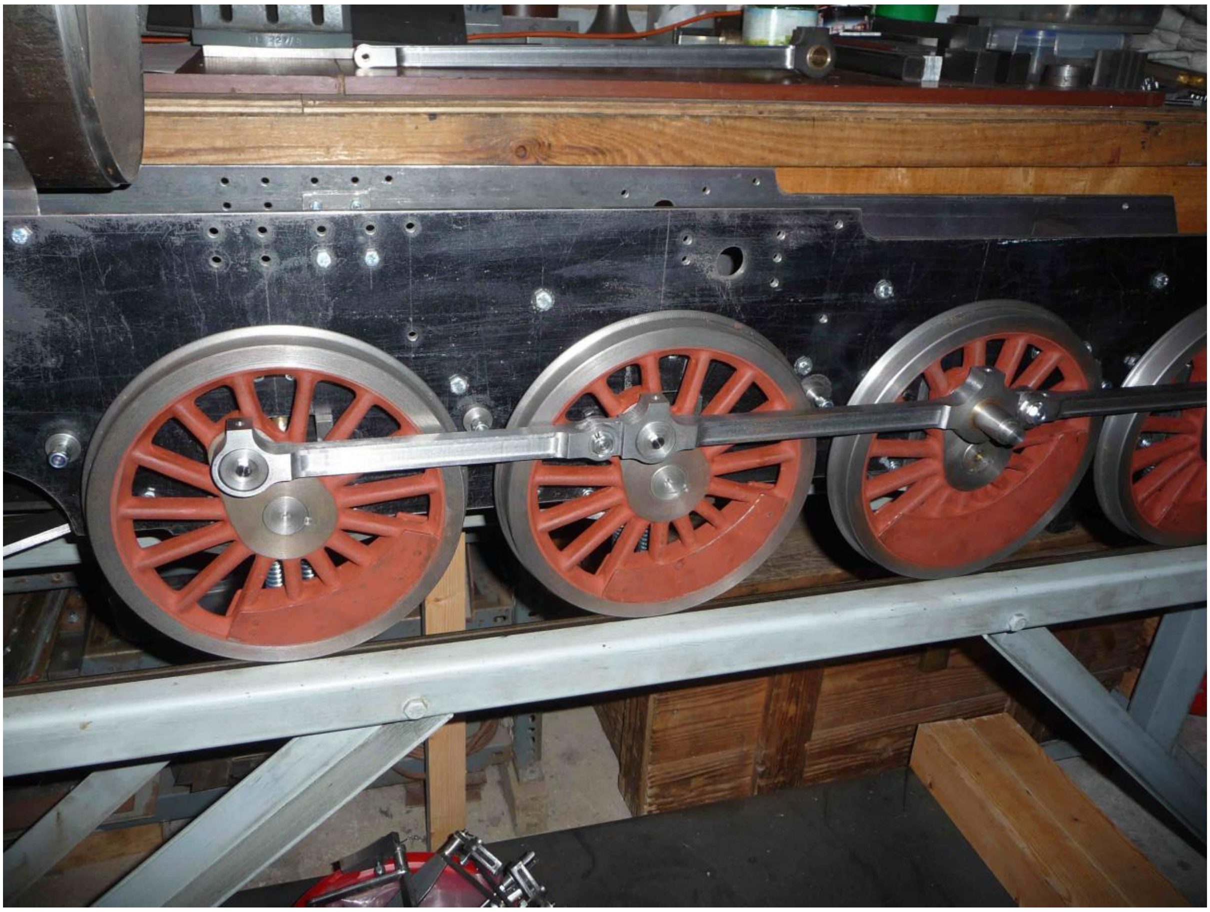

Fig 6: Quartered driving wheels with the coupling rods fitted – it was a great relief to know that the 45° method actually works and that the coupling rods rotated freely. The keys and the epoxy/ atomised iron loaded balance weights are also visible.

atomised iron (definitely not iron filings or turnings) – up to 75% atomised iron by volume, so only 25% epoxy resin by volume - produces an excellent material of 3/4 the weight of solid iron which can be pressed down into all the voids between the spokes and dressed at the top for painting. The epoxy behaves as though the iron was not there and, once it has set it is never going to fall out. A slow hardener is used which gives time to do three coupled wheels with each mix and then the two driving wheels at the end, as the weights are larger and more filler is needed. The wheels have to be rotated every few minutes until the filler has gone fairly solid, as it will flow towards the lower spokes if this is not done.

The crankpins were then pressed in with a 0.0005" interference fit on the ½" diameter spigot, with the driving wheel crankpins also pinned to prevent rotation, as they have to drive the valve gear. Finally, the driving wheels were pressed onto their axles again with great help from Peter Southern. These similarly had a 0.001" interference on a wheel seat diameter of 1" diameter. A slight taper was machined of about ½° for ¼" onto each axle which makes the alignment of the wheels and the keys easier before actually pressing them on – making sure that the wheels didn't rotate at all as they were being pressed on and also using some Loctite as both a lubricant and an adhesive to aid the process. It is best not to use a rotating fly press for this operation as this can generate rotational forces (unless measures are taken to stop this happening) which could spell disaster if the wheels rotate at all as they are being pressed on – a hydraulic linear press is much better.

More Chassis Items

The coupling and connecting rods had their profiles cut with a water jet as there can be a huge amount of machining to do to generate rods from solid. The results were excellent and proved to be a far better solution than laser cutting as the steel is not affected by the cutting process - it remains unhardened - and can readily be machined to completion afterwards. Although I had planned to do my own CAD design, in the event Precision Waterjet quickly produced the CAD data from my drawings and quickly delivered excellent rods ready for finishing and fluting. The holes in the rods were included in the water jet process as these were accurately produced a few thou less in diameter than the required finished size, requiring only reaming to complete the bores.

The brake gear was generally a straightforward job though the brake hangers are a bit more complicated than normal as the wheel flanges are quite close together to keep the coupled wheelbase as short as possible and the hangers sit 'behind' the wheels in the space between them and the frames with an extension piece coming forward between the wheels at the bottom to hold the brakes shoes. This is possible because the frames on those BR standards which have wide fireboxes were set closer together than in the older designs of the 'big four' companies, with the axleboxes centrally located in the frame plates. As usual, I opted for the brakes on the loco to be non-operational, relying instead on the vacuum brakes on the tender when running 'light engine'. This avoids any possibility of locking the driving wheels and putting a 'flat' on them.

The motion brackets on some of the BR standards are interesting, as the slide bars are not bolted to the back of the cylinders as is often the case but instead are fully supported by a substantial bracket, similar to some Bullied designs. This is not a method I particularly like, preferring a solid attachment on the rear cylinder cover – but I did it that way anyway. Near the end of the construction, I discovered that the team currently overhauling the full-size *Duke of Gloucester* have, I understand, decided to make a new design of rear cylinder cover to which the front end of the slide bars will be attached. I think I would have done it this way had I known that at the time. Because the leading coupled wheels are directly behind the slide bars, the brackets are bolted to the top of the main frames and then loop over the front coupled wheels. So, the question was how to make this complex and strong component. Castings were considered but the eventual solution was to fabricate the brackets out of steel and weld them up prior to final machining. This required a suitable jig to hold the parts in place while the welding is done. The final result was very good and these brackets will never 'bend' and I probably will never make the rear cylinder cover attachment version.

Cylinders and Valve Gear

The brackets to hold the expansion links are a fairly complicated shape – had the 2-8-2 been built in full-size, they would have followed Britannia and 9F practice and have been an all-welded assembly. I decided, however, to fabricate these items and they are thus quite straightforward to make, with the parts bolted together. At this stage, I needed to complete the design of the valve gear. This was similar in concept to the Royal Scot, with the appropriate changes to cover the longer piston stroke etc using the excellent little book on Walschaerts Valve Gear by Don Ashton – in particular he deals with the otherwise mysterious subjects of understanding the components that add together to provide the correct valve travel and of getting the expansion link backset determined, as well as other good advice on such items as getting the eccentric rod holes in the correct place. The book has only 16 pages but is extremely useful – there is one for Stephenson's Link Motion as well. Don Ashton also has a web site on which there can be found a couple of computer programmes to

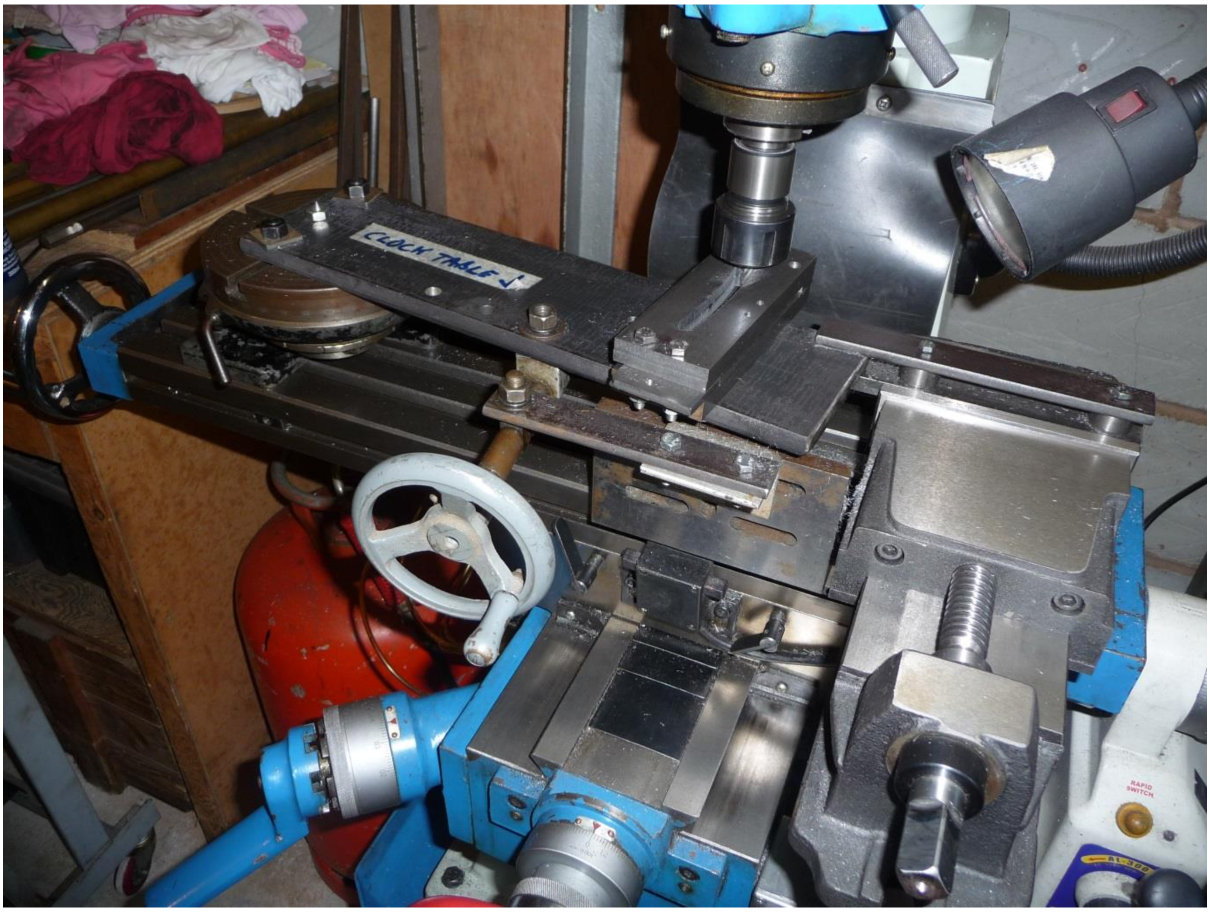

Fig 7: Milling the Expansion Links slots – the grey handwheel in the centre moves the link blank as milling progresses, My normal 6" rotary table would be hard to use as the link radius is over 11" and juddering would be a problem – the fixture on the right also helps to minimise juddering whilst allowing the job to swing at its correct radius.

aid valve gear design. The opportunity was taken to load up my dimensions and check out the anticipated valve events. This was particularly interesting as it allowed me to optimise the position of the lifting link which sits ahead of the expansion link and therefore contributes to the movement of the valve rod as it swings – unlike the Royal Scot and A3's where the valve rod is constrained to move in a straight line by a slotted extension to the rod to the rear of the expansion link. Having satisfied myself that I had a basically good design, the valve gear was drawn out very carefully and all the clearances checked.

The reversing gear, which is a screw reverser fitted to the top of the left-side expansion link bracket, could then be completed. After some deliberation, I settled on a 3/8” x 20 tpi (left-hand) thread, being a compromise between not having too many turns of the handle to change from forward to reverse and not so few that the gear could move back on its own. All was well until I realised that with the screw being hidden beneath the running board the driver would have little idea what cut-off he was using (or even whether he was in forward or reverse). The reversing gear in the cab (which employs a pair of bevel gears to rotate the reversing shaft) is therefore equipped with an indicator which uses a similar 20tpi screw.

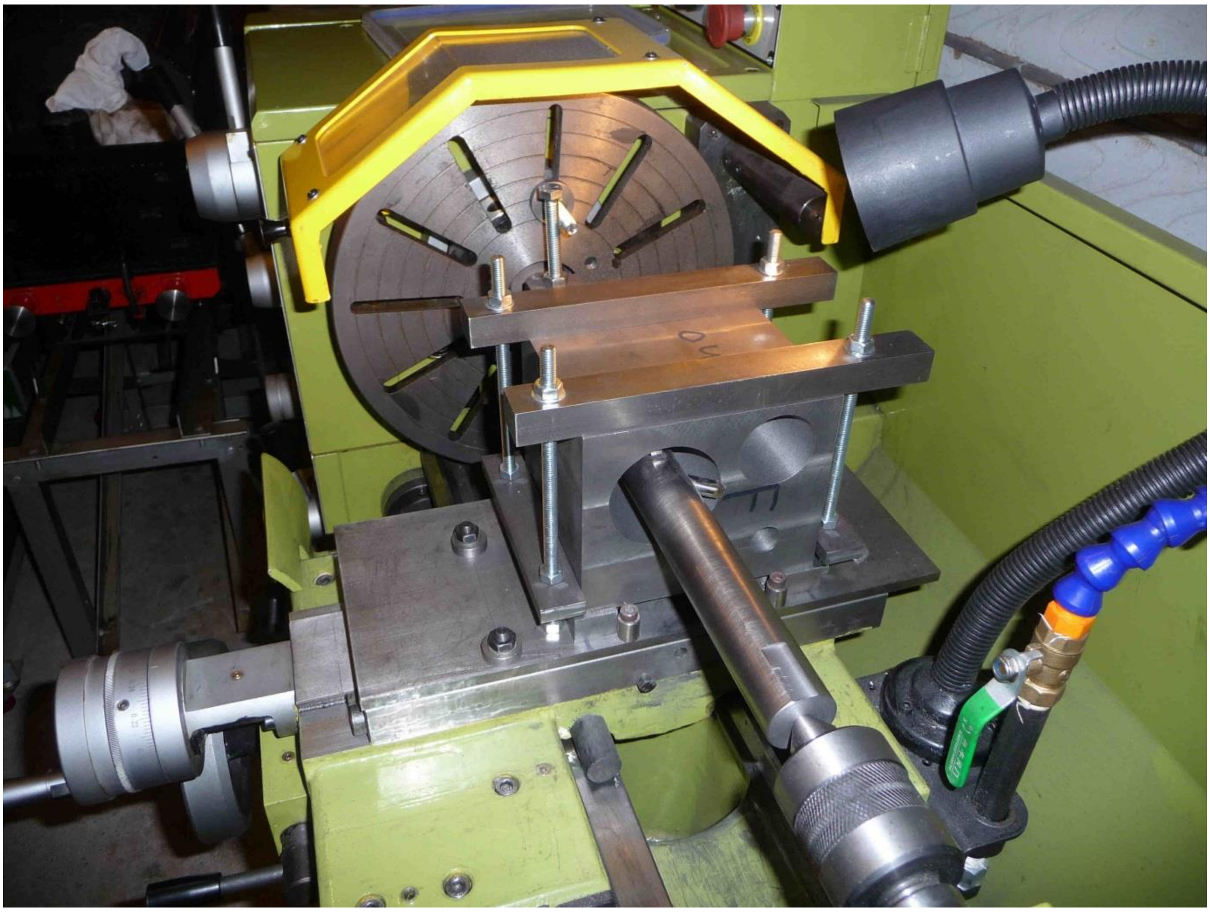

Fig 8: Boring the cylinders using a ‘between centres’ boring bar – the bore for the piston valves is seen to the right of the main bore, with the exhaust passage below it. The plate fitted to the cross-slide overcomes the absence of T-slots on many modern lathes. The tool-bit (set at 50° to the rotating axis rather than 90°) can be seen inside the bore. The main bores are 2 ½” diameter.

The expansion links were then made – a substantial fixture is required to hold the pair of links in their initial form so that the milling of the curved slots could be done. Figure 7 shows the fixture in use – the radius of the links is the same as the hole centre dimensions of the valve rod – following which the weighbar shaft and lifting arms were made and pinned.

The next jobs to be tackled were the cylinders. Having had some problems with voids in the cylinder castings when machining them for the Royal Scot, requiring the bores to be made larger than the 2 ¼" dia I had intended, this time the cylinders were machined from solid blocks of Meehanite. The blocks were first milled square to the overall finished dimensions, using a 2" diameter face mill, running at 200 rpm. I had initially planned to machine the cylinder main and valve bores using a very large lathe which a local machine shop trusted me to use. However, it was obviously going to take some time and so I decided to purchase a Warco GH1322 lathe to be able to do the job at home, including drilling the hole for the exhaust passage at top of the block to the rear of the valve bore. If I had bought it earlier I would have been able to do that first job on the driving wheels at home too. The cross-slide of the Warco does not have T-slots and so a thick plate was made which picked up the two bolts for the top-slide fixing and a further two holes were drilled and tapped in the cross-slide itself to hold the plate at the rear. The cylinder blocks were then bolted to the plate with suitable packing to bring each block to the required centre height for each of the main bores. Once in the correct position, the cross-slide was **tightly locked in place** and each bore was commenced by drilling a hole initially by holding a drill in the 3-jaw chuck, then opening it up in stages to 1 3/8" (the largest drill I have) with this drill finally held in a MT4 sleeve directly in the lathe mandrel (which is MT5). A pair of 'between centres' boring bars were made to complete the actual boring - a pleasant task largely characterised by watching the operation proceed by itself and drinking lots of cups of tea! The tool-bits in the boring bars are set (arbitrarily) at 50° to the rotating axis (rather than 90°) to allow a micrometer to be used to measure the distance from the tip of the tool-bit to the rear of the boring bar itself without the back of the micrometer being in a hole. The problem that usually occurs when using a boring bar is that it is often difficult to accurately measure the bore with an inside micrometer or callipers without taking the boring bar out, which I feel is undesirable. So, the technique here, since you will know the exact diameter of the boring bar, is to measure the distance from the tip of the tool to the back of the boring bar with the micrometer after completing a cut and then make a small calculation (bore diameter = twice the measurement made minus the known diameter of the boring bar). To take the next cut, simply set and lock the micrometer to the new desired setting and slacken the tool-bit. Then, with the fixed jaw of the micrometer touching the back of the boring bar carefully bring the tool bit forward towards the moveable jaw of the micrometer (making sure it doesn't rotate at all) to the place where it feels right - as you would for a normal micrometer measurement. The tool-bit is then locked in this position, the measurement double-checked and the cut taken and the process repeated until the desired bore diameter is reached. Excellent accuracy is obtained by this method. Consideration was given to adding a 40TPI adjusting screw to the boring bars but, in the event, this proved unnecessary, with all the bores coming out at exactly the desired dimensions, with just a gentle honing to complete. The mounting holes for the cylinders were then drilled and tapped using the jig made when the frames were being drilled. The curved edges of the blocks were milled by clamping them between two large angle plates on the milling machine and taking a series of cuts with the blocks being rotated every 10 degrees between the angle plates – this produces an almost perfect rounded shape. Finally the blocks were completed by jig drilling the holes for the covers and milling the steam passages between the main and valve bores using a 1¼" diameter x 3/16" woodruff key cutter. This operation requires a cut to be made from both the valve chest side and the main bore side to create a passageway connecting the two. These passageways are only 1/8" in from the ends of the bores and there are no studs for attaching the cylinder covers in this region of course.

I used the 3-piece *Highlander* design as the basis for the valve chests, with appropriate dimension changes and fitted two clupet rings on each end of the bobbins (four in total on each valve head) – similarly there are two clupet rings on each piston. More about this later.

As mentioned earlier, the slidebars are not attached to the cylinder rear covers, only to the substantial bracket which holds them in position on the frames. Whilst making the slidebars is straightforward enough, accurately aligning them is tricky. I chose to make a dummy front cylinder cover, through which an extra-long piston rod would slide in a reamed hole, passing through the rear cover as normal. This arrangement eliminated the slight amount of movement you would otherwise get on the tail-end of the piston rod due to the few thou gap that exists between the piston and the bore. The crossheads and the piston rods have a 7/16" x 26 tpi thread and the extra-long piston rod was temporarily fitted to each crosshead in turn (without the piston itself being attached) and the crosshead fitted as normal to the slide bars. After ensuring that the crosshead could move easily over the full range of its travel and was therefore correctly aligned the bracket was drilled using the holes already drilled in the frames and bolted into place. The real piston rods were attached to their respective pistons and screwed into the crossheads and a taper pin fitted to prevent any rotation.

The remainder of the valve gear was then tackled - the various rods were made by using billets longer than the finished rod in each case. This facilitates holding the rods whilst the first task of drilling and reaming the holes in the correct places is done. The rods were then profiled and finished to the required shape and size. A self-aligning bearing was fitted at the return crank end of the eccentric rod and the final length of this rod was checked on the job before cutting metal – the only rod that really needs to be treated this way. Don Ashton's book talks about determining the hole centre dimensions for the eccentric rods without the need to make a dummy adjustable rod. I tried his method but eventually went back to the dummy adjustable rod which can then be used as a drill jig, which I found easier.

Unlike car engines, where the piston ring gaps are fairly generous, with clupet rings the gaps are quite small (about 4 thou) and so it is a good idea to check the ring gap before fitting the rings to either pistons or valve heads at several places in their respective bores – just in case there are any tight spots which could cause a valve or even a piston to cease up. When fitting the rings to the pistons, it is best to ensure that the gaps in the rings are well away from the edges of the steam passages, as it is quite easy for the rings to jam in a passage when a piston is being inserted into the bore if they happen to be in that position. Once in place the pistons do not get close enough to steam passages in normal operation and the problem no longer exists. Not so with the valves – see later.

Prior to fitting the rings to the valve bobbin and pushing the valve assembly into the steam chest bore, it is essential to ensure that the valve is located at the correct position on the valve spindle (effectively the coarse bit of valve setting) and that it is running true on the valve spindle. I like the spindle to have the valve crosshead end threaded to allow a fine adjustment of the valves by rotating the spindle in the valve crosshead when doing the final valve setting. A suitable locknut is then tightened to retain the setting permanently.

The position of the bobbin on the valve spindle is initially checked by a trial assembly (without the valve clupet rings on) of the bobbin/ spindle into the valve bore with the spindle screwed most (but not all) of the way into the valve crosshead to allow for the final fine adjustment in either direction. The piston/ crosshead is then set in mid-stroke position and the valve rod positioned in mid gear. A careful measurement is then made from the front of the steam chest and the front and rear inner bobbin locknuts adjusted accordingly, and gently 'nipped' in place. However, there is a problem of ensuring that the valve is running truly on the spindle which occurs because the *Highlander* design rightly has a hole through the valve bobbin somewhat larger than the valve spindle due to the difficulty of drilling a long hole (5" in my case) true over such a length. So, the hole is larger than the spindle and yet the bobbin needs to run true when the locknuts holding the bobbin are set and tightened. My solution was to take the bobbin/ spindle after carrying out the adjustment described above and then to hold the back of the valve spindle (valve crosshead end) in the three jaw chuck in the lathe, supporting the front end of the valve spindle in the tailstock in a suitable rotating centre and then gently 'skim' the bobbin at each end alternately using a piece of brass bar where the normal lathe tool would normally go (so no actual cutting is taking place), with the lathe running at about 200rpm with plenty of lubricant. When running true, fully tighten the inner locknuts, double check, then tighten the outer locknuts and all should be well.

Before fitting the rings onto the valve bobbins, make sure that the sharp ends of the valve rings are gently filed away on their outer edges to prevent the rings catching in the ports (which, unlike the pistons, they pass over all the time in normal use). Fitting the rings to the innermost slots on the valve head can also be tricky – one method is to temporarily fill the outer slot with string to prevent the inner ring accidently getting into the outer slot and then carefully work the inner ring past this slot and in to its correct place, then remove the string and fit the outer ring. Alternatively, let the ring go into the first slot and then gently ease it back out and into the next slot. Use plenty of oil for this task to minimise risk of breaking a ring, though they are probably more flexible than you might imagine! It is probably also true, that if the ring survives this fitting process, it is unlikely to break later and equally if it does break at this stage, it is probably faulty and should be replaced before final assembly anyway. Getting the completed valve bobbin into its correct position in the valve chest can also be a bit nerve wracking, so it is best to make sure that there are no nasty burrs anywhere (especially where the tapered part of the outer liner meets the slightly larger diameter of the centre liner) and, again, plenty of oil plus a fairly positive push is needed to complete the task. It can be really difficult to get clupet rings into their bores and a good tip is to machine (or even a file) very slight taper in both the main and valve bores in the cylinder blocks and valve liners (extending no more than half the length of the respective spigots). This can make the task of inserting pistons and valves when the clupet rings are fitted, much easier.

Steam operated drain cocks were chosen, partly because the real engines would have had them and partly because I had previously struggled on my other locomotives to find a suitable route for the mechanical linkage from the cab to the cylinders and thought a small copper pipe would be easier to route through. The actual drain cocks consisted of a brass body fitted with a stainless steel shuttle (or piston), provision being made for a light stainless steel return spring to be fitted if it was found that the cocks do not readily return to the open position after a days running. In the event, no spring has so far been needed and the drain cocks work well. A small manifold was made and fitted above the pony truck with the four steam pipes and the feed from a suitable drain cock control valve in the cab. Care was taken to ensure that the steam used to close the drain cocks could be released to atmosphere when it was required to open the cocks.

Smokebox and Boiler

The smokebox tube was made from a piece of 228mm diameter thick-wall steel tube, turned for the recesses at the front and rear – the front for the ring that holds the smokebox door and the rear to accept the boiler barrel. The smokebox door was machined from a piece of 30mm thick steel – this sounds very thick but when the front and rear curves are machined and a boss left to hold the dart, it becomes approximately ¼" thick. The overall weight of the smokebox is quite substantial - this is deliberate to help in creating a heavy engine and to help balance the weight of the firebox at the rear. Machining the curve on the smokebox door might have been a challenge if I had not learned of a neat method of doing this. The curve is 11" radius and the method is to drill two holes in a piece of scrap bar (15mm x 3mm black steel for example) 11" apart, fix one end to a suitable anchor point (I use a modified bolt on the top of the Myford gearbox, allowing the bar to rotate or swivel sideways). The other end of the bar is attached to a plate bolted to the front T-slot on the cross-slide, also able to swivel. Set the cross-slide such that the tool is at the centre of the job with the bar parallel to the lathe axis. As you wind the cross-slide out, the tool tip describes the required arc, as the saddle moves slowly towards the headstock. Subsequent cuts are put on using the top-slide. This is an extension of the method originally used for turning buffer heads, except in this case I did all the rough machining on the Warco lathe and switched to the Myford for finishing as it is easier to find a suitable anchor point.

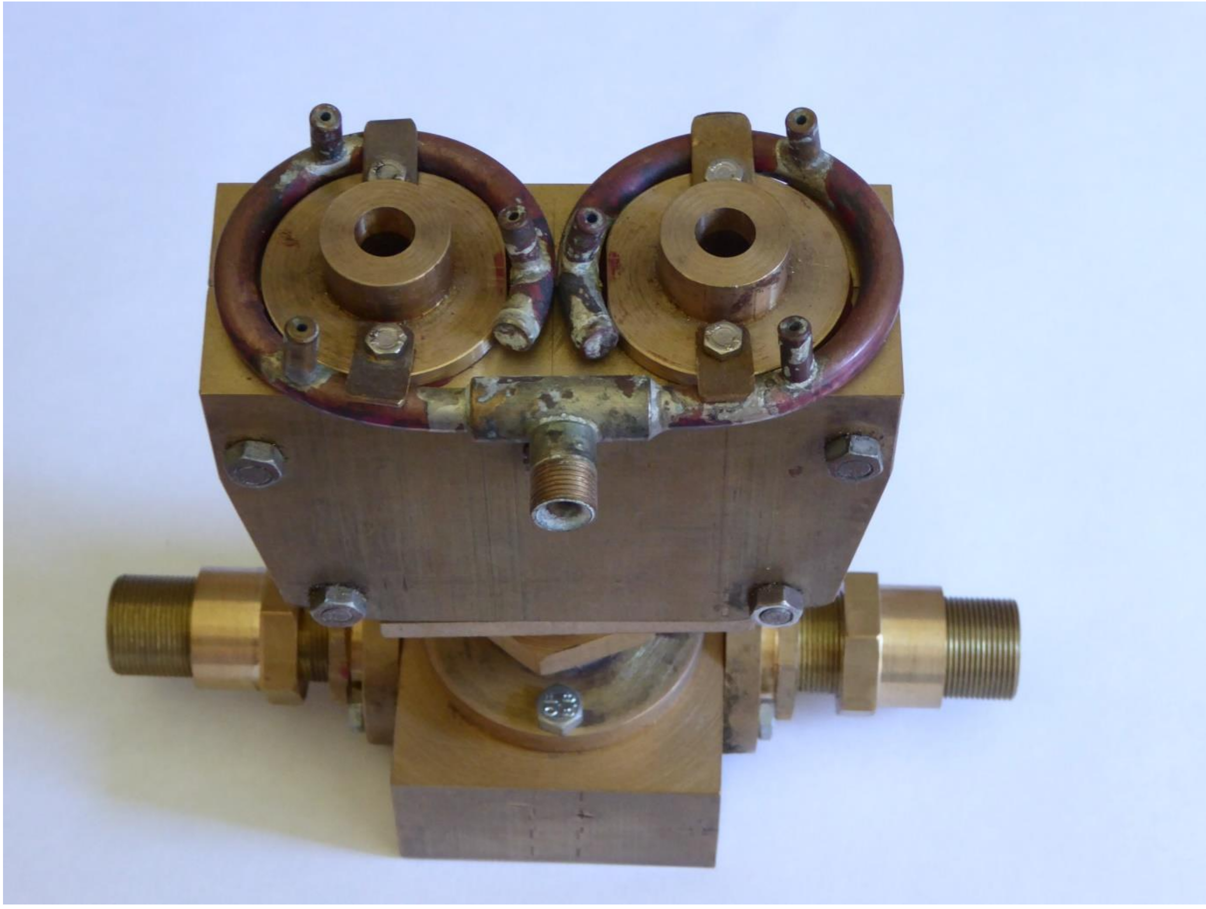

Fig 9: The blastpipe assembly – the exhaust pipes from the cylinders are at the bottom and the blower ring with its six jets surrounds the blast nozzles. I forgot to rotate the top through 90 degrees before taking the photograph and it was assembled into the smokebox before I noticed – the double chimney lies fore and aft, of course!

The Britannia's have a curved cover on the top of the smokebox at the rear to allow the smokebox regulator to be accessed – mine had a ½" x 26tpi plug hidden beneath this cover to allow access to a small bolt that holds the regulator operating shaft to the regulator itself – see later for more information on a modification I made later to improve access to the regulator.

The double blast pipe was made in a similar way that I had used for my Royal Scot - by machining semi-circular section Y-shapes in the mating halves of two pieces of brass, using a 5/8" diameter round-nosed milling cutter. The mating halves were then sealed and bolted together, the final machining done and the blast-pipe nozzles made and fitted. The petticoat pipes were made from pieces of copper tube and the flares put on the bottom by spinning the pipe in the lathe and working the metal, annealing as necessary – Henry Greenly's book on Miniature Steam Locomotive construction is invaluable in areas such as this as it deals with the correct angle, size and position for the exhaust nozzles and petticoat pipes to ensure that the blast really draws the fire.

The construction of the boiler was halted when it was nearing completion when Harry Holt sadly died very unexpectedly in September 2013. Harry had for some time been joined by Andrew Kirk who, he hoped, would continue building boilers after his retirement. In the event, Harry sadly never actually retired but Andrew was able to complete my boiler and go on to build boilers for other steam locomotive and traction engine enthusiasts, thus continuing the tradition of fine boilers that many of us had purchased over the years.

The top feeds are a fairly conspicuous item on the standard locos and I decided to make a pattern and have them cast in gunmetal – again by the local White Eagle foundry. The pattern was made with two substantial spigots to permit holding the completed casting in the correct place for machining - they were subsequently removed after all the main machining had been done. Although I had considered incorporating the clack valves in the top feeds, I opted for separate clack valves beneath the running boards at the rear and leaving the top feeds plain.

The safety valves were tackled next – I used one of Gordon Smith's drawings as the basis of the mild 'pop' action. The safety valves are fairly squat (though I should probably have made them just a little shorter) and sit side by side on the boiler barrel at an angle of 12 degrees to the vertical. I settled for a 7/16" diameter stainless ball fed via a 3/8" diameter orifice which should be large enough to handle the steam produced by a boiler with this amount of heating surface – another quick reference to the Henry Greenly bible provided the necessary data. Hexagonal PB102 was used in what was a straightforward machining task. It is important to ensure that the ring of holes on the top of the safety valve have a total area similar to the main orifice at the base – 3/8" diameter – so that there is no impediment to the release of the steam. So there are ten 3mm diameter holes set in the adjuster disc which fits into a 7/8" x 26tpi thread in the body. Initially, the bodies were made longer than required with more of the 7/8" thread than I expected to need so that the valves could be set to 100psi. I was keen to keep the overall height of the valves as short as possible, so the valves were set using *Scots Guardsmans's* boiler on compressed air. With the adjuster set, the valves bodies were reduced to the correct size and the external profiling completed.

The original plan for the regulator was to use a proprietary high temperature ball valve fitted in the smokebox attached to the main steam header. However, I later decided that as the internal temperatures could get as high as 450 degrees Centigrade, this would be well above the limit that such a ball valve could safely be expected to work at, before the PTFE seats melt. So, a change was made to a cylindrical regulator, made of stainless steel running in a phosphor bronze housing. As mentioned earlier, the idea for this form of regulator came from the book titled *So You Want To Build A Live Steam Locomotive* written by Joseph Foster Nelson in the USA in 1974 and which, although out of print, I managed to obtain a copy directly from a second-hand bookshop in the USA for the princely sum of $10, including delivery which turned out to be about 3-4 days only! By choosing stainless steel in Grade 316, the potential problem of differential expansion causing the regulator to seize was prevented as the phosphor bronze expands slightly more than the stainless steel - the clearance between the cylindrical shaft and its phosphor bronze housing is approximately one thou all around. A stainless steel shaft was made with a quadrant to register against the fully open and closed stop on the valve. Aligning this shaft was tricky as it has to pass out of the side of the smokebox horizontally fairly close to the top, so the regulator handle linkage could be fitted – this runs the complete length of the boiler on the Britannia's (but only as far as the dome on the 9Fs, as the regulator is located there and not in the smokebox). It was very important to liberally coat the block internally and the valve with Rocol Dry MolyP, which should provide a permanent lubrication. After quite a bit of searching, I eventually discovered K35 gland packing which I obtained from J A Harrison in Manchester and this was chosen for both the internal gland on the regulator and for the gland where the operating shaft exits the smokebox, as it could also operate at a high temperature.

Fig 10: Preparing to bend the outer firebox cleading on the modified simple bending machine – a long lever is located beneath the sheet metal and a good upward push 'rolls' the metal round the tube visible at the top of the picture.

Just before fitting the boiler, I made a determined effort to remove the not inconsiderable amount of swarf from inside the boiler (created when the firebox stays were being drilled and tapped). After a good wash out there were still bits of swarf inside so, with the boiler on its end most of this settled on the font tubeplate. A good vacuuming and a magnet on the end of a rod finally removed (I think) all the offending matter.

Platework and Piping

The running boards were fairly straightforward to make. They have a folded edge and this required the use of fairly thin steel to get a tight bend. A substantial angled support frame was therefore made to support the ‘thin’ running boards, retaining the appearance whilst making them much stronger (and heavier). As with many of the BR Standards, the front of the running board close to the front buffer beam is narrower than the rest of it and has a gentle S-bend at the front to achieve this. The footplate has an extended piece which sits above the front of the tender which was designed to avoid the problems of the tender and the loco moving in opposite directions when firing the full-sized locos – this can be quite disconcerting if you have ever tried firing on the main line at a reasonable speed. The barrel cleading was rolled to a taper thanks to the use of the bending rolls at my local blacksmiths and a lagging ring made to temporarily locate the cleading at the rear of the barrel. I have found it difficult to correctly form the firebox cleading at the front where it meets the boiler – for me this is one of the trickiest jobs on the whole loco – sheet metalwork is obviously not my thing. Many miniature steam locomotives have been spoiled by this area being made incorrectly and, being in a very prominent position, it can impact the whole loco – a great shame when so much effort has been put into everything else.

The Britannia’s have their characteristic Belpaire firebox with a slightly rounded top and tapered sides. I had made a somewhat crude but effective bending machine (see Figure 10) to do the same job on *Scots Guardsman* some years ago – this consisted of a piece of 2 ½” diameter steel tube in a simple frame which produced a 1 ¼” radius bend in sheet up to 1/16” thick over any required angle. So, it did the running board curves as well as the firebox cleading. The 1¼” radius turned out to be fine for the bend at the top of the cab roof sides on *Morning Star* but was much too tight for the top of the firebox which needed to be a larger radius. The machine was therefore modified to accept a larger diameter tube and the required bends duly made on the cleading. This meant I now had the exact dimensions for the throatplate at the top (most visible) part in particular. However, the boiler assembly was getting heavier (or maybe I am getting older) and, as it had to go on the chassis and come off again a few times, I bought one of the remarkably good value electric hoists that are available now. This was attached to a much-strengthened garage roof and, together with a suitable spreader beam, it made a major contribution to the ease of construction and will be handy for other jobs too.

The firebox throatplate cover was formed from brass using a hard wood former using panel beating hammers and lots of annealing. The cab spectacle plates were then finalised – they are set at 45 degrees to create the characteristic wedge shaped front – and the cab itself completed. The ‘glass’ for the spectacle plates is actually a polycarbonate – this being a far better material than Perspex which I had used before and which is prone to cracking. It is a strong material, (I used 1mm thick clear sheet) and it can be shaped and drilled with ease and appears under the trade name of ‘Lexan’. Finally, the running boards were completed by trimming them to line up with the tapered boiler barrel and the firebox sides, after which the cylinder and axlebox lubricators were fitted.

The dome cover was made out of brass, again using a pair of hardwood formers which (with some modifications) have now successfully been used to make three different dome covers. Usual technique of annealing and squeezing the brass between the hardwood formers maybe six or eight times, with a bit of judicious panel beating to ensure that the cover to sits correctly on top of the boiler.

The piping was generally straightforward though since I have thought for many years that the rather messy pipework seen on the BR standards just ahead of the cab, whilst being very accessible for maintenance purposes, was also something of an eyesore, I opted for a tidier arrangement. As the loco never existed, it couldn’t be wrong and it made construction considerably easier! A cop out perhaps but I was happy.

Ashpan and Grate

Two of the last significant parts to be made were the ashpan and grate, both out of (mainly) stainless steel. On previous engines it has been tricky to remove these completely without lifting the boiler off. So, this time I set out to make them removable without having to do this. As the main frames pass beneath the ashpan and the grate, both are each made in three pieces. The two outer sections of the grate are arranged to bolt on separately to their respective left or right main frame plates, with the bolts easily accessible from either side. The centre piece of the ashpan can be lifted into place when the rear ruck is removed (just two split pins) and it

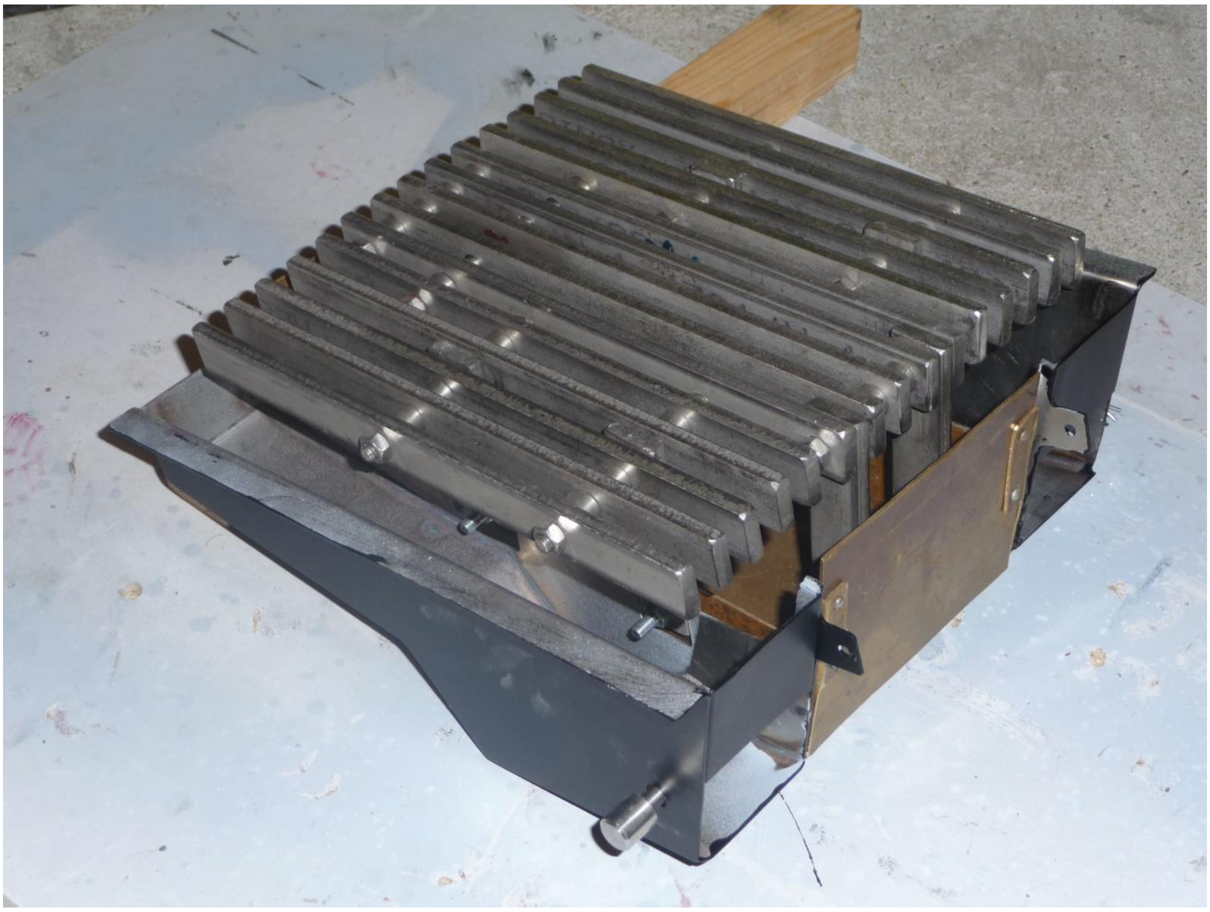

Fig 11: Ashpan and Grate – the centre section of the ashpan is brass, everything else is stainless. The end of the long pin (used to drop the fire) is visible at the bottom of the photograph. The centre section of the grate can be completely removed when needed.

picks up same the bolts mentioned above. The centre section of the grate also lifts into place and rests on pins fixed to the two outer sections at its rear and is then held at the correct height by a long pin which goes right through the complete assembly at the front and which can be withdrawn quickly to allow the fire to be dropped either in an emergency or after a days running. The outer ashpan sections are attached with two bolts each directly into the main frames and can be accessed for cleaning and can also easily be removed if necessary, though it is anticipated that this will only be required very occasionally, such as for the routine hydraulic boiler testing. The outer ashpan sections were fabricated and welded and the complete assembly is seen in Fig 11.

Painting and Finishing

The first key decision about painting was that I had decided some time ago that *Morning Star* would be painted in BR Express Passenger Green rather than just plain black. No particular reason other than, rather like the GWR 2-8-0 Night Owls, it would have been reasonable to think that these 2-8-2s would have been pretty good as Mixed Traffic locomotives and be used on passenger trains as well as freight. The next decision was that I was not going to spray paint very much – most painting would be by brush, generally a ¾" sable flat brush.

Fig 12: Nearly finished, just a few parts to make and a lot of painting still to do in March 2017. Hopefully the firebox cleading is like the original might have been. Note the tidy appearance just ahead of the cab roof – no pipes.

Another very important thing was to ensure that the correct primers were used and I chose:

- Blackfriars Red Oxide Primer for all ferrous items, loco/ tender chassis, smokebox etc
- Craftmaster Etch Primer / U-Pol Acid 8 for all the Zintec parts – cab, cleading etc
- Hammerite Special Metals Primer for all brass, copper and stainless steel (noting that stainless steel is tricky to paint and the surface must be roughened up with fairly coarse emery before applying the primer to ensure it keys correctly).

The only actual undercoat I used was Craftmaster Dark Green, for those parts which were going to be finished in BR Green. As far as the top coats were concerned, Phoenix Precision enamel is one of my favourites as it brushes well and is easy to use, thinning occasionally as required. Their BR Post-1954 Gloss Green and other required colours were a must.

I have struggled a bit with Satin Black in the past but, after some experiments, I settled on Halfords High Temperature black engine paint which is available in both satin and gloss finishes. I have found this to be an excellent paint to use, it dries pretty quickly to a lovely finish in both the satin and gloss variants. The gloss is similar to other enamel gloss paints whilst the satin has just the right amount of sheen without appearing either too 'glossy' or too dull. Both have the added advantage of being able to withstand fairly high temperatures making them ideal for the hot bits such as the ashpan, smokebox etc.

Fig 13: Number 91000 is finally finished, at Bentley Miniature Railway steaming bays in April 2018 for its first less than successful test run.

As I had chosen not to paint anything until construction was complete, the whole engine had to be stripped down, starting with the tender. Some small surface rust was apparent here and there, as construction had commenced 4/5 years previously. This cleaned off easily and, with no oil on any of the parts, painting was pretty straightforward. Generally, it was one coat of the appropriate primer, one of undercoat (if used) and two, three or four coats of top coat, depending whether a part had been undercoated first, with gentle rubbing down of all coats apart from the primer and final top coat, of course.

Although I had lined both *Scots Guardsman* and *Flying Scotsman* previously, the considerably greater complexity of applying the BR lining of Orange/ Green/ Black/ Green/ Orange to the sides of the cab and tender plus boiler bands was beyond my skill, despite several attempts and many practices, so I eventually decided to turn it out in the plain green livery which many of the Britannia's wore in the 1960's, rather than spoil an otherwise acceptable paint job. It also fitted in with the idea that had these engines been used for Mixed Traffic then plain unlined green would perhaps be better than a full Express Passenger finish, as the real *Evening Star* had, as a celebrity engine.

I had for a while been confused about which direction the BR 'ferret and dartboard' totem applied to the tender sides should face, as there are many photographs showing both lions facing left on full-size locomotives as well as a few with both facing forwards (i.e. one right and one left hand). The mystery appears to have been caused by a dispute with the College of Arms which eventually forced BR to only use the left-facing lion as this was the only version suitably registered, so most later full-size locomotive photographs have the lion on the right hand side facing rearwards! I bought a left and right hand pair of transfers from Polly Model and they both face forwards which seems far better.

Fig 14: First successful steaming for 91000 *Morning Star* and the first run for one of Mike Carroll's new coaches at Bentley Miniature Railway 26 March 2019

Trials and Testing

The first outing to Bentley was in late April 2018, when 91000 was subjected to its hydraulic and steam tests which it successfully passed. The pony truck had a tendency to lift on uneven track which would probably not have been an issue on the 'mainline'. However, it appeared that my attempts to get the maximum possible weight on the driving wheels may have gone a bit too far and adjustments were subsequently made to increase the load on the pony truck.

Because I have no facilities to steam an engine at home any more, the first tests had to be done in public at Bentley. I found, unsurprisingly, that the valves (and pistons) were all very stiff and squeaky with insufficient lubrication and perhaps too much load on the valve gear. This, in turn appeared to have had an effect on the valve timing, possibly due to the return cranks shifting on their crankpins, so it was decided to retire gracefully and look into these issues before steaming again.

The second run a few weeks later was better though something was still very amiss as there were only two exhaust beats instead of four per revolution and so a further round of checking and valve setting appeared to be needed. The boiler steamed well with little priming and all the other things that should work did so nicely. The regulator, however, had become stiff which was a big disappointment, so the decision was taken to modify the top of the smokebox to include a large access hole (as per full-size Britannia's) and to add a lubrication point to the regulator body which sits between the double chimney and the front tubeplate. This is the first item on the list of lessons learned as, with hindsight, I should have done this when the loco was being built, as it required taking the boiler off with all the work that this entails.

Fig 15: First day in full service. Number 91000 with the beautiful coaches built by Mike Carroll at Bentley, April 2019. Not much imagination needed to think that this ensemble is all full-size and not 7 ¼" gauge.

After spending quite a long time searching for the timing problem, I finally discovered the cause of the strange exhaust beats - I had inadvertently machined both rear cylinder covers with the register that fits inside the cylinder bores to the wrong dimension– a case of not checking my own drawing before becoming absorbed in the machining operation. They were blocking both rear steam ports and the drain cock holes and were extremely close to pistons when they reached the rear end of their stroke! The front covers were correct. Lesson number two therefore is to check and check again before cutting metal which I thought I knew anyway. Perhaps it is worth consoling yourself that if you have never made a mistake, then you probably have never made anything anyway! So the rear covers had to come off for corrective action, after which a successful test on air showed that the valve timing was now very good with the engine able to be notched up to mid-gear and still continue running smoothly in either direction. Phew! Whilst this work was going on, winter had arrived and I had to wait until Spring 2019 to have another run. This time, all was well, the engine steamed superbly with no priming at all, everything worked as it should and it ran smoothly at a good pace even accelerating away with a light load when in mid-gear. She also had plenty of power and should be a good performer. Job done and smiles all round!

Postscript:
It might be worth recording that 91000 consumed approximately 2000 hours of design and 6000 hours in the workshop, spread over about 6 years (or around 25 hours per week), with a total cost of £4800 (which works out at around £16 per week and doesn't seem too bad for an enjoyable hobby if you think of it this way).

Acknowledgements

I am very grateful for the help given to me by Peter Southern for allowing me to use his large lathe, his broaching machine and his hydraulic press, without which the project would never have been completed. Also I am grateful to Mike Carroll who arranged for the main frames to have their edges milled at the Bluebell Railway and to Tony Tidman who ‘bent’ the tender sides.

Although some model engineers (such as my late father) often made absolutely everything, I have tried to balance the time I have with the requirements of the project and have chosen to purchase some items rather than make them from scratch. The following suppliers have been very helpful to me both in the construction of number 91000 *Morning Star* and with number 6115 *Scots Guardsman* previously. They are not in any way related to me and I have no vested interest in the dealings I have had with them. All I can say is they were without exception kind, helpful and professional.

Supplier	**Item**	**Location**
A J Reeves	Injectors	Atherstone
Alan Miles	Blacksmith/ Metal Supplies	Henfield
Andrew Kirk (and previously Harry Holt)	Boiler	Aldbrough
Ashfield Springs	Loco and Tender Springs	Nottingham
Clupet Piston Ring & Gauge Company	Piston and Valve Rings	Maryport
Dave Noble	Water Gauges	Ashbourne
Diane Carney	Nameplates and Numberplate	Milnthorpe
Horley Miniature Locomotives	Pony/ Rear Truck Wheel Castings	Horley
HPC Gears	Bevel Gears Reverser/ Tender	Chesterfield
J A Harrison	High Temperature Gland Packing	Manchester
M-Machine	Metal Supplies	Darlington
Phoenix Precision Paints	Paint	Chelmsford
Polly Model	Steam Fittings/ Transfers	Nottingham
Precision Metal Products	Sheet Metal Supplies/ Welding	Southwick
Precision Water Jet	Connecting / Coupling Rods	Lyme Regis
Sapphire Rivets	Rivets	Birmingham
Simply Bearings	Various Bearings	Leigh
Steam Fittings	Lubricators etc	Barmouth
Sussex Tools	Machine Tools/ Cutters	Worthing
T H Dick Foundry	Driving Wheel Castings	Hull
White Eagle Foundry	Non-Ferrous Castings	Hurstpierpoint