Reducing the Amount of Entrained Air in Oil, Wet-Sump Systems

In a previous article, I discussed aeration and the nature of air in oil. (See "Archives" section for "Aeration and the Nature of Air In Oil") Unfortunately, in certain applications, it may not be possible to prevent aeration from occurring. When that happens, one is faced with taking steps that will reduce the amount of aeration to a level which can be tolerated.

Because wet-sump, dry-sump and semi-dry-sump systems are so different, I will address them separately. In this, the first of three installments, the focus will be upon wet-sump systems.

In a typical wet-sump system, the oil resides in the sump of the crankcase. The sump can be structural or it can be a traditional oil pan. After being ingested and discharged by the one and only oil pump in the system, the oil passes through the engine, does its job and then gravity takes over, causing the oil to drain back to the sump, where the process is repeated. In a perfect world, starting and operating an engine goes something like this:

- At start-up, the bulk of the oil resides in the sump.
- The end of the pick-up tube is located slightly above the bottom of the sump but is totally submerged.
- When the engine starts, the pump creates a partial vacuum at its inlet port(s).
- Atmospheric pressure within the sump pushes the oil through the inlet circuit.
- Oil enters the inlet side of the pump, is transported to the discharge side of the pump.
- High pressure oil enters a network of passages and flows through, the oil filter and the oil cooler, as well as various features and hydraulic devices within the engine, all of which present resistance to the discharge flow, causing pressure to build.
- As the operating speed of the engine increases, oil pressure increases proportionally.
- After the oil has circulated through the engine, it drains back into the sump, keeping the end of the pick-up tube covered.
- At some elevated speed, the pump's rate of output exceeds the engine's rate of demand for oil.

If the pump is of the typical, fixed-displacement type, then system pressure causes the pressure regulating valve to open and excess flow is either returned to the sump, or it is directed to the inlet side of the pump where it mixes with new, incoming oil. Regardless of where the excess oil goes, the pressure regulating valve causes the predetermined system pressure to be maintained throughout the rest engine's operating speed.

If the pump is of the variable-displacement type, then system pressure causes the internal workings of the pump to reduce its theoretical displacement and the predetermined system pressure is

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maintained throughout the rest of the engine's operating speed. Note that in this case, there is no excess oil.

In a perfect world, the oil is very thin and the inlet circuit provides very little in the way of resistance (a/k/a pressure drop). That being the case, the level of vacuum that is created at the pump's inlet is not sufficient to cause the dissolved air to be drawn out of solution.

Also, being a perfect world, the oil is able to find its way back to the sump without striking rotating and reciprocating components like the crankshaft and the connecting rods.

But the world isn't perfect.

- When cold, oil is very thick.
- Packaging constraints often force the inlet circuit to be overly restrictive.
- Rotating and reciprocating components whip much of the drain-back oil into foam.
- Poor drain-back, vehicle dynamics (acceleration, braking and cornering...) and/or vehicle attitude (angle of attack...) cause the pick-up to become uncovered.
- Residence time in the sump is very short.

What to do?

If, after employing all reasonable preventative measures, the level of aeration that exists cannot be tolerated, then the amount of air that is entrained in the oil must be reduced. (I stress that the amount of entrained air must be reduced. For all practical purposes, the entrained air cannot be completely eliminated.)

The problems that are associated with aerated oil are not unique to traditional motor vehicles, or electrically-powered vehicles, for that matter. Virtually every machine that is lubricated and/or cooled by oil or uses oil to transmit force can suffer from the ill effects of aeration. That being the case, there are literally thousands of designs for devices that deaerate oil. (If you are curious, then Google "oil dearator". When I did, I got 120,000 results...)

There are two ways in which oil can become deaerated: passively and actively.

Passive Methods

Passive methods do not rely upon the use devices that have moving parts. Instead, they rely upon time or the combination of time and surface area.

Time

At sea level and at room temperature, oil normally contains approximately 7% air by volume. Given enough time and the right conditions, most of the entrained air will go back into solution with the oil and the rest of the air will enter the atmosphere within the sump as free air. That is one of the reasons

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why commercial/industrial hydraulic systems have relatively large reservoirs which are well vented to atmosphere via filters.

If time is the only method of deaeration that is employed, then the high turnover rates that are seen in most applications may not allow enough residence time for much more than partial deaeration to occur.

"Turnover rate" is something that is foreign to many within the powertrain community. That's a shame, because understanding the turnover rate of a particular engine, transmission or gearbox provides a great deal of insight as to what is happening to the oil. Let's use a contemporary four cylinder engine as an example.

By definition, an oiling system must be in equilibrium when it is operating. In order to attain and maintain equilibrium, the rate at which the pump delivers oil to the engine and the rate at which oil drains back to the sump must match the engine's rate of demand.

To keep things simple, let us consider just two parameters: the engine's rate of demand and the volume of oil that is in the sump during operation.

For the sake of this exercise, we will assume that the engine demands oil at the rate of 16 lit/min when it is operating at a speed of 3000 rev/min. Also, for the sake of this example, we will assume that the sump holds 4 liters of oil when the engine is at rest and that it holds 2 liters of oil when the engine is operating at a speed of 3000 rev/min.

If the demand rate of 16 lit/min is divided by the sump volume of 2 liters, the result is a turnover rate of 8 times per minute. Or, looking at it another way, virtually none of the oil resides in the sump for a period that is longer than 7.5 seconds. (60 seconds divided by 8 = 7.5 seconds) That is not a lot of time.

Surface Area

Encouraging the aerated oil to fan-out over a relatively large surface before settling in the sump, allows some of the entrained air to go back into solution with the oil and the rest of the air to enter the atmosphere within the crankcase as free air. Again, citing commercial/industrial applications, the reservoirs usually contain large, flat plates that force the oil to fan-out before joining the oil that has already settled in the reservoir. Once the oil settles in the reservoir, baffles force the oil to travel a fair distance before reaching the pick-up. Traveling that extra distance provides additional time for the oil to deaerate and to cool.

The combined effects of time and surface area can be very effective at deaerating oil than either time or surface area acting alone. That being said, the high turnover rates that are seen in most applications make for challenging situations.

Active Methods

It is highly unusual for a wet sump system to employ a form of active deaeration. That is because the deaerating device must be placed ahead of the pump in order for the entrained air to be expelled prior to its entering the pump.

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Most designers and engineers go to great lengths in order to avoid placing anything between the pick-up and the inlet of the pump. That is because any failure in the feature or the device that is placed in the inlet circuit can inhibit or prevent oil from entering the pump. That being said, a simple impeller placed ahead of the pump's inlet can provide a solution that is both effective and robust.

Centrifuge

Perhaps the most direct way of implementing active deaeration in a wet-sump oil pump would be to add a centrifuge stage to the pump its self. (I said "direct" not "easy"...)

If a centrifuge were integral to the pump and incoming oil, along with entrained air, were to pass through the centrifuge prior to entering the pump, then much of the entrained air would be driven from the fluid stream and enter the atmosphere of the sump as free air. The mostly deaerated air would then continue along as it normally would, entering the pump, being discharged from the pump, passing through an oil filter and, perhaps, an oil cooler prior to entering the engine proper.

The primary benefit would be that the deaerated oil would have vastly improved properties related to:

- Lubrication film strength
- Heat transfer
- Transmission of force

Two significant secondary benefits include:

- Increased density of the oil would markedly increase in the effectiveness of the oil cooler.
- Supercharging effect would enhance the filling of the pump at elevated operating speeds.

The same principle can be applied to a pump of similar construction that would be mounted externally and driven by timing gears, a chain or a timing belt. However, that arrangement would have a greater number of failure modes, all of them being major. For example, the oil would have to travel from the sump to the pump by passing through the side of the sump or the crankcase. This arrangement would require seals, gaskets, fittings and lines in order to allow oil to travel from the sump to the pump and to allow air to travel from the pump to the crankcase.

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