TITLE: BMW E39 M5 Exhaust Manifold Technical Review
VMTP: 001/01-01

1. ABSTRACT

This document presents an explanation of the design consideration around V8 exhaust manifolds and specifically the VANMANEN performance manifolds for the BMW E39 M5.

2. INTRODUCTION

Few compromises were made producing the final power output of the 4.9-litre, 400PS E39 M5 engine. The first BMW engine to include double-VANOS, electronically-controlled individual throttle bodies for each of its 8 cylinders and, in typical M-division style, modified cylinder heads to enable cross-bank cooling, the S62 engine set itself apart from the competition – it is still regarded to this day as a feat of engineering excellence.

When considering the optimum exhaust manifold design for the BMW E39 M5 engine, VANMANEN's principle consideration of the installation, while producing the greatest performance improvement, was that of packaging. The S62 engine presents an already tight installation due to its shear size; the standard manifolds are far from optimum, yet they are configured in such a way so as to ease the 'decking' process (when the engine/subframe/body are assembled on the production line). To conform to the assembly process, the subframe-mounted engine is installed from beneath the body, demanding that any exhaust manifolds can package within the 'chassis' longitudinals.

3. V8 MANIFOLD DESIGN

Primary tube design

There are many approaches available to the exhaust engineer when deciding on a performance header installation for the E39 M5. The reader will invariably have heard terms such as equal length, 4-1, 4-2-1 and exhaust scavenging with regards to exhaust manifold design. The two roles an exhaust manifold must play are to:

a) allow the removal of exhaust gas as smoothly and efficiently as possible; and

b) encourage the pressure related scavenging effect.

Computational fluid dynamics simulation backed up by empirical data clarifies that, for a target torque curve, both an optimum 4-1 and 4-2-1 design exists. The obvious question that must be asked is how to package such a design in a production car. There is no question that, irrespective of whether a 4-1 or a 4-2-1 design is used, equal length primary tubes are, in principle, more conducive to producing good power gains due to exhaust scavenging.

The crucial factor that must be considered for equal length primary tubes to work, is that the length of the tubes must be long enough to transport a suitable pressure wave for a given rpm (peak torque) if exhaust scavenging is to be benefited from. In other words, if the primary tubes cannot satisfy the length requirement for the engine and usage specification, then designing them to be equal length will not take advantage of the pressure spike, also know as 'blow-down', when the exhaust valve opens just prior to BDC.

Considering these points, a question can be raised over the requirement of equal length tubes in a tightly packaged installation such as the E39 M5. Increasing the number of welds (typical with an equal length primary set), will increase the risk of tube fracture during extreme heat cycling; this is not due to the quality of the welds but instead the metallurgy change caused during the welding process. A real-world example that causes extreme heat cycling would be prolonged high-load, high-rpm conditions (e.g. accelerating to 100mph) followed immediately by minimum heat input into the tubes (e.g. coasting down from the run with the vehicle in neutral and the throttles closed). The closed throttle allows minimum exhaust to flow through the tubes and the vehicle speed provides additional cooling as air is circulated around the engine bay.

Merge collector design

An important consideration for routing the primary tubes is their convergence at the merge collectors. The ideal condition for a 4-1 merge collector is for the primary tubes to be inserted into the collector such that a rotational firing order can be created to aid scavenging. In other words, a high-velocity exhaust pulse travelling down one tube in the collector can produce a relative pressure drop assisting the induction of fresh fuel/air in the neighbouring primary's combustion chamber during valve overlap at TDC. For a V8 engine with a 4-1 merge collector on each bank, the target is for a rotational firing cycle in the collector to happen every 180 degrees of crankshaft rotation. Unfortunately, the reality is not so simple.

The firing order of the S62 engine, typical of cross-plane crank engines, results in two adjacent cylinder firings per cycle. Using the BMW cylinder naming convention, the firing order on the S62 engine is 1-5-4-8-6-3-7-2. The adjacent firing occurs on cylinders 2-1 on bank one, and cylinders 5-4 on bank two. Without routing one primary tube across to the other bank's merge collector (and vice versa), it is not possible to create an ideal 180 degree rotational firing pattern as the adjacent cylinders (2-1 and 5-4) fire only 90 degrees out of phase.

4. VM DESIGN APPROACH

VANMANEN chose a 4-1 design for the VM M5 manifolds, affording sufficient length of primary tube to take advantage of pressure pulses created at the front four cylinders. To enable the system to package correctly while still using sufficient primary tube length, a decision was made to reduce the lengths of the rear primaries relative to the front. An absolute emphasis was placed on achieving the smoothest flow possible - there is little point trying to tune for pressure scavenging if the exhaust has to flow through a tortuous path to the merge collector.

A multitude of merge collectors were used during development of the VM manifolds; initial prototypes used a narrower merge angle, more akin to forced induction applications, to capitalise on the smoother flowing capabilities of the VM primaries. Taking into account the adjacent cylinder firing on the S62 engine, the arrangement of tubes in the collector was organised to separate their respective pulses, helping to de-couple the 90 degree phase lag. Through extensive testing, many merge collector test units, and countless hours on a chassis dynamometer, the final VM collector merge angle was tuned to suit the VM primaries.

One of the most radical design efforts made during the VM manifold project was to create a symmetrical layout for the primaries; not only comparing right and left hand banks but also RHD and LHD vehicles. It seemed prudent to map the dynamic gas modelling to a single set of exhaust manifolds that could fit both RHD and LHD vehicles. Unlike alternative options available on the market, where for a given vehicle the right hand bank manifolds are different to the left hand bank (for packaging around the steering box and starter motor), VANMANEN has taken particular care to equalise cross-bank port pressure for a given cylinder row by mirroring the tube properties as closely as possible.

This review document has covered the fundamentals of V8 manifold design and the particular approach taken by VANMANEN. Following documents will be released reviewing design methods and fabrication techniques. The extent of the work involved in the VM manifold project has been considerable, but the result, a work of art.