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ABSTRACT

The ability of modern diesel engines to operate successfully with high soot loadings in their lube oils together with extended drain intervals has been achieved through the use of a range of techniques to condition the oil. Full flow filters, bypass centrifuges, heat exchangers and a range of sensors and complex monitoring systems have all been added to engines to nsure that the oil is delivered to the lubricated surfaces at the optimum temperature and cleanliness. Traditionally each of the devices in the lube oil circuit has been considered, designed and purchased separately from different suppliers.

The current trend throughout the automotive industry to reduce the number of first tier suppliers can be seen as a good reason to combine the elements of the lube oil circuit into a single unit, however this is a short sighted approach. There are very serious gains to be made in oil conditioning performance, energy consumption (and hence fuel economy) and cost reduction by taking a full systems approach from the outset. Applying the systems methodology to oil conditioning can result in the whole unit being of greater value than the sum of its parts.

INTRODUCTION

The pace of change in engine design has been increasing steadily over the last half decade or so, driven largely by economic and environmental factors [1][2]. Whilst engine demand has fluctuated somewhat around the world due to local economic conditions, global manufacturing capacity has remained high resulting in aggressive pricing and equally aggressive purchasing by OEMs. The development of engines to meet new emissions targets [2][3][4] is a costly business and there is a strong need for OEMs of all engine sizes to recoup some of this expenditure through manufacturing efficiency gains.

Supplier reduction programmes such as the one implemented by the Swedish motor manufacture Volvo, who it is reported plan to be reduce their customer supply base by 75% to approximately 100 over the next seven years [5], are now commonplace. Supplier reduction programmes are not only restricted to large OEM's but are also evident at all levels in the supply chain and the last 12 months has seen much jostling amongst global first tier suppliers as they realign themselves to contend with further streamlining of the supplier network. Changing engine design has been the net result of all this activity. OEMs are looking for greater functionality and more advanced technology at lower prices from fewer suppliers.

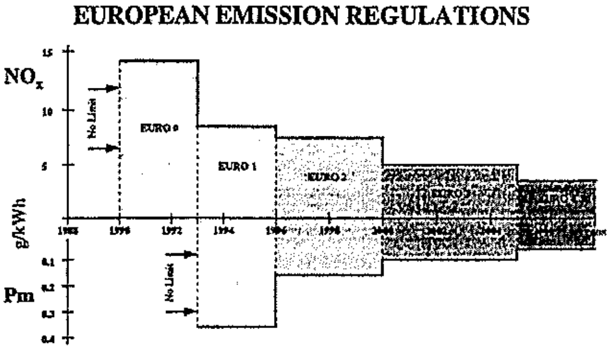

Figure 1 - Proposed European Emission Regulations[1]

One favoured method for achieving both technology benefits and economic gains through supplier streamlining is the integration of diverse engine components into functional systems, supplied to the OE from a single source. A good example of this process, especially in heavy duty diesel applications, is the power cylinder system. It is now increasingly common for a single supplier to provide a HDD manufacturer with an assembly comprising a piston, rings, gudgeon pin, liner, liner seals, con rod, small end bush, big end bearings and big end bolts. On the line this assembly is simply dropped into the cylinder block, the big end cap fitted and bolts fitted and tightened. This modular approach not only reduces the number of first tier component suppliers but also reduces assembly time and space on the engine line.

Traditionally in engine design elements of the lube oil system have not been considered as core engine components. Filters, coolers, pumps and even the lubricant have been tackled from a mechanical design point of view as largely separate parts, the only common element being the fluid conditions required. In recent years some manufacturers have combined coolers and full flow filters into the same housing however this is a small first step down a long road.

Engines being designed today will demand far more of their lube oil system than their predecessors.

combined with the constant demand for longer oil drains will push the boundaries of lubricant system performance [6]. These technical requirements combined with the economic pressures for simplification and supplier streamlining demand a fresh look at engine lubrication as a "package deal", i.e. taking a true systems approach.

TRADITIONAL LUBE SYSTEMS

In early engines lubrication was often an afterthought with bearings being oiled with the occasional squirt from a can. Later enclosed sumps and reliable engine driven pumps made pressurised lubrication a possibility. This is still essentially the system used today. Oil cleanliness was achieved through regular changes but demands for increased component life led to the introduction of firstly suction strainers and then barrier filtration. The first barrier filtration systems tended to be bypass units fitted remotely or bracketed to the engine block and plumbed in with external pipework. When full flow barrier media filters arrived they too were hung on the side of the block out of the way and have by and large remained there.

Current production engines have moved a considerable distance from their crude beginnings with respect of the design of the individual parts of the circuit but they have remained mostly separate. Pumps are today largely driven directly from the crankshaft, full flow filters use exotic media and many are housed for ease of service, bypass filters are often centrifugal, offering high efficiency with large capacity and heat exchangers are often compact water/oil devices.

A traditional lubricating oil system for an automotive or heavy duty engine is shown in figure 2. The elements of the system are grouped to represent the common physical groupings found in today's production engines.

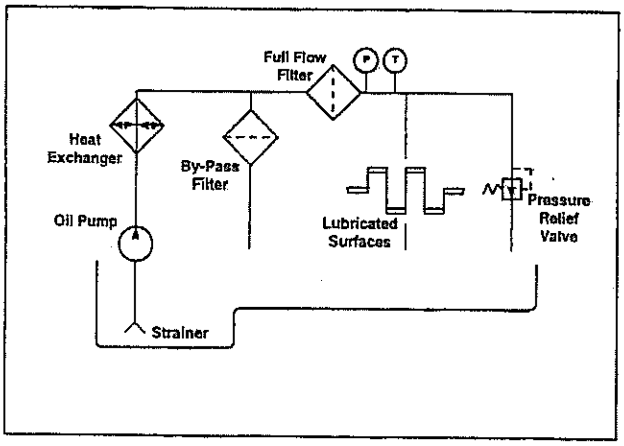

Figure 2 - Traditional Lube Oil System and Component Grouping

REQUIREMENTS OF THE MODERN ENGINE

The major influences on engine design in recent years have been largely environmentally driven. Legislators have imposed strict limits on tailpipe emissions [3][4] concerned about waste disposal as well as cost of ownership, have pushed for engines with longer service intervals and better fuel economy. These pressures have resulted in today's engine designs being markedly different from those of 10 years ago. Today's engines therefore have a number of specific requirements from their lubrication systems.

Drain intervals are being extended to reduce the cost of ownership [6], at the same time lube oil contamination has increased due to technologies (such as EGR) used to control tailpipe emissions. OEMs are undecided on sump sizes since larger pans allow longer service intervals with lower contamination loadings but smaller pans reduce service cost and vehicle weight, reducing fuel consumption.

Power densities have increased through better combustion technology and the increased use of turbocharging on both petrol and diesel models. This has led to the need to remove more heat from components such as pistons and the provision of piston cooling oil jets is now a common requirement. This has placed a greater load on the lube system and increased the need to monitor and control oil pressures and flows over the engine operating range.

Component technology has changed placing greater demands on the oil. Bearing clearances have become smaller with the advent of higher loadings and the use of lower viscosity lubricants to improve fuel economy. New bearing materials and processes such as sputter coating are considerably less dirt tolerant than their predecessors. Piston ring technology has also advanced considerably to enable rings to resist the high temperatures and high speed scuffing experienced in their operation. All these advances point to the need for improved oil cleanliness and hence improved oil cleaning systems.

Lubricants and lubricant specifications have altered too to respond to the higher temperatures, longer drain intervals and higher contaminant loadings seen in modern engines. Fully and semi-synthetic base stocks are now more common and additive loadings have reached surprisingly high levels, 20 - 25% now being typical [7].

The trends in engine design indicate that tomorrow's engines will demand a good deal from their lube systems. They will require small package size and low weight, ample pressure for bearing lubrication and ample flow for turbo and piston cooling whilst maintaining low power consumption from the pump. A high degree of oil cleanliness will be needed and long life, high temperature lubricants to cope with the severe service conditions. These requirements can easily be met by careful section of oil grade and use of a single oil conditioning unit which provides functional and economic advantages over stand alone components.

SYSTEM ELEMENTS

The basic elements of any system for conditioning ubricating oil are devices for controlling cleanliness and temperature. In the majority of today's small and medium size vehicle engines oil cleanliness is controlled by the application of a full flow barrier filter or screen in combination with a bypass oil cleaner - often of the centrifugal type [8]. A heat exchanger is used to control the lubricant temperature.

FULL FLOW FILTRATION - The full flow filter or screen, as its name suggests, is situated in the lube oil circuit after the oil pump and processes the "full flow" of lubricant before it passes to other engine components. Traditional full flow filters are of the barrier media type and work by passing the lubricant through a media with a defined pore size distribution as shown in figure 3. Particles generally larger than the media pore size are captured whilst smaller ones pass through. Nominal media pore sizes are in the 20 - 40µm range for current production filters.

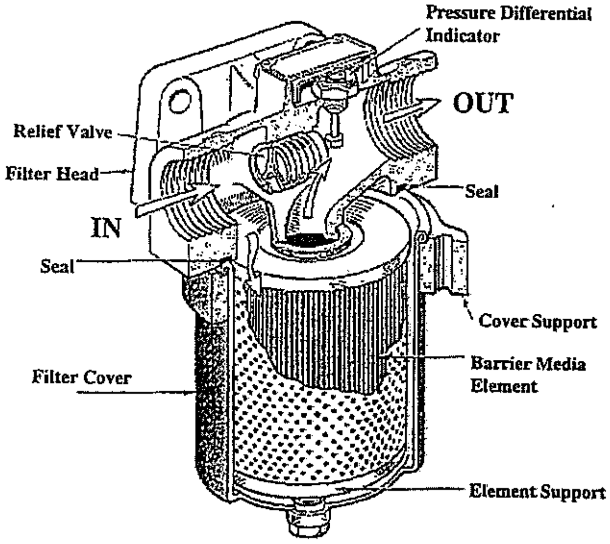

Figure 3 - Traditional Full Flow Barrier Media Filter

Media full flow filters are designed with a finite life and hence are replaceable units. In recent years the introduction of bypass oil cleaners has allowed the use of cleanable and in some cases fit-for-life full flow screens [9]. These units use a long life woven mesh or random fibre media (normally metallic but plastic medias are also available).

It is now recognised by most OEMs that it is impractical to attempt to maintain oil cleanliness with full flow filtration alone. To do so requires very fine medias which in turn demand large surface areas to keep their pressure drop within acceptable limits. Such large, fine filters are very expensive and difficult to house in tight engine bay spaces.

he concept of full flow filtration is therefore changing om one of cleaning to one of ensuring that large contaminant particles do not reach the critically lubricated surfaces causing catastrophic failure.

BYPASS FILTRATION - The use of a fine filter to process a small amount of the total flow and then return it to the engine sump is an old concept however when used in combination with a full flow filter or screen as an "insurance policy" against small amounts of larger particles then excellent oil cleanliness results can be achieved [10]. Two types of bypass filters are commonly applied, barrier media and centrifugal.

Barrier media bypass filters - Barrier media bypass filters work in the same way as barrier media full flow filters, by providing a physical restriction to solid particles larger than the media pore size. They differ in application however since they process approximately 10% of the total engine flow and return it directly to the sump. The large pressure differential tolerable by bypass system enables fine medias to be used in these types of filter.

The main drawback with media bypass filters is their inefficient use of space and as medias have become finer this has become more of a problem. A recent study conducted for a Japanese manufacturer has revealed that many current full flow and bypass filter systems are designed with insufficient bypass filter area to allow useful operation over the whole oil drain period. In the worst case the bypass filter was found to be 10 times too small, i.e. the bypass filter life was only a tenth of the full flow filter life.

Centrifugal bypass devices - Centrifugal oil cleaners also work in bypass processing about 10% of the total lubricant flow. Fluid is passed through a rotating chamber and hence subjected to centrifugal force [11][12][13]. Particles with a higher density than the fluid are separated out and contained. As the centrifuge is not a barrier type filtration device, it does not rely upon a filtration media to remove the contaminant particles from the lube oil and never become blocked. Unlike a barrier media bypass filter which only removes particles of contaminant larger than the pore size of the media, a centrifuge removes particles based upon their relative density and hence can remove particles of any size provided they are more dense than the lube oil [14].

The principles behind and oil cleaning centrifuge are well documented [11], however to summaries briefly with reference to figure 4, oil is pumped into the centrifuge by the engine's oil pump at pressure. The oil is directed into a hollow spindle where it exits via a cross hole and into the centrifuge rotor. The rotor becomes full of pressurised oil which is then allowed to exit via two tangentially opposed nozzles in the rotor base. This causes rotation of the free spinning rotor assembly thus generating centrifugal force within the rotor. As dense particles of dirt carried by the lube oil enter the rotor, they are subjected to this centrifugal force which causes them to migrate radially outward to the inner surface of the rotor wall. Over time, these contaminant within the centrifuge.

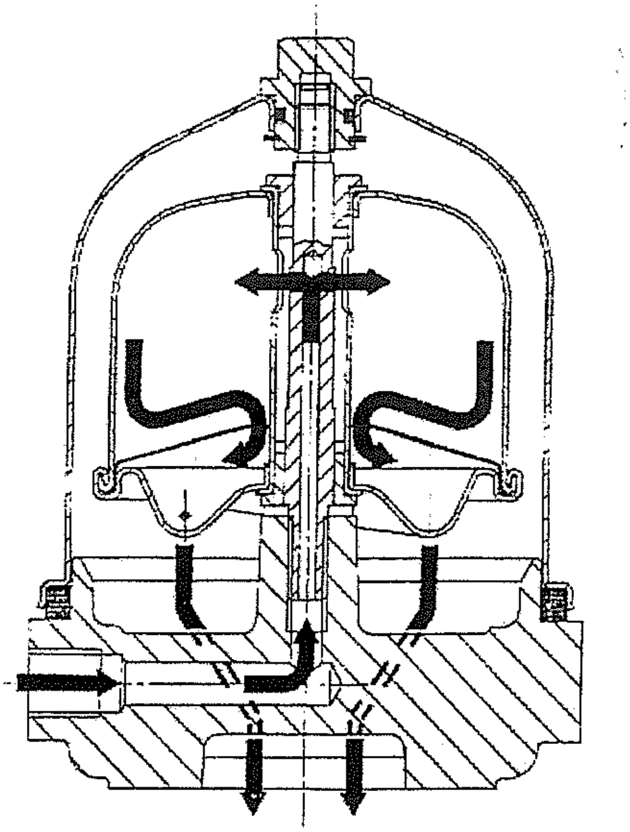

Figure 4 - An Oil Cleaning Centrifuge Schematic

By using centrifugal force, the centrifuge is capable of removing a wide range of particles from the oil including those in the sub-micron range. By using a centrifuge to remove the bulk of the contaminants either produced or ingested by the engine, the role of the full-flow device alters from one of pure filtration to more of a "safety net". As the oil is pumped to the engine components the full flow media filter or screen prevents large particles of debris from reaching the lubricated surfaces and causing catastrophic failure.

HEAT EXCHANGERS - Besides lubricating, oil provides the vital service of cooling engine components. As engine power densities have increased and with the increased use of turbochargers oil temperatures have moved steadily upwards and the need to remove some of that heat has become more pressing. Two main types of heat exchanger are commonly in use on small and medium sized vehicle engines, air-to-oil and water-to-oil.

<u>Air-to-oil types</u> - These are the traditional oil coolers which act as a small radiator and are commonly placed together with the main cooling system radiator and intercooler (if the vehicle has a turbo) at the front of the vehicle in the incoming airflow. Heat from the oil is dissipated from the fins of the unit to the air passing through it.

Coolers of this type suffer from a number of disadvantages however: Oil system pressures are the cooler has to be constructed much more rigidly than a normal radiator, making it expensive. The thermal efficiency of the unit varies depending on the ambient temperature thus in very hot climates large cooling areas and high airflows are required whereas in cold conditions a thermostatic valve is required to prevent overcooling.

<u>Water-to-oil types</u> - In heat exchangers of this type the oil is brought into thermal contact with the engine cooling water. Because the coolant in the engine block and cylinder head tends to heat up quickly when an engine starts from cold this type of heat exchanger arrangement gives the added benefit of allowing for the oil to be heated by the coolant during engine warm-up periods. This reduces its viscosity and improves fuel economy. These systems can be divided into two subtypes, submerged and remote.

Remote systems are typically used on small vehicles and consist of a heat exchanger assembly with a sealed outer shell having both oil and cooling water inlet and outlet connections. Very often the heat exchanger is sandwiched between the spin-on full flow filter or screen and the filter head, having internal passage for oil flow and external hose connections for cooling water flow. Water for these devices is often taken from the cabin heater circuit.

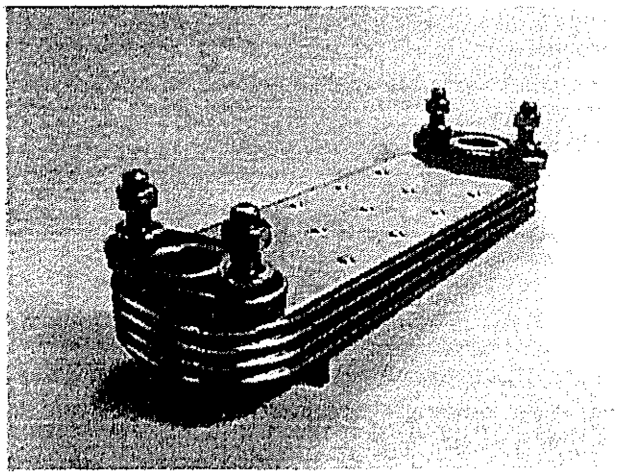

Figure 5 - A Typical Oil-to-Water Plate Type Heat Exchanger

Submerged types consist of tube or plate assemblies such as the one shown in figure 5, through which the lube oil flow. These are mounted into the water jacket of the cylinder block and due to the good heat transfer properties of this arrangement are compact and offer low fluid pressure losses due to short oil drilling lengths. Submerged heat exchangers are ideal for use in oil conditioning systems since they can be incorporated into a single housing and assembled onto the cylinder block with the same single mating face as the oil system connections. A thermostatic valve can be provided to control the proportion of oil passing through the heat exchanger matrix as opposed to the amount bypassing it thus regulating the lube oil temperature. This too can be incorporated into the oil conditioning housing.

YSTEM DESIGN & IMPLEMENTATION

Collecting elements of the lubrication circuit together and mounting them in a single housing will undoubtedly provide some financial benefits and may improve the serviceability of the unit but this action constitutes an assembly, not a system. In order to derive real benefits from the exercise it is necessary to examine the requirement of the system and the constraints upon it.

The current piecemeal fitment of lube conditioning elements often results in less than optimum operating conditions for these elements. One example is the placement in the circuit of the heat exchanger, full flow filter and bypass centrifuge. Through historical design and the constraints of other engine components many lube oil circuits are arranged as shown in figure 6, with the oil passing from the pump to the cooler, then to the full flow filter and then to the take-off point for the centrifuge before passing to the lubricated surfaces. is is a less than ideal situation. Oil from the pump is hot, coming straight from the sump, and at relatively high pressure. It is also relatively dirty. These are the ideal conditions for the operation of the centrifuge therefore the centrifuge takeoff should be as close to the pump as possible.

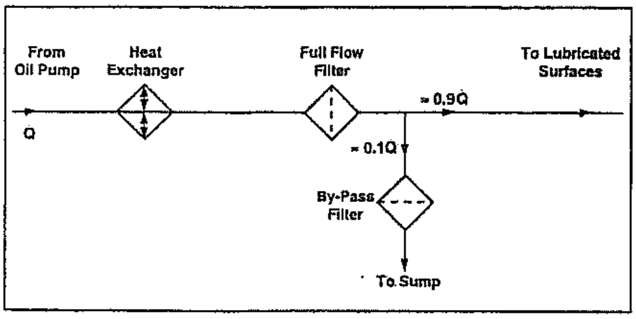

Figure 6 - Typical Lube Oil Filtration and Temperature Control Schematic

Hot oil has a relatively low viscosity and this means lower pressure drop when passed through a full flow filter or screen. The full flow device therefore should be the next element in the circuit. Heat exchangers are susceptible to contamination from dirty oil which can cause silting or coating of the internal surfaces causing loss of thermal efficiency. Placing the heat exchanger after the full flow filter therefore will increase its lifetime efficiency. This more appropriate arrangement is shown in figure 7.

Reducing the length of connection ports between the various system elements and especially reducing the number of changes of direction the fluid has to make will reduce pressure losses and ultimately allow more of the work done by the oil pump to be delivered as oil flow to the bearings. This can more easily be achieved if the elements are mounted in close proximity in an oil nditioning housing.

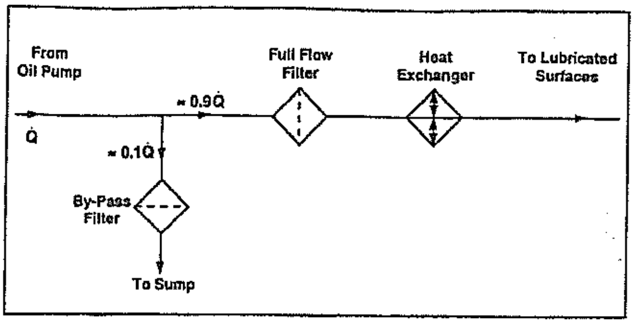

Figure 7 - Optimal Lube Oil Filtration and Temperature Control Schematic

The serviceability of components in the lube system is also a concern and this can be improved in a number of ways. Changing or cleaning the full flow filter or screen traditionally results in a degree of oil wastage however with element type full flow units which are serviced from the top becoming more popular, service friendly options are available. For example the oil conditioning unit will incorporate a drain path to the sump pan for bypass centrifuge drainage, turbo drainage, oil fill, etc. This drain path can be used to drain the full flow housing of residual oil when the casing is opened for service, thus resulting in cleaner and easier servicing. Such systems are starting to be used on some European vehicles but the full benefits of component integration are yet to be realised.

ADDITIONAL POSSIBILITIES

Incorporating extra functionality into an oil conditioning system can open the door for more radical changes in engine lube design. Research has focused on the following areas:

LUBRICANT SUPPLY - The method by which the oil is provided to the system (traditionally an engine driven pump) could be incorporated into a single housing with the filters and heat exchanger. This reduces the flow losses between pump and conditioning elements. Because of the need to supply a mechanical drive to the pump, designers who have moved in this direction have grouped the oil conditioning elements around a "G-rotor" type pump mounted on the nose of the crankshaft.

This arrangement has several advantages in that conditioned lubricant can be fed down a single gallery running the length of the block to the bearings, etc. The heat exchanger can be immersed into the cooling water jacket on the front of the block and accessibility to filter and centrifuge elements is potentially good.

The inclusion of the pump in this manner however does restrict design flexibility and mounting on the front of an engine can interfere with camshaft drives and waterpump placement. Another arrangement could use the timing belt to drive the oil pump thus moving the oil conditioning unit to the side of the engine block where space is more readily available.

driven pump mounted within the oil conditioning unit housing. This allows for the oil conditioning module to be divorced from the engine with the exception of fluid connections and hence allows far greater design flexibility.

The use of an electric pump also allows for the expansion of the functionality of the unit. The pump can be speed controlled to regulate its output using information from a pressure sensor. This obviates the need for a pressure relief valve and on a typical small to medium size engine can reduce the power required to run the lubrication system by 10-15%. By linking the control of the pump into the main engine ECU it is possible to pre-pressurise the system prior to start-up (improving lubrication conditions in main and big end bearings) and to maintain residual pressure in the system after switch-off (improving turbocharger life). It is also proposed that further power savings could be achieved by matching oil pump delivery to engine load and speed conditions.

LUBRICANT DELIVERY - Modern engines incorporate a wide range of different lubrication requirements. Main and big end bearings for example require lubricant at sufficient pressure and flow rate to maintain hydrodynamic lubrication over varying load conditions and to overcome centrifugal pressure gradients in crankshaft drillings. Turbochargers however require a sufficient volume of fluid within a set temperature range to dissipate the heat generated by their operation. The oil conditioning unit is an ideal location for devices to regulate lubricant pressure and flow and to control distribution to the relevant parts of the engine.

Connections to different recipient section of the engine can be made via galleries in the cylinder block leading to a mating face with multiple ports. Such an arrangement is shown in figure 8. Turbocharger connections are also well suited to be run to and from the oil conditioning unit which can incorporate an anti drainback valve for the turbocharger supply.

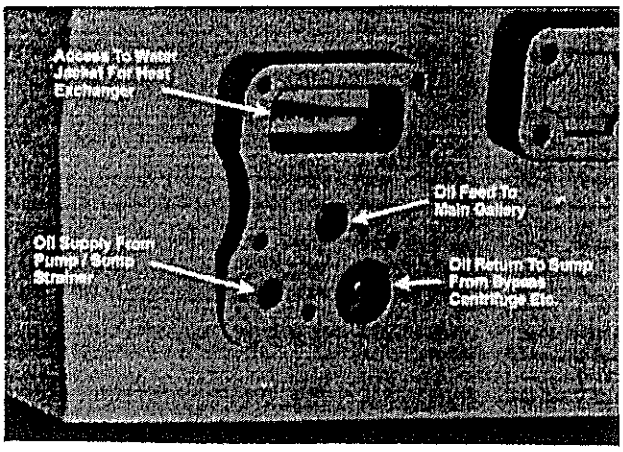

Figure 8 - Oil Way Connection

CONDITION MONITORING - Control of lubricant conditions is facilitated by data on the lubricant condition. Grouping sensors for pressure and simplify the vehicle wiring harness and reduced OEM assembly times. Sensors can be pre-wired to a single connection block fixed to the housing, enabling the engine harness to simply be plugged in on assembly.

The incorporation of an effective oil condition sensor or sensors into the module, together with information on full flow filter pressure drop, would enable the introduction of "on condition" oil changes to replace the common interval based system. Some manufacturers are moving down this road but further sensor development is required before this technology becomes cheap and reliable.

Oil level sensing is another established technology which can be incorporated into the conditioning unit housing. This would remove the need for a boss on the sump pan or an elaborate electronic dipstick and remove the need for the OE to fit the level sensor as a separate operation.

SUMP PAN AND CRANKCASE ACCESS - Various elements of either operating or servicing a vehicle engine require access to its internal space. This access can be centralised and combined into a single area. An example of this is shown in figure 9 where the full flow filter, bypass centrifugal oil cleaner, heat exchanger, pressure relief valve and other valves/sensors share the same housing and block connection as the crankcase breather and oil mist separator. Additional connections can be applied for the turbocharger drain, for dipstick access (if a level sensor is not fitted) and for oil fill. An additional benefit of incorporating the oil fill point is the "service item grouping" which this achieves.

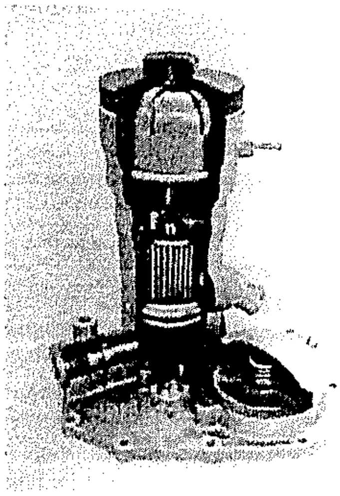

Figure 9 - An Example of an Oil Conditioning System Embodiment.

CONCLUSION

Demands on small and medium size engines are increasing and as they do then the demands on the lubrication systems also increase. Design changes in response to environmental and customer driven economic pressures have led to the need for greater functionality and lower cost from lube system components.

Using a systems approach to oil conditioning can help to achieve these goals. The combination of several lube oil system components into a single housing and the design of these components for optimum interaction and performance can provide the extra functionality OEMs are looking for (better filtration, better temperature control and improved system monitoring).

This approach also provides OEMs with the opportunity for substantial cost savings through component reduction and supplier reduction. Peripheral savings are achievable through simplification of other components (incorporating the oil filler into the OCS unit for example may make the engine top cover a much simpler unit).

It is clear therefore that considerable benefits are available to engine builders, engine users and component suppliers through taking a systems view on the design and implementation of lubrication elements. The oil conditioning system is becoming a beneficial reality for engines world-wide.

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