Engine Bearings and how they work

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Bearing is a device supporting a mechanical element and providing its movement relatively to another element with a minimum power loss.

1. Functions of bearings in internal combustion engines

The rotating components of internal combustion engines are equipped with sleeve type sliding bearings.
The reciprocating engines are characterized by cycling loading of their parts including bearings. Such character of the loads is a result of alternating pressure of combustion gases in the cylinders.
Rolling bearings, in which a load is transmitted by rolls (balls) to a relatively small area of the ring surface, can not withstand under the loading conditions of internal combustion engines.
Only sliding bearings providing a distribution of the applied load over a relatively wide area may work in internal combustion engines.

The sliding bearings used in internal combustion engines:

- **Main crankshaft bearings** support crankshaft providing its rotation under inertia forces generated by the parts of the shaft and oscillating forces transmitted by the connecting rods. Main bearings are mounted in the crankcase. A main bearing consists of two parts: upper and lower. The upper part of a main bearing commonly has an oil groove on the inner surface. A main bearing has a hole for passing oil to the feed holes in the crankshaft. Some of main bearings may have thrust bearing elements supporting axial loads and preventing movements along the crankshaft axis. Main bearings of such type are called flange main bearings**.**

- **Connecting rod bearings** provide rotating motion of the crank pin within the connecting rod, which transmits cycling loads applied to the piston. Connecting rod bearings are mounted in the Big end of the connecting rod. A bearing consists of two parts (commonly interchangeable).
- **Small end bushes** provide relative motion of the piston relatively to the connecting rod joined to the piston by the piston pin (gudgeon pin). End bushes are mounted in the Small end of the connecting rod. Small end bushes are cycling loaded by the piston pushed by the alternating pressure of the combustion gases.

- **Camshaft bearings** support camshaft and provide its rotation.

2. Lubrication regimes

Sliding friction is significantly reduced by an addition of a lubricant between the rubbing surfaces.
Engine bearings are lubricated by motor oils constantly supplied in sufficient amounts to the bearings surfaces.

Lubricated friction is characterized by the presence of a thin film of the pressurized lubricant (**squeeze film**) between the surfaces of the bearing and the journal.
The ratio of the squeeze film (oil film) thickness **h** to the surface roughness **Ra** determines the type of the lubrication regime:

- **Boundary lubrication (h<Ra)**.

  A constant contact between the friction surfaces at high surface points (microasperities) occurs at boundary lubrication.
  This regime is the most undesirable since it is characterized by high coefficient of friction (energy loss), increased wear, possibility of seizure between the bearing and journal materials , non-uniform distribution of the bearing load (localized pressure peaks). Very severe engine bearing failures are caused by boundary lubrication.
  Conditions for boundary lubrication are realized mainly at low speed friction (engine start and shutdown) and high loads.
  Extreme pressure (EP) additives in the lubricant prevent seizure conditions caused by direct metal-to-metal contact between the parts in the boundary lubrication regime.

- **Mixed lubrication (h~Ra)**.

  An intermittent contact between the friction surfaces at few high surface points (microasperities) occurs at mixed lubrication.
  Mixed lubrication is the intermediate regime between boundary lubrication and hydrodynamic friction.

- **Hydrodynamic lubrication (h>Ra)**.

  High rotation speed at relatively low bearing loads results in hydrodynamic friction, which is characterized by stable squeeze film (oil film) between the rubbing surfaces.
  No contact between the surfaces occurs in hydrodynamic lubrication.
  The squeeze film keeps the surfaces of the bearing and the shaft apart due to the force called hydrodynamic lift generated by the lubricant squeezed through the convergent gap between the eccentric journal and bearing.

Bearings working under the conditions of hydrodynamic lubrication are called hydrodynamic journal bearings.

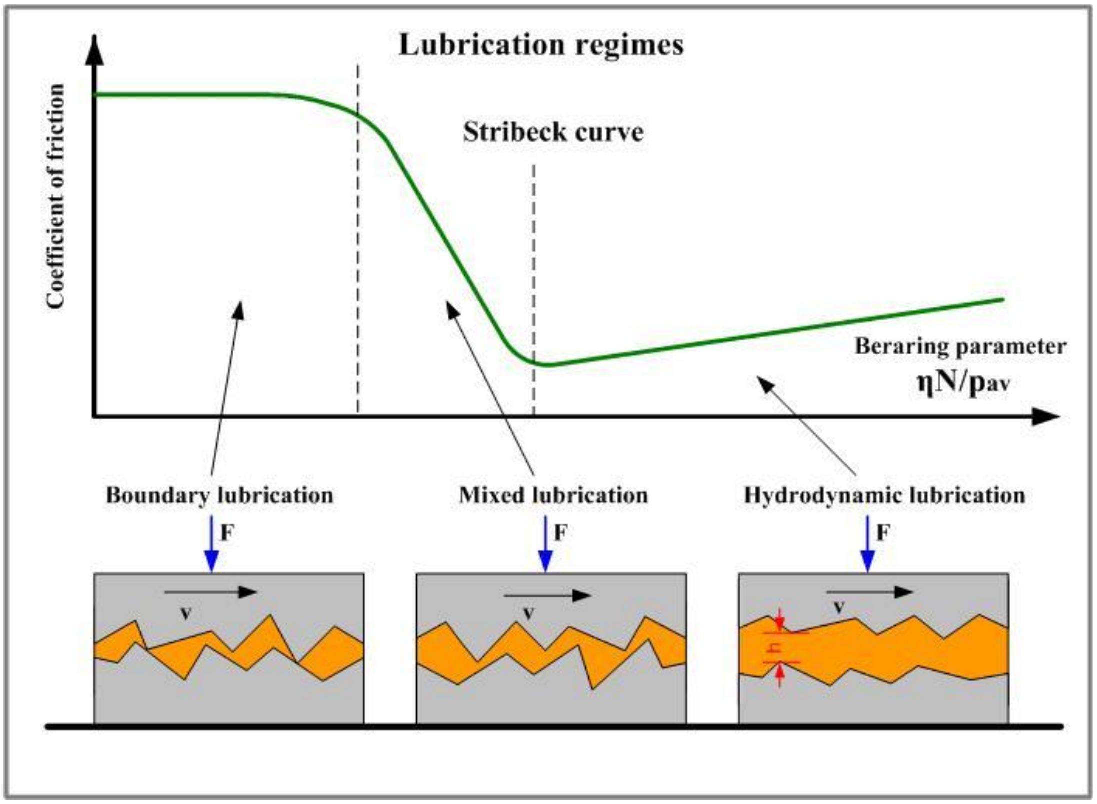

Fig.1 Lubrication regimes

The three lubrication regimes are clearly distinguished in the Striebeck curve (Fig.1), which demonstrates the relationship between the coefficient of friction and the bearing parameter **η*N/p$_{av}$** (**η** - dynamic viscosity of the lubricant, **N** - rotation speed, **p_{av}** - average bearing pressure).
Stability of different lubrication regimes may be explained by means of the Striebeck curve: Temperature increase due to heat generated by friction causes drop of the lubricant viscosity and the bearing parameter.
According to the Striebeck curve decrease of the bearing parameter in mixed regime causes increase of the coefficient of friction followed by further temperature rise and consequent increase of the coefficient of friction. Thus mixed lubrication is unstable**.**
Increase of the bearing parameter due to temperature rise (lower viscosity) in hydrodynamic regime of lubrication causes the coefficient of friction to drop with consequent decrease of the temperature. The system corrects itself. Thus hydrodynamic lubrication is stable.

3. Hydrodynamic journal bearing

Hydrodynamic journal bearing is a bearing operating with hydrodynamic lubrication, in which the bearing surface is separated from the journal surface by the lubricant film generated by the journal rotation.
Most of engine bearings are hydrodynamic journal bearings.

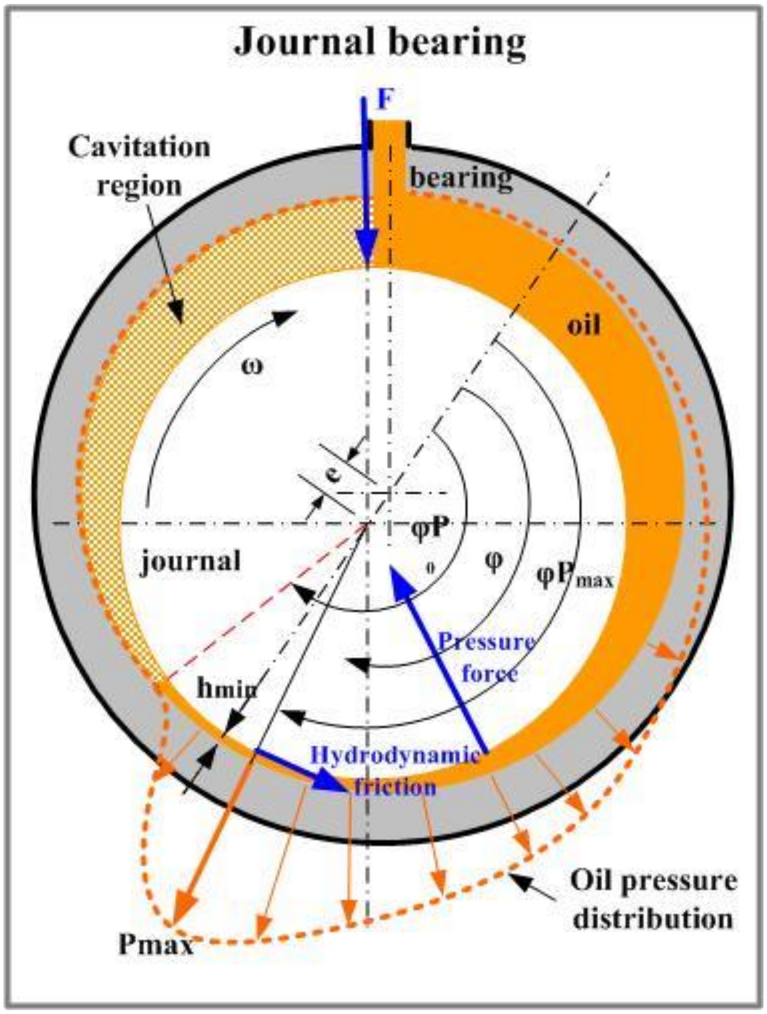

Fig.2 Journal bearing

Fig.2 demonstrates a hydrodynamic journal bearing and a journal rotating in a clockwise direction.
Journal rotation causes pumping of the lubricant (oil) flowing around the bearing in the rotation direction.
If there is no force applied to the journal its position will remain concentric to the bearing position. However a loaded journal displaces from the concentric position and forms a converging gap between the bearing and journal surfaces.
The pumping action of the journal forces the oil to squeeze through the wedge shaped gap generating a pressure.

The pressure falls to the cavitation pressure (close to the atmospheric pressure) in the diverging gap zone where cavitation forms.

Two types of cavitation may form in journal bearing:

- **Gaseous cavitation** associated with air and other gases dissolved in oil. If the oil pressure falls below the atmospheric pressure the gases tend to come out of the oil forming gaseous cavitation voids. The cavities are carried by the circulating oil to the pressurized converging gap where they redissolve in the oil and disappear without any damaging effect.
- **Vapor cavitation** forms when the load applied to the bearing fluctuates at high frequency (e.g. bearings in high RPM internal combustion engines). The oil pressure instantly falls causing formation of cavities due to fast evaporation (boiling). When the pressure rises the vapor cavities (cavitation bubbles) contract at high velocity. Such collapse results in impact pressure, which may erode the bearing material.

The oil pressure creates a supporting force separating the journal from the bearing surface. The force of oil pressure and the hydrodynamic friction force counterbalance the external load **F**.
The final position of the journal is determined by the equilibrium between the three forces. In the hydrodynamic regime the journal “climbs” in the rotation direction (left side of the bearing).
If the journal works in boundary and mixed lubrication the hydrodynamic pressure force disappears (the other two forces remain). Thus, the “climbing” direction is opposite to the rotation direction and the journal rolls up the right side of the bearing.

4. Conditions of Engine Bearing Operations

Engine bearings are referred to as hydrodynamic journal bearings operating with hydrodynamic lubrication, in which the bearing surface is separated from the journal surface by the lubricant film generated by the journal rotation.
The lubricant (oil) film prevents localized overloading providing a distribution of the applied force over a relatively wide area.
However there are some factors that adversely impact the oil film, changing the lubrication regime from hydrodynamic to mixed:

- oil starvation, high loads;
- low rotation speed;
- low viscosity oil;
- elevated temperature additionally decreasing the oil viscosity;
- roughness of the bearing and shaft surfaces;
- oil contaminants;
- geometrical distortions and misalignments.

The mixed lubrication regime produces intermittent metal-to-metal contact, which may lead to bearing failure due to seizure or excessive wear.
Internal combustion engines are characterized by the cycling load of the bearings caused by alternating pressure of the combustion gases in the cylinders and inertia forces developed by the accelerating parts.
Cycling loads applied to the bearings may cause their failure as a result of the material fatigue.

5. Properties of Engine Bearing Materials

Properties of bearing materials should provide their stable operation in the hydrodynamic and mixed lubrication regimes under cycling loads in the presence of a lubricant at an elevated temperature and containing some amount of contaminants.

Here are the general bearing material properties:

- **Fatigue strength (load capacity)** is the maximum value of cycling stress that the bearing can withstand after an infinite number of cycles. Cycling stresses applied to the bearings are the result of combustion and inertia forces developed in internal combustion engines. If the bearing loading exceeds its fatigue strength then fatigue cracks form in bearing material, which spread to the back bearing layer and may result in flaking out of the material.
- **Compatibility (seizure resistance)** is the ability of the bearing material to resist physical joining with the journal material when the direct metal-to-metal contact between the bearing and journal surfaces occurs. High seizure resistance is important when the bearing works in the mixed regime of lubrication.
- **Wear resistance** is the ability of the bearing material to maintain its dimensional stability (oil clearance) despite the presence of abrasive foreign particles in the oil and under the conditions of intermittent direct contact between the bearing and journal materials.
- **Conformability** is the ability of the bearing material to accommodate geometry misalignments of the bearing, its housing or journal. Shape irregularities of a bearing with poor conformability may cause localized decrease of the oil film thickness to zero where the bearing material experiences excessive wear and high specific loading.
- **Embedability** is the ability of the bearing material to entrap and sink beneath the surface small foreign particles (dirt, debris, dust, abrasive residuals) circulating in the lubricating oil. Poor embedability of a bearing material causes accelerated wear and produces scratches on the journal and bearing surfaces, which may lead to seizure.
- **Corrosion resistance** is the ability of the bearing materials to resist chemical attack of oxidized and impure lubricants.
- **Cavitation resistance** is the ability of the bearing material to withstand impact stresses caused by collapsing cavitation bubbles, which form as a result of sharp and localized drops of pressure in the flowing lubricant.

6. Summary

- Engine bearings are sliding bearings operating mostly in hydrodynamic regime of lubrication in which the bearing and journal surfaces are separated by an oil film.
- Engine bearings withstand the alternating load generated by the combustion gases pressure and by the rotating and reciprocating engine parts.
- High loads, low viscosity of the lubricant, low rotation speeds, surface roughness and geometrical irregularities may cause direct contact between the bearing and journal surfaces.
- Engine bearing materials combine properties related to the material strength (load capacity, wear resistance, cavitation resistance) with the properties attributed to the material softness (compatibility, conformability, embedability).