Recent trends in engine development have seen significant gains in performance by reducing internal friction, through improvements in lubrication and the reduction of ancillary loads. Alongside such increases in performance, a concurrent (and potentially conflicting) demand for increased service life is also being met through lubrication technologies.

Crucial to satisfying an engine’s demand for adequate lubricating and cooling oil, with minimal frictional losses, is the humble oil pump, an often overlooked ancillary. The function of any oil pumping system is to distribute a volume of oil at pressure throughout the engine. In a wet-sump configuration this oil can be collected directly from the engine’s sump and pumped to the oil galleries, after which it naturally returns to the sump again. If an engine runs a dry sump system, however, then the pump serves a dual purpose – delivering pressurised oil from the oil reservoir to the engine, then collecting the oil from the sump pan in order to return it to the tank. This multi-purpose nature of dry-sump systems tends to lead towards pumps with multiple stages, each with its own task. In its simplest form – a two-stage pump – there is a scavenging stage, which draws in oil and air from the sump pan and delivers it to the oil tank, then a high-pressure stage that delivers this stored oil to the engine.

The requirements for pressure and scavenge pumps differ markedly,
The flow characteristics of Roots pumps are too irregular for use as pressure pumps; they give a very ‘lumpy’ flow’

so they are usually of differing types. For scavenge pumps it is desirable to achieve a high intake volume that contains not only oil but a considerable quantity of air or blow-by gases. While spur gear-type pumps can be (and often are) used as scavenge pumps, it is more typical for this function to be carried out by a Roots- or gerotor-type pump. These are generally regarded as superior to gear pumps for pumping quantities of air as well as oil, while gear pumps provide a better solution for high-pressure oil delivery, as they exhibit smaller amplitude and higher frequency fluctuations in the oil delivery volume/pressure compared to Roots pumps.

Scavenge pumps

A Roots pump uses a pair of lobed rotors to trap and transfer a volume of oil from inlet to outlet; however, unlike gear pumps, the pumping elements themselves do not make contact with each other and therefore an additional pair of gears are required to transmit drive from the driving shaft to the second, driven, shaft. These drive gears may be an additional item, or in cases where gear-based pressure pumps are housed with Roots scavenge pumps, the gear pump itself may be used to transfer the drive for the scavenge pumps, saving weight and volume. Unlike gear or Roots pumps, gerotor pumps do not use two pumping elements side by side, but locate an inner rotor (with its shaft positioned off-centre) within an annular outer element which is then driven by the inner rotor, the entire assembly being housed within a cylindrical casing.

For scavenge pumps, the Roots type may perhaps be more commonly used than the gerotor type, with some manufacturers exclusively offering one or the other, or others offering both types depending on customer requirements. While gerotor pumps can be easy to house within a simple cylindrical bore – either as an aftermarket pump or within a bespoke engine casting – Roots pumps are easily packaged in multi-stage pumps which run two side-by-side shafts and a gear pressure pump.

Roots-type pumps provide a much higher pumping volume than gear pumps, making them ideal for scavenging applications where it is desirable to draw in high volumes of oil as well as air, creating a partial vacuum within the crankcase and reducing windage losses. It is worth noting of course that generating such a vacuum depends heavily on the engine builder, and requires effective sealing not only of the casings but piston rings and so on – simply fitting a scavenge pump with a high inlet flow is no guarantee of horsepower!

While Roots and gerotor pumps can be run with a clearance between the rotors, this is typically reduced to a bare minimum to reduce cavitation and improve efficiency. Indeed, in some cases PTFE coatings applied to anodised rotors are intentionally manufactured without clearance, then ‘run in’ to wear the coatings back to a running clearance. On the other hand, any debris collected from the engine during normal running should preferably be able to pass through the pump without damaging the rotor surfaces or shafts, so a degree of clearance between rotor tips can be desirable.

The number of scavenge pump stages used depends very much on the engine in question, and the design of its sump pan. If for example each cavity between the main bearings is a separate compartment, then each requires its own scavenge pump. It is here that oil pump design is inextricably linked to the design of the sump pan. While some manufacturers prefer to use a large number of scavenge pump stages (sometimes as many as six) to collect oil from as many points on the sump – or indeed elsewhere on the engine – as possible, others reduce pump size and weight by optimising the sump pan design to feed oil to the inlet of a smaller number of pumps.

Pressure pumps

However, the flow characteristics of Roots pumps are too irregular for use as pressure pumps; they provide a very ‘lumpy’ outlet flow. By contrast, gear pumps provide a much smoother flow, often using more teeth than strictly necessary in order to smooth the outlet flow further. Their high reliability and ability to achieve a wide range of flow rates and pressures at an equally wide range of operating speeds make them an almost universal choice for pressure pumps. Operating speeds can
FOCUS : OIL PUMPS

“While feasible and beneficial, the cost evaluation of an exotic rotor material rarely turns out in its favour”

range from 1000 to 10,000 rpm, delivering pressures from 5 to 250 psi at flow rates up to 40 gallons per minute, as required by the specific application and achieved by the design of the pump geometry.

While gear pumps will always provide a fixed-volume flow of oil, they are capable of building very high pressures against the outlet restriction. Excessive pressure is undesirable not only from a pump builder’s point of view, risking damage to the pump elements or distortion of the shafts, but also from the engine’s perspective, as high pressures can result in oil build-up in the crankcase, reduced time for heat transfer from piston cooling jets, and increased aeration of the oil under pressure.

To prevent excessive oil pressure, a pressure relief valve (PRV) is almost always fitted. This is typically a spring-loaded piston: if oil pressure becomes too high then the spring force is overcome and the oil flows through the valve to return to the pump inlet or oil tank. However, the PRV can be one of the most vulnerable elements of a pump. If it is fouled by debris it can be stuck open, reducing oil pressure with potentially race-ending consequences. Fortunately though, pressure pumps (and therefore the PRV) tend to be fed from the oil tank, the contents of which have been filtered.

Scavenge pumps, on the other hand, collect oil from the sump directly, and typically receive oil that has only been strained through a gauze, so they may encounter much larger debris than would be expected after complete filtration. Any debris larger than the pump clearances can lead to damage of the rotors or shafts, so typically a maximum size is specified by manufacturers, or where complete sump pan and oil pump solutions are manufactured together, the pump design can be optimised alongside a known level of straining.

Allowing shafts to deflect can enable a pump to deal with larger debris, but this can compromise pump efficiency, so manufacturers seek to support shafts more rigidly to enable closer running of the pump elements and a higher volumetric efficiency to be obtained from the pump.

Materials and construction
Various materials are used in the construction of oil pumps, depending on pump type. For scavenge pumps an aluminium construction is typical, with both housings and rotors machined from billet, while steel is used for shafts, and ground stainless steel dowels for aligning components. Aluminium alloys such as 7075 are desirable for their low weight, while manufacturing the rotors and the housing from the same material can be beneficial with regard to the effect of thermal expansion on the designed tolerances, since by using materials with the same or similar thermal expansion coefficients, a consistent performance can be found over the pump’s entire operating temperature range. Hard anodising of aluminium rotors is rarely used, however, as it is desirable that any debris generated from the pump should not be so hard as to risk damage to the engine.

The use of polymeric-based materials such as carbon fibre reinforced polymer or poly-ether-ether-ketone (PEEK) have been examined by some manufacturers, and are indeed available if an application calls for such a significant reduction in weight and pump inertia. On the whole, however, they are far more expensive to make than an aluminium rotor, particularly in the case of PEEK which, while having excellent chemical resistance and high-temperature properties, is very hard and costly to machine. So while technically feasible and beneficial, the cost evaluation of such an exotic rotor material rarely turns out in its favour.

Pressure pumps typically use steel alloys for gears and shafts, while aluminium may remain as the housing material. In some cases, bronze or brass materials may be substituted for the manufacture of the gears, having a thermal expansion coefficient of about 80% that of aluminium, or the housing may be cast iron to match more closely the expansion of steel gears. Brass materials also exhibit more favourable dry-sliding performance if used in gear-type scavenge pumps that may run semi-dry. On the whole though, gear pressure pumps use steel alloys for gears primarily for their durability, as contact forces are present, yet tight tolerances need to be maintained over as long a life as possible.

The use of coatings can vary between pump manufacturers,
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although on the whole the pumping elements used are largely uncoated. Where friction-reducing coatings such as PTFE have been evaluated, some manufacturers questioned for this article indicated that they can actually be quite counter-productive, as a lower friction surface can allow oil to ‘slip’ back between pumping elements rather than being forced through the pump, costing a measure of efficiency and requiring the pump to be worked harder to achieve the same flow rates, costing shaft horsepower for the same result. The use of such coatings on inlet and outlet ports or pipework can of course provide a benefit in reducing flow losses though.

**Pump drive and packaging**

The vast majority of oil pumps are driven from an auxiliary belt; this provides an excellent solution, whereby drive ratios can be altered to achieve desired pump speeds. Alternatively, drive can be taken directly from the engine’s camshaft, running the pump either at camshaft speed or geared to achieve the desired flow rates.

The engine’s requirement for lubricating and cooling oil rises roughly linearly with engine speed, so a direct relationship between engine and pump speed has proven quite satisfactory. While a rule of thumb is that oil pumps run at around half crank speed – indeed, precisely so if run directly from the camshaft – the use of pulleys or gearing is advantageous to provide the optimum oil supply. If high volumes of oil are required (as in drag racing) then a higher pump speed may be used; alternatively a lower pump speed may be adequate to provide for the engine’s needs, while reducing the parasitic losses as far as possible (as is often the case for NASCAR engines).

In both cases, however, the drive tends to dictate the placement of the pump, which sometimes creates a packaging problem. One manufacturer has unveiled a new product designed for drag racing Hemi engines, where the standard pumps can stick out and create a packaging issue. Its solution is a pump that turns the drive through 90°, placing the pump alongside the block and reducing the overall packaging length of the engine in the process.

It might be imagined then that an electrically driven oil pump would provide the ultimate in packaging versatility and non-linear speed control. While this may be true, there are however some significant problems with an electrically driven solution, primarily the additional complexity and weight.

An average oil pump is estimated to need about 5 hp from the engine’s crankshaft in order to drive it, so to provide an equivalent electric solution requires not only a reasonably sized motor, it also places greater demands on the electrical system of the car, potentially requiring a larger alternator and/or battery. To reduce the motor size to some degree, oil can be pre-heated before cold starting to reduce viscosity, again though adding further complexity and electrical load. While some electrically driven oil pumps do exist, they are a niche solution, and are unlikely to see widespread use in the near future.

If the weight and complexity issues can be addressed though, they do offer some additional benefits, being able to run and provide oil pressure both before engine start-up and after shutdown, which could be particularly useful in extending bearing life during turbocharger spin-down for example. Currently their use is more suited to test bed engines or experimental equipment, or for cooling circuits where demand is not constant. (Perhaps a future use exists in cooling for hybrid batteries as the size and cooling requirements of these systems increase?)

If sufficient gains in sump design and pumping efficiency can be realised, this can enable further benefits for the engine package as a
FOCUS : OIL PUMPS

By providing a scavenge pick-up at the front of the engine to remove oil more effectively from the horizontally opposed configuration (notorious for trapping oil in the cylinder heads/blocks), the number of scavenge stages can be reduced.

While in its own right this pump configuration improves engine performance, providing crankcase vacuum estimated at a possible 8 hp gain otherwise unavailable with OEM equipment, its reduced length and packaging options also lead to the potential for other modifications. While engine capacity on the Porsche engines can be increased to 4.6 litres, the location of the oil pump has until now placed a limit on capacity, as it would interfere with the con rod if a longer stroke were to be adopted; with the revised aftermarket pump though, capacity can now be increased to as much as 5.0 litres.

Integration of components can also be highly beneficial to overall system weight. Some offerings are based around an integrated sump pan/oil pump, whereby the pump is built into the sump pan. While this cuts down on weight and volume, the original reason for its development was far more fundamental. Pumps that provide a very high scavenge volume (and hence desirable crankcase vacuum) can cause the feed hoses between sump and inlet port to collapse, particularly if the hoses have been weakened by kinking during installation or storage. By integrating the pump, the need for hoses was eliminated and the issue resolved. Installation and servicing is also simplified, with no risk of kinking hoses or otherwise damaging them, and the potential for failure or leaks at joints or connections reduced.

Integrating other components such as the oil filter can also help to simplify an installation, reduce overall system weight or reposition the filter to a more convenient location for that particular installation.

**Air separation**

The problem of oil aeration can be a significant issue: air can be entrained either during scavenging or as a result of pump cavitation, and in extreme cases leads to oil foaming. The presence of air in the oil decreases its lubricating and cooling capacity, possibly requiring higher oil pressures than would otherwise be needed to avoid bearing damage, and increasing the parasitic losses placed on the engine in providing a higher pressure.

By their nature, scavenge pumps draw in a quantity not only of oil but also air, in the process entraining air bubbles within the oil itself. Typically the oil is returned to the tank at the top, having only a short time to separate before being drawn out at the bottom. It is worth noting of course that oil tank design in itself will improve oil-air separation – to quote one manufacturer queried on this topic, “it is far from a simple beer can” – and a good oil tank design is often more than adequate to achieve separation.

However, in some cases only so much can be achieved within the oil tank, especially if a particular installation places a limit on tank size or configuration, so a more proactive approach to resolving oil aeration is needed. Typically this results in the use of a centrifugal air-oil separator incorporated into the pump as an additional stage. This spins the air-oil mixture, and the differing fluid densities encourage a radial separation of the two components, which are returned to the oil tank separately.

Recently though an alternative to a mechanical centrifuge for this task has emerged. Dubbed Spintric, the device is a passive (no moving parts) component in the oil system, so it does not impose a parasitic shaft loss or increase the bulk of the oil pump itself. The device can be placed in any dry-sump oil system, just before the tank return, and relies completely on the geometry of its internal passages to force the separation of oil and air, again using the principle of differing densities in a rotating flow.

While the precise internal geometry of this device is
Focus: Oil Pumps

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Obviously a trade secret, with work ongoing by the manufacturer to improve the trade-off between separation efficiency and the back pressure imposed, overall an estimated separation of about 60-70% is possible, with minimal losses. The internals are manufactured from nylon, which provides more than adequate heat resistance for very low weight, and is machined and ported to reduce flow losses. Most significantly, comments from some users about the device indicate dramatic reductions in oil temperature – as much as 30 F (15 C) – as the thermal conductivity of the oil is maintained through the oil cooler without excess air being present.

In particular, compared to a centrifugal separator, the Spintric system does not add an additional pump stage, which can prevent the use of any separation device in series such as NASCAR where the number of oil pump stages is limited.

Conclusions
The fundamental technology of oil pumps has remained largely the same over the past three to five years, with small gains being made in efficiency through manufacturing quality and the provision of cleaner operating conditions to allow tighter tolerances. It is evident though that larger overall powertrain improvements can be achieved in specific applications where the oil pump installation can be completely optimised, even if this means unusual drive or packaging solutions.

One of the most exciting developments uncovered in the research for this article is the use of new passive air-oil separation devices. These provide a double benefit to overall oil system design, permitting a faster flow of oil through the tank and potentially less complex baffle requirements, while eliminating the parasitic losses of a mechanically driven separation device. Further optimisation of such devices could be interesting indeed – if tank settling times can be reduced then they could lead to an improvement in oil cooling and a potential decrease in the total amount of oil required.

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