Investigation and repair of 541 Cylinder Head failure

Introduction

Over the years, 541 owners (especially those with the most common DS5 Austin Sheerline engine) have suffered cylinder head failures in which the coolant flowing around the cylinder head leaks into the cylinders or the exhaust ports. The symptoms can vary and often include:

- water vapour in the exhaust which does not clear when the engine has warmed up,
- emulsification of the oil, visible within the rocker / valve cover after removing the oil filler cap,
- unexplained gradual loss of coolant,
- over-pressurising of the cooling system leading to coolant exiting the overflow pipe,
- detection of combustion gases within the coolant.

The usual cause of this is development of cracks around the exhaust valve seat, said to arise from the inherent porosity of the original (poor quality) cast iron, but corrosion within the coolant chambers within the head arising from lack of inhibitor, failure to regularly change the coolant to maintain the efficacy of the inhibitors, or engines left standing for years with some residual water in the waterways, will all eventually thin and weaken the casting leading to weakness and localised over-heating.

The solution to these problems has typically been replacement with a known good and pressure-tested head (if you can find one!) or specialist welding repair requiring the whole head to be "red hot" prior to welding, followed by slowly controlled cooling and peening of the welds to avoid further cracking. However, for the past couple of years or so, there has been another far more satisfactory, but expensive, option in that one specialist historic motorsport component supplier has invested significantly to be able to offer brand new aluminium alloy cylinder heads for the DS5 4 litre engines fitted to the Jensen 541 models and the Austin Sheerline.

This report describes the symptoms exhibited by one particular, catastrophically failed, low-mileage 541 engine and the process of replacing the failed cylinder head (considered too risky to repair) with a new alloy head provided by Denis Welch Motorsport.

General assessment of engine

Initial inspection and description of symptoms indicated a major coolant leak into one or more of the cylinders. A compression test determined that cylinder 1 had no compression, 2 to 6 were all ok at around 120psi. There was a small trace of emulsification under the rocker cover indicating some contamination of the engine oil by coolant. The oil level appeared to be correct although it was suspected that some of the fluid in the sump was likely to be coolant. After removal of all the ancillaries around the upper part of the engine, the cylinder head was able to be removed for visual inspection. This clearly showed that the cylinder head had failed allowing coolant to enter cylinder 1.


... around #1 cylinder

Following the discovery of significant damage to the head, the three / four options open to us were discussed and it was decided that a new Denis Welch Motorsport "fast road" aluminium cylinder head would be ordered. This has a delivery time of about 8 weeks.

The rocker shaft assembly was removed and dismantled for inspection. It showed very little wear but (unusually) the pillars had been shimmed up from the head, and subsequent investigation showed that the ball-ended adjusting bolts had all been overtightened and stretched in the past - and could not be adjusted to give the correct tappet gap unless the shims were fitted! None of these bolts would turn out from the rocker arms, and they all had to have the ball-ends cut off so that they could be removed anticlockwise. A second-hand set of these bolts was located as none appeared to be immediately available from the usual AH suppliers.

The block was prepared by removing the head gasket and cylinder head studs, cleaning the gasket surface, decarbonising the tops of the pistons and cleaning the waterways that go through the head gasket (which were partially blocked). The block flatness was tested with an accurate straight edge – it was just possible to slide a 2 thou feeler gauge under the straight edge in one or two places, but it is likely that the straight edge itself is not sufficiently accurate to draw any conclusion from this.

There was no evidence of incorrect piston movement and the 6 bores showed little evidence of wear (+/- 0.001 inch variation in front to back, side to side and at the top, middle and bottom of the piston stroke). All 36 bore measurements were between 3.440 and 3.442 inch. The engine assembly turned over smoothly using the starting handle and oil flowed up to the feeder hole (for the rockers) when turned over using the starter motor.

Measurements and Calculations

To determine the desired compression ratio and thereby the combustion chamber volume in the new cylinder head, various measurements were taken (all converted to metric to ease calculations later):-

- Stroke: 111.3 to 111.5mm
- Piston to deck height: between 0.0 and 0.13mm
- Used gasket thickness (relaxed state): 1.50mm (1.35mm assumed for gasket when compressed)
- Piston dish depth: 14.3mm
- Piston dish diameter: 77.5mm
- Old head combustion volume: 58.6 to 64.1 cubic centimetres (cc) (variation due to measurement difficulties, meniscus
- repeatability, original manufacturing tolerances and possible small variations in valve recession). 61.5cc was assumed as the nominal value.

The above measurements were fed into an Excel spreadsheet (which was developed from first principles) to confirm a nominal compression ratio of around 7.4:1 which verified that the old cylinder head had been skimmed by circa 3/32 inch (2.38mm). Without this skimming, the compression ratio would have been around 6.8:1 – the figure quoted for the standard Austin Sheerline engine. Not surprisingly, this explains the combustion volume in the new head, 70cc (the as-designed volume of the new alloy head) and the desired 60cc (close to the measured volume in the old head). Following estimation of the cross sectional area of the kidney-shaped combustion chamber and knowing that we need a reduction in volume of 10cc, the amount to skim off the new head can be determined.

After discussion of the measurements and calculations with Jeremy Welch at DWM, the dish volume was measured (35cc) to confirm the previously estimated value (35.26cc) and the new head was skimmed accordingly. The objective was not to produce a high performance race engine, but to produce an engine that, on paper, should be similar in specification and longevity to the original, but that would breath more efficiently by the use of slightly larger valves, shaped valve guides, polished and gas-flowed ports, carefully aligned manifolds etc.

Preparation for assembly

The new cylinder head, with pre-installed valves and double valve springs, was inspected and painted.

Measuring the volume of the kidney-shaped combustion chambers.......................................

The new cylinder head fitted with pre-installed valves and double valve springs

The original BSF female threaded holes in the head are UNC threads in the new alloy head and DWM provide a stud kit (UNC one end and BSF the other) to go with the new head. Initially the manifold studs and rocker cover studs within this kit, were not all of the correct length, but this was quickly rectified.

The gas flowing and polishing work on the head had eliminated the counterbore in the inlet ports - thereby removing the original method of aligning the bore of the inlet manifolds to the ports. As a result, DWM suggested the use of roll pin dowels (2 per inlet port) to ensure correct alignment in place of the original split (Osbourne?) rings that originally pass through the gasket. A drilling jig was manufactured and used to drill the new head and the original inlet manifolds to accept these dowels. The holes drilled were circa 6mm deep and 5mm diameter (slightly larger diameter holes were drilled in to the manifolds with the aim of retaining the dowels in the head during assembly and disassembly). Holes had to be made in the manifold gasket to accommodate the 6 dowels. Note that manufacturing tolerances, particularly in the manifold gasket, meant that the gasket would only fit in one of the 4 possible orientations! The counterbores in the inlet manifolds were ground out to match the smoothed diameters of the ports in the head.


Old cylinder head showing counterbore


New cylinder head - counterbore machined out


Alignment (Osbourne?) ring


Alignment Ring fitted to counterbore in inlet manifold (1 of 3)


Development of dowel drilling jig


Dowel drilling jig in position on cylinder head


Inlet manifold after removal of counterbore


2 dowel holes drilled, jig registration piece still in place


Drilling dowel holes in one inlet manifold


5mm roll pin dowels (3 per inlet manifold)

Alignment of the Austin cast iron one-piece exhaust manifold, although less critical than the inlet manifold, was achieved by using the gasket as a template. This required some trimming of the gasket bores and then some grinding of the manifold to minimise unwanted disruptions in the gas flow at this interface. New thicker washers were obtained for the cylinder head nuts, as recommended by DWM. To optimise the available bore of the three standard SU carburettors, three stub stacks were machined in aluminium, sized to fit within the original filters and air box.


Roll pin dowels fitted to new cylinder head

Using manifold gasket to improve exhaust gas flow (part 1)

part 2

Part 3 - gasket to be trimmed

Part 4 - exhaust manifold to be ground out to match gasket aperture

The cam followers were removed and cleaned and although slightly pitted, these were refitted with assembly lube. There is a slight risk that the stronger (double) valve springs may accelerate wear on both the cam shaft lobes and the cam followers – this will be monitored by measuring achieved valve lift in the years to follow.

The sump and oil filter were removed and fully cleaned out – some undesirable brown sludge (from the coolant leak above piston no 1) had accumulated which would have shortened the effective life of any new engine oil and accelerated wear throughout the engine.

Re-assembly

The new cylinder head, with pre-installed valves and double valve springs, was fitted on to the new old-stock head gasket. The nuts were torqued gradually to 60lbft. The various studs were fitted to the alloy head and each component (rocker shaft pillars, rocker cover, thermostat cover, manifolds etc.) trial fitted to ensure the thread lengths were correct and would allow gaskets to be compressed and fixings to be fully tightened without "bottoming" in the blind tapped holes.

BSF threads on the rocker pillars had to be extended and the two central manifold bolts had to be shortened slightly. The studs were then finally fitted with either copper slip or Loctite thread seal (depending on whether the holes broke into the water jacket and needed to be sealed).

The rocker shaft assembly, associated oil feed pipe, cam followers and pushrods were fitted and the tappets provisionally adjusted (12 thou cold). DWM had previously confirmed that the factory tappet adjustment was still correct with the new alloy cylinder head. At this point the compression of the 6 cylinders was measured and confirmed at around 120psi. This was the figure achieved by cylinders 2 to 6 prior to removing the original (damaged) head.

Valve lift was measured using a DTI for each of the 12 valves. This varied from 0.364 to 0.395 inch, measured at the top of each valve assembly.

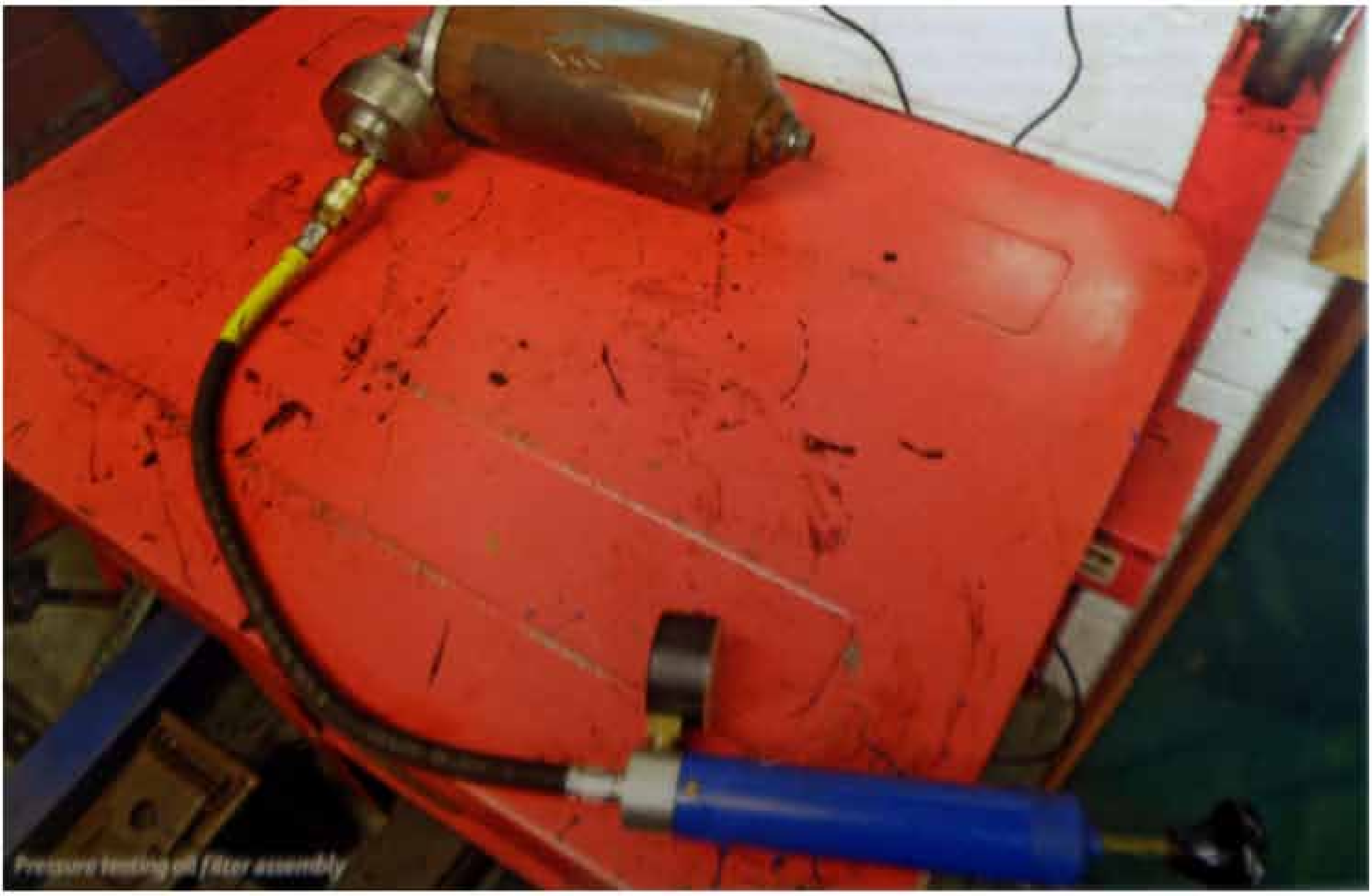
The sump, new oil filter and canister were fitted using new 20/50 mineral oil. To minimise the risk of problems with the oil seals at the top and bottom of the filter canister, the oil canister assembly was pressure tested before bolting it as an oil filled assembly to the side of the engine block.

The exhaust manifold and gasket was refitted and the exhaust clamping arrangements adjusted to minimise stress on the cast iron manifold – a new plate was fabricated to slightly reposition the two U clamps adjacent to the bellhousing.

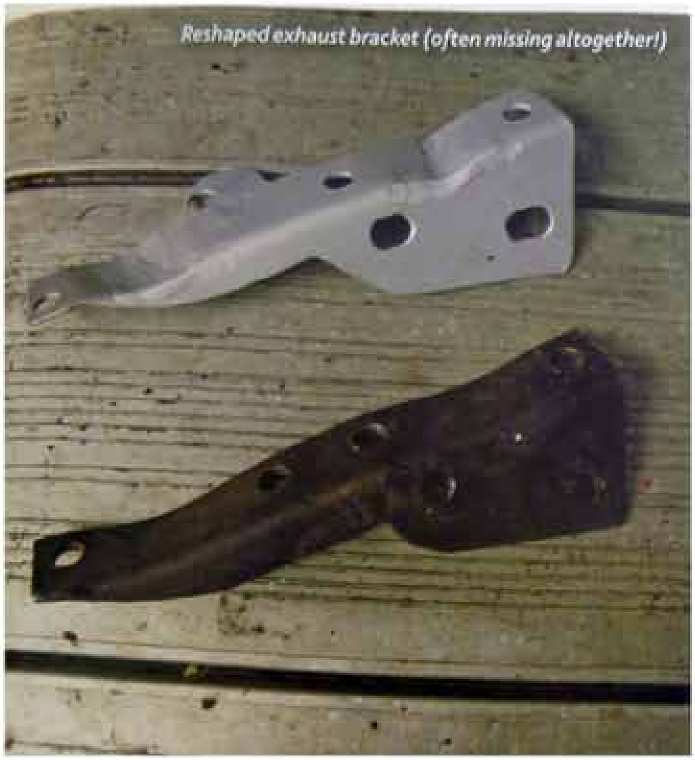
The inlet manifolds and associated alignment dowels were fitted and the bore alignment checked visually.

The inlet manifolds are joined by a balancing pipe which was sealed with graphite loaded packing string (sourced from steam engine suppliers) and hand cut paper gaskets. Note that the central inlet manifold has to be the one that is already drilled and tapped to accept the choke fuel supply pipe.

Valve lift measurements



Pressure testing oil filter assembly


Reshaped exhaust bracket (often missing altogether!)

The carb assembly was completed, although the air filter box is not fitted until balancing and tuning has been completed. Note the rearmost carburettor has to be connected to the distributor vacuum pipe. The electrical connections to the AED were reinstated for the choke solenoid.

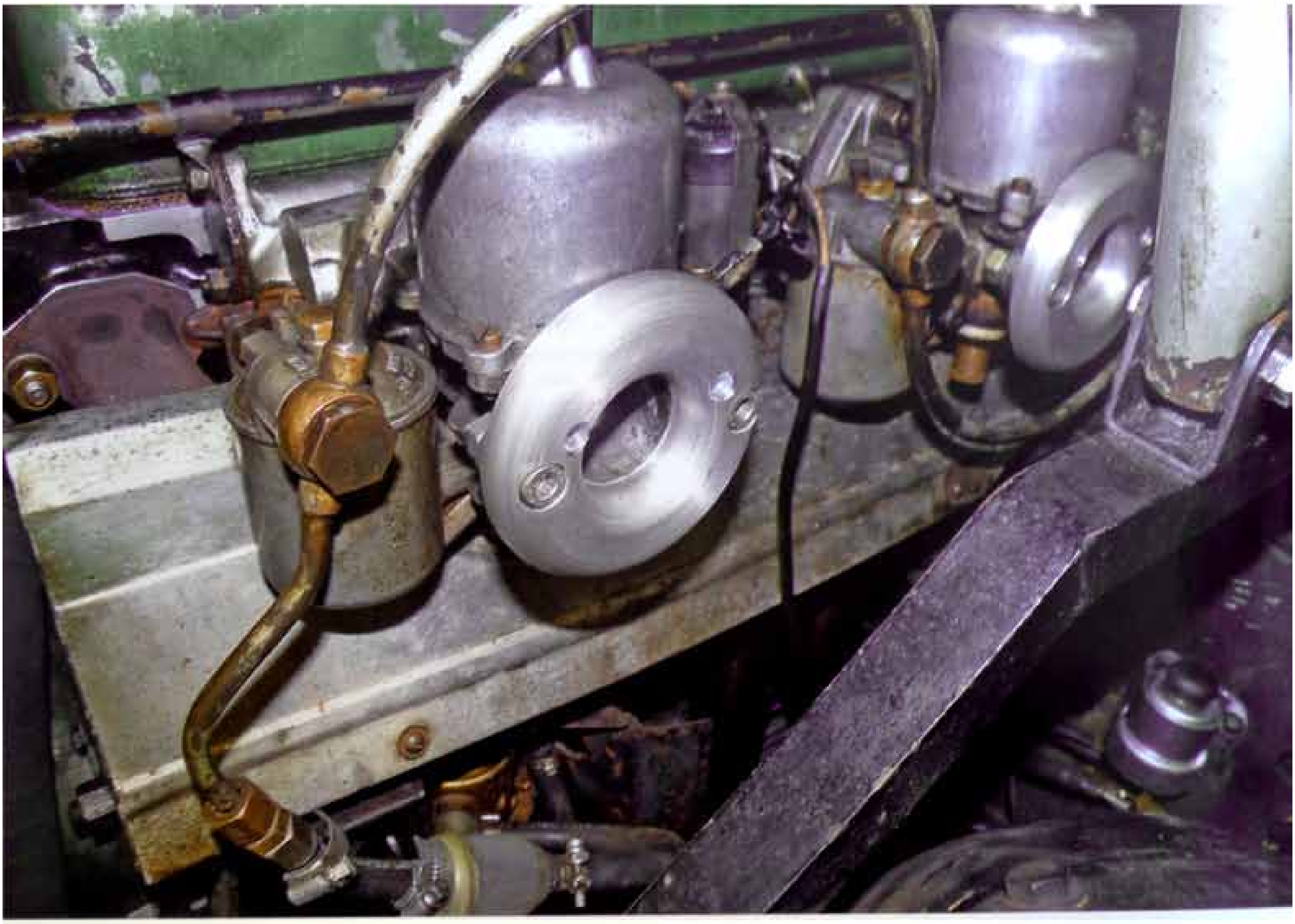
The heater tap (screwed into the head) had to be shimmed with different thickness washers to achieve the desired orientation of its outlet pipe (towards the bulkhead). One turn of the 19tpi BSP thread coincides inconveniently with the thickness of most standard fibre washers, so this was not a quick task.

The top radiator hose, bypass hose, heater hoses and vacuum hoses were reconnected. The cooling system was flushed out and then filled with water and pressure tested to greater than the 4lb/square inch rating of the radiator cap, to minimise the possibility of leaks when road testing the fully-assembled car.

Finally after draining via both the drain taps, coolant (antifreeze suitable for alloy components mixed with deionised water) was added and the system was pressure tested. Note the heater tap(s) needs to be left fully open during refilling and initial engine commissioning.

The three stub stacks were temporarily connected to the carburettor inlet ports.


Engine partially reassembled



Stub Stacks fitted for carb tuning and balancing (eventually these are hidden within the original 541 air box and fit within the standard Burgess air filters)

Starting and Testing

With the spark plugs removed, and rocker cover left off, the engine was turned over to ensure all the oil ways up to the rocker assembly were receiving oil and ideally to confirm a good pressure reading on the oil pressure gauge. With plugs installed and the LT side of the ignition circuit disconnected the engine was turned over. The carburettor settings were adjusted for the recommended default settings (1.5 turns of the idle screws and 2 turns down from the top for the jet adjustment screws). The fuel pump was hand primed.

Finally the engine was started, initially requiring the choke solenoid to be energised, and allowed to run to warm up and check for good oil circulation, good oil pressure and no unexpected fuel or coolant leaks. High rpm running in of the cam shaft and followers was not considered necessary.

After balancing the carbs at idle and adjusting the jets to achieve smooth and even running (easier said than done but not detailed here) the engine was run, fully warmed and exercised through the low to medium range of rpm. After turning off and allowing the engine to cool, the tappets were readjusted and the engine restarted and checked again. At this point the leaking jet on the front carburettor was fixed after soaking the new cork washers in oil overnight.

With everything apparently in order, the rocker cover was fitted, the accelerator cable connected to the carbs, the air filter, stub stacks and air box fitted. Note with the engine off, it is important to ensure that the full range of accelerator pedal travel allows the butterfly spindle to relax to the correct idle position AND to achieve full opening against the butterfly end stops.

Finally a short road test was carried out to ensure smooth running at various throttle positions across the rpm range, although at this early stage the self-imposed rev limit has been set to about 3000 rpm. Strictly speaking, as many of the critical bearings in the engine have not been disturbed, this may be overcautious, but there is plenty of torque and performance to allow the rebuilt engine to be exercised and "run in" over the first few hundred miles. Once the running in period has been completed it is recommended that the head bolts are re-torqued, the tappets readjusted and the valve lift re-measured.

There is a good argument for considering re-jetting the SU carbs with non-standard needles on a rolling road to optimise the available performance from the slightly modified and optimised components now fitted to this engine, but initial testing has indicated excellent smooth and flexible power delivery on the road, so this decision can be deferred until the engine is fully bedded-in with proven reliability.

Driving and road testing

After all this work, the car was driven a hundred miles or so to confirm its reliability and initial performance. As with all properly set up manual gearbox 541s, the considerable torque makes driving (at all legal and some illegal speeds!) effortless with smooth delivery of power and acceleration. The full benefits of the improved breathing and valve springing will not really be evident until the upper rpm range is explored after fully running in the new components.

Postscript (since writing the above article):-

After a few months and a few hundred miles, the engine was checked over, including re-torqueing the cylinder head fixings, removing the sump to check for swarf, oil (and filter) change, confirming the compression in each cylinder, measuring the tappets and measuring valve lift – all was well; and the 541 continues to be used and enjoyed throughout the South of England and France.

Suppliers

Denis Welch Motorsport - https://www.bighealey.co.uk/
Andy Fowler – 01258 881283

Dave Turnage