Oil for Classic British Sports Cars

Over the last couple of years, the question “which oil should I use in my classic car?” has been posed and answered (and argued about) in almost every corner of the automotive world. The discussion was sparked, at least in part, by increasing reports of tappet and / or camshaft failures in vintage engines. A number of articles in print and posts on the forums link these problems to modern motor oil, and specifically the reduction of the levels of zinc dialkyldithiophosphate (ZDDP, ZnDTP, or ZDP) in API SM oil. Many of you are familiar with Keith Ansell’s article “Oil is Killing Our Cars” (Oct 2006), which has been reprinted and referred to extensively. More recently, we have seen another series of articles that have appeared under several different titles, among them “Engine Oil Mythology”, “Motor Oil Myths and Facts”, and “Starburst Oil Myth”. These articles seem to prove that the level of ZDDP in modern oil is adequate for older engines. How can there be two groups, both of which include engineers and professional mechanics with years of experience, with mutually exclusive positions? This is a complex issue, and I hope to unpack this and see if we can understand how we got here.

To make this more manageable, I have broken this discussion into seven parts.

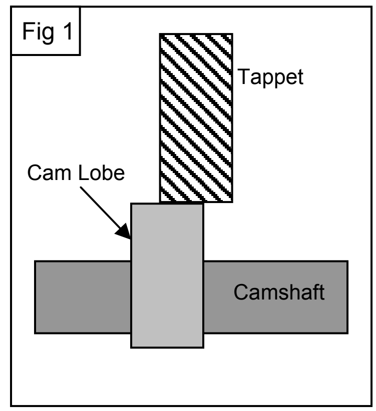
- What Exactly is the Problem?
    - Technical discussion of the components involved
    - The nature of the cam lobe / tappet interface
    - Type of damage to the cam and/or tappet
- About Oil
    - Base oils and the additives used to fine-tune the properties of the oil
    - ZDDP and how it works
- Oil Standards – Where do they come from?
    - ELOCS, API, SAE, ILSAC, ASTM
    - Engine oil quality marks and what they mean
- Timeline – Development of Oil Standards and Use of ZDDP in Oil
    - 1911-present
    - Introduction to various tests developed to certify oil performance
    - Changes in oil formulations made to solve specific problems
    - Changes in ZDDP concentration over time
- Testing and ZDDP reduction in API SM Oil
    - Why ZDDP was reduced
    - Specific tests done to SM oil
- Real World Experience
    - Engine Rebuilders Association (AREA)
    - Cam / Tappet Manufacturers
    - Oil Companies
- What Does It All Mean?
    - ZDDP level for break-in (first 20-30 minutes)
    - ZDDP level after initial break-in
        - for first 500 miles
        - second 500 miles
        - after that

There is also an appendix which a collection of cam/tappet related tech tips on rebuilding and breaking in vintage British flat tappet cam engines.

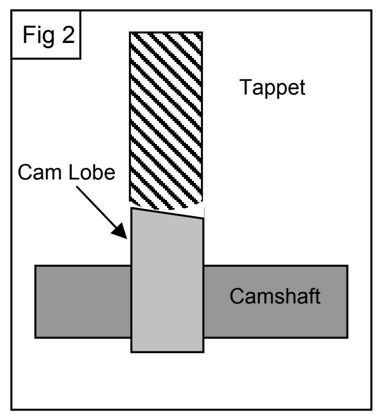
What Exactly is the Problem?

Before we dive in, we need to understand a little about the parts involved, just so we are all on the same page. The problems associated with cams and tappets are due in part to the nature of the contact between them, which is unique. Engine bearings are separated from the rotating shaft or journal by a thin film of oil. A rotating shaft will drag a “converging wedge” of oil between the shaft and the bearing. The faster the rotation, the more oil is pulled into the space between the two surfaces. Because oil is thick or viscous, the liquid pressure in the oil wedge will prevent the bearing and the shaft from touching. This is described as “hydrodynamic lubrication”.[24] In contrast, the lobe of the cam slides across the foot of the tappet and the contact area is very small. Cams and tappets are pressed together under high pressure and high heat.

The tappets must rotate or they will wear out quickly because the rotation of the tappet pulls a “converging wedge” of oil into the area where the cam lobe and the foot of the tappet come together. The oil film is the only thing preventing metal-to-metal contact. The continuous flow of oil also carries away heat, which is critical to long cam and tappet life. The oil circulating through the engine “may be 50°F (10°C) hotter than the crankcase oil.” [13] Cams and tappets in older engines are lumped together as “flat tappet cams” and you will see that term in any discussion of oil and classic cars. This is referring to the design of the tappet, where the foot or bottom of the tappet sits directly on the lobe of the cam, as opposed to “roller tappets” which have – you guessed it – a roller bearing that rides on the lobe of the cam. The term “flat” is perhaps misleading. It is true that the original tappets used in early British engines (like the MGT series XPAG) were “dead flat”, and the lobes of the cam were also “dead flat”, meaning the lobe was the same height all the way across from front to back. (Fig 1) The tappet rotates because it is offset with respect to the lobe of the cam. For these engines the term “flat tappet cam” makes perfect sense. However, not all cams and tappets are “flat”.



It was discovered that tappet rotation could be enhanced if the cam lobe were tapered and the foot of the tappet was “domed” or “curved” like a lens. (Fig 2) These tappets may or may not be offset. The taper of the cam lobe is measured in ten thousandths of an inch, and the shape of the foot of the tappet is often measured in diopters, like the lens in a pair of glasses. The “dome” and the “taper” are very subtle, not generally detectable with the naked eye. Fig 2 greatly exaggerates the curve and taper. They dome and taper are also matched, one to the other; it is important to use tappets that have a curved surface that is matched to the taper of the lobes on a specific camshaft. For the T-Series, we sell a Crane cam with a 0.0011” taper on the lobes. To match the cam, we offer specially modified tappets which are crowned to match. Crane considers a 0.002" hemispherical crown on a tappet to be normal, but for the T-Series cam, the tappets are crowned 0.0005” to 0.0008"



Even though cams with tapered lobes and tappets with a domed foot are not really “flat”, they are lumped together with the cams and tappets that actually are flat under the general heading of “flat tappet cams and tappets”.

Whatever the design, new tappets and cams have to wear-in” together during the initial break-in, usually considered to be the first 20-30 minutes that the engine is run after a rebuild, and this is a very critical period. The break-in is the key, because it does not take much to wear to trigger the failure of a lobe. Once the surface of the cam lobe is worn just 500µm (0.5 mm, .0197 inches), the lobe will fail rapidly.[1]

The cam/tappet failure problems usually start with a freshly rebuilt engine. Sometime after the initial break-in period, the engine starts making expensive sounding noises and it is discovered that the bottom of one or more tappets has “gone away”. Instead of a smooth machined surface, the face of the tappet looks like to surface of the moon. Or perhaps it is the camshaft, which has one or more lobes that have been worn down. With metal debris in the sump, there is no choice but to tear the engine down and rebuild it again. Usually, it is just a couple of tappets or cam lobes that have failed, but all it takes is one. The damage can be broken down into three groups.

Scuffing

Scuffing is defined as “damage caused by solid-phase welding between sliding surfaces” [25], in this case the transfer of metal between the camshaft and the tappets. “Microscopically, the scuffed surface appears irregular, torn, with plastic deformation, and shows evidence of melting.”[25] Break-in scuffing, as the name implies, occurs during break-in, and it is the result of direct metal-to-metal contact between the cam lobe and the foot of the tappet. Scuffing, also called “galling”, can cause “spalling”, the second type of damage.

Spalling

Spalling describes the damage where small chunks of metal are lost from the lobe of the cam or the foot of the tappet. The foot of a chilled cast iron tappet has particles of iron carbide (very hard, very dense) imbedded in a softer iron matrix. This type of surface is very resistant to wear in areas of high contact stress, like the point of contact between the cam lobe and the foot of the tappet. If metal is transferred from the cam lobe to the tappet (scuffing)[2], the transferred material can cause a very high load to be applied to a very small area on the face of the tappet. The softer iron matrix may develop small cracks around the harder iron carbides. Under high loads with areas of concentrated stress, small pieces of the lifter foot will fall away, leaving a tiny pit or crater. Anything that causes highly localized loading of the contact surface can cause spalling. If the lifter fails to rotate, or if debris in the oil winds up between the foot of the tappet and the cam lobe you can have spalling. Minor scuffing and spalling will frequently heal over during break-in, and it will not be discovered until the engine is torn down for a rebuild sometime in the future. Spalling of the tappet foot will not necessarily affect the lobe of the cam. Teledyne Continental considers spalling of less that 10% of the foot of a tappet to be acceptable. If the damage to the lifter foot is extensive, the cam lobe can be damaged. [26]

Corrosion

The third type of damage can be termed corrosion, and generally does not by itself cause problems that lead to the tear-down of a freshly rebuilt engine. For many British cars, it is a serious issue because so many of these vehicles are not driven frequently. It is enough of a concern to affect the choice of a motor oil. Surprisingly, corrosion due to rust caused by water vapor in the engine can be found on an engine that was rebuilt with well-oiled components, then bagged waiting for the restoration of the chassis. The oil present in the engine will absorb moisture from the atmosphere. Normal operation of the engine will drive off the moisture, but if it just sits, there will be corrosion. [26] Normal motor oil is designed to lubricate, not to coat and protect metal surfaces from corrosion.[33] When the engine is fired, any surface rust on the cam lobes or tappets will disappear, but any pitting will remain. The pitting and surface erosion found when the engine is torn down next time may be confusing unless you know what you are looking at.

Because it takes time for the corrosion to form the pits, you can minimize this problem by driving your car more frequently. You will need to drive it long enough for the oil to come up to temperature (170°F to 200°F), and you need to drive it long enough to reduce the moisture and acids in the oil. According to the aircraft engine manufacturer Teledyne Continental, a minimum of 30 minutes is needed once the oil is up to operating temperature.[26] If it is not possible to drive the car frequently, it is important to change the oil more frequently than you normally would. I have not found specific recommendations for automotive applications, but Teledyne Continental recommends that the oil and filter be changed four times a year, not because the oil has broken down, but to eliminate “wear particles, combustion by-products, moisture and acid buildup in the oil. [26] You can also use oil designed for classic cars. They do a much better job of protecting the metal surfaces inside the engine. [33] Just remember, when you do drive, drive it long enough to bring the oil up to temperature and keep it there for at least 30 minutes.

There is a second type of corrosion, chemical in nature, which may be discovered in a tear down. It is usually not a problem until an engine has been run for some time, and so it is not relevant to this discussion at this point. We will discuss this type of corrosion in due course.

Scuffing and spalling problems are much worse with high performance cams. The more radical the cam, the more trouble they can be. Smokey Yunick, legendary NASCAR mechanic and innovator, reportedly resorted to breaking in racing cams and lifters in multiple sets, looking for a set that survived the process.[7] The focus of this article is on general principles and problems with engines built for use on the street rather than the race track.

Shops specializing in British cars have been dealing with these problems for years, and most of them have developed a set of procedures to minimize the chance of a cam/tappet failure. Having arrived at this combination of parts, machine work, engine prep and lubricants, most of the specialists have contained the problem, or at least kept it at a low level. Some have gone to considerable lengths to deal with this situation, and it does not stop with the rebuild. Skip Kelsey of Shadetree Motors probably put as many miles on a 52 MG TD as anyone. Skip bought his tappets from a supplier in the UK, and had experienced a couple of tappet failures. He used to check the tappets in his engine every 3,000 mile or so. If he thought one was starting to go, he'd replace it.

After talking to several of these specialists, it was clear that no two shops would agree on exactly what the cause or causes of past problems had been. They all had their own ideas about what needed to be done to prevent problems based on their personal experience. One thing common to every list was oil, particularly break-in oil. Although the brand and type of oil varied, it was clear that oil was perceived to be a problem, and they had selected a specific oil that they felt offered the best protection. This brings us to our next topic of discussion – oil.

About Oil

Oil is complex, and to understand how it works we need to know what goes into it and how the additives affect the properties of the oil.

Every manufacturer starts with a “base oil”. Base oils are divided into five groups (I, II, III, IV, V). Group I, II and III are mineral oils, increasing in purity as you go from I to III. Some automotive oil is made using Group I base oils, but more manufacturers use a Group II base which has better lubricating properties and better stability. In the last 10 years, there has been an increase in the use of Group III base oils, which represent the highest level of refined mineral oils. They have excellent lubrication properties, and they are very stable. Some of the oil marketed as “semi-synthetic” or “synthetic” is made by combining a Group 3 base with a selection of additives that improve the performance of the base oil. Group IV base oils are chemically engineered and are truly “synthetic oils”. The Group IV base is augmented with various combinations of additives to produce oil sold as synthetics or synthetic blends. Group V are also pure synthetics, and they are generally used to produce additives rather than being used like other base oils. The properties of the base oil are “fine tuned” to meet specific needs by the oil companies using a wide selection of additives.[27] We will work our way through these properties and additives one by one, starting with something familiar.

Viscosity

Viscosity is the oils “thickness”, or resistance to flow. The Viscosity Index is a measure of the oils resistance to thinning at high temperature. A 10W-30 oil may have a viscosity index of 154, which means something to engineers, but most of us understand the 10W-30. (You may think of it as “weight” as in “10 weight” or “30 weight”). Most everybody knows the lower numbers (0,5,10) mean the oil flows well at low temperature, and it may thin out at high temperature. The higher numbers (30, 40, 50) mean the oil will not thin out at high temperatures, but it may be too “thick” for use at low temperatures. Most owner’s manuals for British Cars specify single weight oil, and a different oil for different operating temperatures because that is what was available when the cars were new. Modern multi-grade oil may have a Society of Automotive Engineers (SAE) viscosity of 0W-20, or 5W-30. The two numbers describe the oils ability to flow at two temperatures; the first is measured at 0° F, second at 212° F. A 5W-30 oil flows well at very low temps, which simply means the oil is suitable for use in winter where temps are very low. With this oil, the engine will turn over easier when it’s freezing. The second number (30) means this oil remains “thicker” at high temps - when the engine warms up, the oil does not “thin out”. This oil will provide good lubrication when the weather turns warm too. This miracle is achieved by adding viscosity modifiers to the oil. These are generally polymers that expand with heat. These make it possible to run same oil year round, which is essential to achieve the “extended use” oil service intervals common with modern vehicles. Modern engines are running thinner oils (0W-20), and the engines have been designed around these modern lubricants. They generally run tighter tolerances and run hotter than any vintage engine. The thinner oils help modern vehicles operate safely in extreme heat or cold, and they help achieve better fuel economy. In general, older engines should use higher viscosity oils because that is what they were designed for; they have larger tolerances. Most of us don’t really care if the oil will allow us to drive our MGs, Triumphs and Healeys in sub-zero weather- the car will be put up for the winter anyway.

In contrast to the SAE viscosity, which is always measured at 0° F and 212° F, “Operating Viscosity”is measured at the actual operating temperature of a specific engine. Visualize a chamber that can be maintained at a specific temperature, say 195º F. In the chamber is a graduated container with a narrow tube for a drain. A precise volume of a oil is placed in the container, and the time it takes to flow out of the container is measured. The unit of measure is square millimeters per second, or “centistokes” (cSt). Because the viscosity can be related to the actual operating temperature of a particular engine, some consider the “operating viscosity” to be more relevant than the SAE viscosity. I have seen “Operating Viscosity” on a couple of oil related websites, but it is usually given along with the SAE viscosity. The SAE viscosity is much more common an gives us a standard we can use to select oil for our vehicles.

Dispersants

Dispersants make up 3%-6% (by weight) of a modern oil. There is more dispersant in the oil than any other additive. These are bi-polar molecules with a polar head and a hydrocarbon tail. The head is attracted to sludge, dirt, and soot in the oil, and a particle of dirt will be surrounded by these molecules. The tail is suspended in the oil, and the particle is therefore kept in suspension until it is trapped in the oil filter or drained from the sump when the oil is changed. These molecules act just like a laundry detergent, forming a very small "bubble" called a micelle around contaminants in the oil. Dispersants prevent contaminants from depositing on piston rings, valves or other metal surfaces.

Detergents

Detergents account for 2% - 3% of the oil by weight, making them the second most common additive. Despite the name, detergents are mainly used to control acids formed by combustion byproducts. They do have some ability to "wash" the metal surfaces of organic deposits, but that is not their main job. Several different types of detergents are being used, but the most important are the sulfonates. Like the dispersant, these are bi-polar molecules. In this case, the head is a salt of sulfonic acid, typically calcium, magnesium or sodium, and the tail is a short hydrocarbon chain. Like the dispersant, these form micelles, but unlike the dispersant, there is a metal carbonate incorporated into the center of the detergent micelle that neutralizes the acids that form in the sump over time.

Anti-Oxidants

Oil subjected to heavy loads and high heat breaks down, or oxidizes. In extreme cases, the oil will get so thick the oil pump can't move it. The term "catastrophic engine failure" sums it up. Oxidation resistance is a measure of the stability of the oil at high temperatures. A base oil has its own "stability" and additives are mixed in to improve that. These additives work at very low concentrations, typically 1% or less by weight.

Friction Modifiers

Friction modifiers are a class of additives that provide "anti-wear", "anti-scuffing" and "extreme pressure" or "EP" protection for the moving parts in an engine. The most common motor oil additive in this group is zinc dialkyldithiophosphate, usually abbreviated ZDDP, ZDP and sometimes ZnDDP. It has been used in motor oil since the 1940s. ZDDP is a molecule that reacts to high pressures and heat to form a tribofilm, a film that effectively prevents metal to metal contact.[3] Conventional theory considers these films to be "sacrificial boundaries composed of easily sheared layers". [3] More recently (~2005) a theory based on the idea that "pressure induces the formation of cross-links through the zinc atoms…"[3] has been referred to in various SAE and Tribology papers. (Tribology is the study of adhesion, friction and wear of materials,[20] not the study of indigenous tribes.) "Cross-link formation strengthens the film, redistributing the pressures to which the underlying surface is exposed." [3] These cross links can only form above specific pressures, and the material in sliding contact must be hard enough for these pressures to develop. The material in sliding contact also must also be harder than the films being formed or the film itself would have an abrasive effect. Cast iron and steel are ideal materials, and the type of pressure exerted by a cam lobe rubbing across the foot of a tappet is exactly the right environment to form the ZDDP tribofilms.[3] The films are not made of ZDDP molecules – the films are formed from the products of ZDDP decomposition. ZPPD initially breaks down to form a short chain polyphosphate. After more rubbing, a bilayer phosphate film is formed with long chain zinc polyphosphates on the surface and shorter chains in the bulk of the film. [6] ZDDP tribofilms provide the critical protection for the cam and tappets. "The cam lobe/flat tappet interface is continually subjected to the highest pressure loads encountered in an internal combustion engine and ZDP in motor oil enables the long term survival of this interface." [11] It is most critical during break-in, and less critical after that. While ZDDP reduces wear, it cannot and does not prevent wear, because some wear is inherent in the operation of the cam and tappets. However, ZDDP can help prevent scuffing and subsequent catastrophic failure. Paradoxically, ZDDP is also a wear agent. One paper on valve train wear points out "…that the formation of an anti-wear film involves an element of metal wastage in the form of chemical wear [chemical corrosion], and that the use of more active ZDPs causes more chemical wear."[2] The available data indicates that ZDDP in concentrations of 0.15% (1500

PPM) provides additional protection against scuffing, but these concentrations will increase wear due in part to this chemical corrosion. At 0.20% (2,000 PPM), the ZDDP has been found to attack the grain boundaries in the iron.[7] Simply stated, ZDDP is like a lot of things; in the right amount, it is beneficial, but too much will cause problems.

To complicate matters, the dispersants and detergents in the oil will have an effect on the ZDDP. In some tests, oil with higher levels of dispersants had greater valve train wear. Wear can also be affected by the detergent type and amount. [2] "Detergents… alter the chemical composition of the films."[3] The article goes on to say "Common detergents contain calcium ions, which are incorporated into the ZP [zinc phosphate] films by replacing the Zn… on iron surfaces this causes… higher pressure and increased wear..." [3] because the calcium cross-links are not as strong. [3]

On the plus side, ZDDP is also an excellent anti-oxidant, which will come up again later. ZDDP is not the only friction modifier. Additives based on molybdenum are currently being used to reduce friction and increase mileage. ZDDP is the main character in this story though.

Measuring ZDDP is tricky, and confusing. It is usually done by measuring elemental zinc and/or phosphorus. The concentration, when it is provided, is usually given as parts per million (PPM) or as "weight %". For example, 0.12% by weight is equivalent to 1200 PPM. Commonly, measurements are done using a Rotating Disc Electrode (RDE) or Inductively Coupled Plasma (ICP) Spectroscopy. While these are good for determining the level of ZDDP is fresh, unused oil, they do not work well on used oil. Oil subjected to high heat in presence of water vapor will break down due to hydrolysis. You will still have significant levels of zinc and phosphorus in the oil but it is not ZDDP. Fourier Transform Infrared (FTIR) is better for measuring ZDDP depletion.[5] Measuring ZDDP levels would not be an issue if the concentration was printed on the label. Unlike food, the ingredients in the oil are not on the label in plain English. The oil companies consider their formulas proprietary, and rightly so. More recently, some of the oil companies have started listing the amount of zinc, phosphorus, or ZDDP in some of their oil, presumably as a result of pressure from consumers.

There are other additives that go into the oil, but the five discussed above will suffice for this discussion.

So…. we have a basic understanding of the major problem- cam and tappet failures- and a basic understanding of the way motor oil is modified with various additives, and what the additives affect. To understand what has happened to oil over the last 10 years, we need to know a little about how standards for motor oil are developed and who has a say in setting these standards.

Oil Standards - Where do They Come From?

Today, the American Petroleum Institute (API) is responsible for the Engine Oil Licensing & Certification System (EOLCS), a voluntary licensing and certification program that sets standards and specifications for motor oil. This is very much a cooperative effort between the oil industry and the automobile and engine manufacturers.

The major players are Ford, General Motors, Daimler Chrysler, the Japan Automobile Manufacturer's Association, and the Engine Manufacturer's Association. This diverse group develops performance standards, test methods, and restrictions in cooperation with the various engine and vehicle manufacturers, the Society of Automotive Engineers (SAE), the American Society for Testing & Materials (ASTM), and the American Chemistry Council. In addition to the organizations mentioned above, the American Automobile Manufacturers Association (AAMA), and the Japanese Automobile Standards Organization (JASO) also have a say about performance specifications for lubricants.

In 1992 the AAMA and JASO formed the International Lubricant Standardization and Approval Committee (ILSAC). ILSAC, according to one source, was formed because of a concern that the API-SAE-ASTM group might not be reacting quickly enough to changes in the industry, and there was concern about the lag in developing more relevant standards for oils. ILSAC sets minimum performance standards for oil used in gasoline powered passenger car and non-commercial light trucks.

ILSAC, API, SAE, and ASTM joined together and formed the Engine Oil Licensing and Certification System (EOLCS). The EOLCS licenses oils approved through the ILSAC. The API provides the overall administration of the EOLCS system, which brings us back to what I said a minute ago. The bewildering array of groups know by three and four letter acronyms just listed is not complete, but we're going to ignore the ACEA, ISO, AIAM and AAIA for now.
Now, about the standards. Companies that market oil that that meets the API standards can print the "API Engine Oil Quality Marks", specifically the API Service Symbol (known as the "Donut"), and the "Starburst" Certification Mark on the packaging or advertising for the oil. These symbols amount to the "Good Housekeeping Seal of Approval". They establish the quality of the product and they provide useful information anyone considering buying that quart of oil. Currently, more than 8,000 products in more than 50 countries carry these symbols.

The API Service Symbol, also known as the "Donut"

1. Performance Level: Gasoline engine oil categories (for cars, vans, and light trucks with gasoline engines) fall under API's "S" or "Service" categories. SM" is the current automotive grade, introduced in 2004. Diesel engine oil categories (for heavy-duty trucks and vehicles with diesel engines) fall under API's "C" (for "Commercial"), and "CJ-4" is the current commercial or diesel truck grade.
2. SAE Viscosity Grade: The measure of the oil's thickness and ability to flow at certain temperatures as established by the SAE.
3. Energy Conserving: The "Energy Conserving" designation applies to oils intended for gasoline-engine cars, vans, and light trucks. Widespread use of "Energy Conserving" oils may result in an overall savings of fuel in the vehicle fleet as a whole.

The API Certification Mark, also known as the "Starburst"

The "Starburst Certification Mark". Unlike the performance level on the "Donut", which will show which standards the oil meets, the "Starburst" simply means the oil meets the ***current*** International Lubricant Standardization and Approval Committee (ILSAC) engine protection and fuel economy standards. Although not as well known, every API classification since 1996 has had a companion GF standard. For example, the API performance level in '96 was "SH" and the ILSAC standard was GF-1. In 1997, the API performance level changed to "SJ" and the ILSAC standard was GF-2. The current standard is GF-4. The "GF" number will never appear in the "Starburst" .

For diesel oil, the lower part of the API “Donut” is a little different. Used in conjunction with API CI-4 and CJ-4, the “CI-4 PLUS” designation identifies oils formulated to provide a higher level of protection against soot-related viscosity increase and viscosity loss due to shear in diesel engines. Like the term “Energy Conserving”, “CI-4 PLUS” appears in the lower portion of the API Service Symbol “Donut.”

The API Service Symbol “Donut” with CI-4 PLUS

It is important to realize that none of these organizations specify exactly what goes into the oil; the focus is on how the oil performs. Oil from different companies may share the API “SM” service level designation, but each oil company uses their own blend of base oil and additives to meet those performance standards.

Many of you may not be familiar with the progression of API and the newer “GF” specifications, which were developed by ILSAC to meet the government regulations regarding fuel economy and long-term emission system performance and durability. It may make more sense if we look at the changes made to the oil over time, and relate those changes to the problems that provided the impetus to come up with newer, better oil. We will also trace the development of the procedures used to evaluate the level of protection provided by motor oil. We will also trace the use of ZDDP over the years.

Timeline - Development of Oil Standards and Use of ZDDP in Oil

1911 **SAE Develops Oil Classification System**
- Based only on viscosity

1942 **First Use of ZDDP in Motor Oil**
- Not to protect the cam and tappets
- Added to control copper/lead bearing corrosion
- A low level of phosphorus (0.03% by weight or 300 PPM) was effective.[2]

1947 **First API Oil Types Defined**
- API designated three types of engine oils: regular, premium, and heavy duty.
- Generally, the regular oils were straight mineral oils.
- The premium oils contained oxidation inhibitors
- The heavy-duty oils contained both oxidation inhibitors and detergent-dispersant additives. [32]

1952 **Engine Service Classification System (ESCS)**
- Developed by API Lubrication Committee and ASTM
- ESCS considered gasoline and diesel engine oils separately
- Service Categories ML, MM, and MS for gas engines
- Service Categories DG, DM, and DS for diesel [32]
- Oil companies rated their own product[2]

1955 **ESCS Revised by API & ASTM**

(Mid 1950s)
- Development of high performance engines in Detroit
- High lift camshafts created problems as well as lots of horsepower.
- "This came to light… when… engines that were developed on one API MS oil and then factory filled with another API MS oil wore camshafts and lifters out within weeks of delivery to customers." [1]
- Problems were overcome by
  - using hardened cast iron camshafts and lifters
  - phosphate etching the camshafts (which creates a surface that traps oil)
  - increasing the level of ZDDP in the oil to 0.08% (based on the measured amount of phosphorus). That corresponds to a level of 800 PPM.
  - They also found that "raising the zinc above 14% would cause increased wear."[1]

1958 **First Tests Developed to Measure Oil Performance**
- Direct result of the problems with MS oil
- Five specific "Sequence" tests were developed by Ford, GM and Chrysler
- One Sequence Test can test for several different things
- Testing is intended to look at these issues:
  - Engine Rust & Corrosion
  - High Temperature Oil Oxidation (oil deterioration)
  - Piston Varnish
  - Engine Varnish
  - Engine Sludge
  - Cam & Lifter Wear
  - Bearing Wear
- Two of these "Sequence Tests" focused on camshaft and lifter scuffing
- General intent: To assist oil companies in coming up with oils that actually worked.

1960 **ESCS Revised by API & ASTM**
- Sequence Tests were updated and used through the 60s
- Used by oil companies and automakers alike.

1969-1970 **New Oil Classification System Established**

- Joint effort by API, ASTM, and SAE
- Intended to address changing warranty, maintenance, and lubrication requirements
- ASTM established the test methods and performance characteristics to be tested
- ASTM technically described each of the Service Categories.
- API prepared a user language, including new letter designations for each of the eight Service Categories relevant that the time.
- Passenger car engine oils in use divided into 8 separate Service Categories
- These eight engine Service Categories were tied to the ASTM technical description and primary performance criteria.
- For API certification, the oil must pass all the tests.
- SAE then published results of the entire project and the methodology as SAE J183.

1971 **Automotive & Oil Companies Adopt Common Performance Standards**

- These were implemented along with the adoption of the API S classification scheme.
- ML became SA, straight mineral oil, no additives
- MM became SB, inhibited oil, minimum duty
- MS (1964 type) became SC
- MS (1968 type) became SD

1970s **Problems with Oxidation**

- US automakers have serious problems with oxidation of oils
- Under high temperature and high load.
- Oil would thicken to the point that the oil pump could not move it, leading to engine failure
- ZDDP is a cost effective anti-oxidant, already being used as an additive
- Simply increasing the level of ZDDP to 0.10% (1000 PPM) solved the oxidation problem

1970s **Problems with Camshaft & Tappet Foot Wear**

- GM had been using API SE grade oils (1971 on)
- More camshaft and tappet foot wear complaints
- It was determined that the performance criteria used to define SE oils was inadequate.
- No engine wear test to adequately define long term wear protection. [1]
- GM tested 127 vehicles (mix of 72, 73 & 74 model year vehicles) for a total of about 12,000,000 km.
- From one group of cars studied they concluded “For minimum wear, the results indicate… a minimum concentration of 0.12 weight percent zinc as alkyl ZDP.” [1]
- They went on to say “The differences in performance observed among the three oils have been attributed to difference in ZDDP, not to differences in the other additive metals present.” [2]
- Data from the field studies was by not conclusive
- Conclusion for entire study: “Within the range of ZDP concentrations evaluated (0.07 to 0.22 weight percent zinc) there was no clearcut effect of ZDP concentration.” [1]
- Wear protection did not always increase with increasing concentrations of ZDDP
- Good wear protection was found with low concentrations of ZDDP.
- Oil without ZDDP provided poor protection

1980 -1988 **API SF Oil (Obsolete)**

- ZDDP % by weight ranged from 0.12% to 0.15% (1200-1500 PPM).
- Testing for the SF category included the Sequence V-D test using an overhead cam (OHC) engine with “finger followers” that was very sensitive to wear protection.
- Lab results were correlated with field tests done with vehicles using the same engines.
- The high temperature III-D test checked for oxidation and piston deposits.
- Sequence III-D also tested camshaft and lifter wear, correlated to data from field tests.
- Use of leaded fuel made a tremendous difference; the camshaft and lifter wear measured in the Sequence III-D test was 2 to 3.5 times higher than it was with unleaded fuel. [2]
- Major problem with SF oils was increased sludge formation

1989 -1993 **API SG Oil (Obsolete)**

- ZDDP % by weight ranged from 0.10% to 0.12% (1000-1200 PPM).

1993 - 1996 API SH ILSAC GF-1 (Obsolete)

- Two sources of information give different data on ZDDP concentration
    - ZDDP % by weight unchanged at 0.10% to 0.12% (1000-1200 PPM).
    - Zinc = 0.130%, 1130ppm (parts per million); phosphorous = 0.120%, 1120ppm
- API SH standards are the same as API SG standards
- The rules for "passing" each requirement (test) were changed[13]
- For API categories through SG, a single "pass" on each test was required.[13]
- Number of attempts and number of failures was not considered[13]
- Chemical Manufacturers Association (CMA) has applied a Multiple Test Acceptance Criteria (MTAC) [13]
- For tests run twice, the data is averaged, and the averages must be a pass for each parameter tested. For tests run 3 or more time, one test may be discarded, the rest of the data is averaged, and the averages must be a pass for each parameter tested.
- To meet the stricter testing, formulas for the oil were adjusted by the oil companies
- As a result SH oils showed improvements over SG oils[13]
    - Less rust
    - Improved oxidation protection
    - Less varnish
    - Less sludge
    - Less wear
    - Better, fuel economy, although API SH has no energy conserving requirement
- First ILSAC specification (GF-1) implemented
- ILSAC GF-1 specifications ***only*** apply to 0W-X, 5W-X and 10W-X oils where X can be 20, 30, 40 or 50.
- API SH applies to ***all*** single and multi viscosity grade oils
- GF-1 requires an API SH oil to meet the Energy Conserving II (EC-II) requirements.
- EC-II oil provides a 2.7% fuel economy improvement over reference oil

1997 - 2001 API SJ ILSAC GF-2 (Current, for 2001 & older engines)

- phosphorus (ZDDP) level maximum 0.10% (1000 PPM)
- improved low temperature operation
- reduced high temperature deposits
- better foam control.

2001- 2004 API SL ILSAC GF-3 (Current, for 2004 & older engines)

- implemented July 2001
- phosphorus (ZDDP) level maximum 0.10% (1000 PPM)
- long-term emission system durability
- improved fuel economy
- reduced volatility
- improved deposit control
- better viscosity retention over the oils service life
- reduced additive depletion over the oils service life
- reduced oil consumption rates.

2004 - API SM ILSAC GF-4 (Current, for engines after 2004)

- phosphorus (ZDDP) reduced to 0.060 -0.085% (600-850 PPM)
- improved oxidation resistance
- better deposit control
- improved wear protection
- improved performance at low temperatures over the life of the oil
- oil with the "Starburst" certification are energy conserving (possibly better mileage)[12]

Testing and ZDDP Reduction in API SM Oil

The level of ZDDP in oil has been reduced from a high of 0.10 - 0.15% (1000 – 1500 PPM) to 0.060 - 0.085% by weight or 600-850 PPM when the API SM and ILSAC GF-4 standards were implemented. This is about the same as the 0.08% (800 PPM) level of ZDDP in oil back in the 1950s when ZDDP was first introduced to prevent premature cam/lifter failures. [2]

The level of ZDDP was reduced to protect the catalytic converter. Catalytic converters have to be covered by the automobile manufacturer's warranty, and the length of the warranty in terms of miles has been increased significantly. Phosphorus is a know "poison" of catalytic converters, and to protect them, the level of phosphorus in motor oils has been reduced in a cooperative effort between the auto makers, the oil companies, and the groups that set the standards. Not all the ZDDP in oil was there to provide anti-scuffing and anti-wear protection. Some of it functioned as an anti-oxidant. This secondary role of ZDDP was taken over by new ashless and phosphorus free antioxidants, which made it possible to eliminate some of the ZDDP. It is important to realize that while the reduction was done to protect the catalyst, the ***actual level*** of ZDDP was not set solely based on the requirements of the catalyst.[2] Extensive testing was done to determine how much ZDDP was required to provide adequate wear protection, and that is what determined the level of ZDDP in the API SM/ILSAC GF-4 oil.

Even so, the latest API "SM" oils have been singled out as being "unsuitable for vintage applications". Many of you have already read or heard that "SM oils were not made for older engines" or that the "EPA and tighter emission regulations forced "them to change the oil", and "SM oil will kill your classic". The reason cited is the reduction in zinc dialkyldithiophosphate (ZDDP, ZnDTP, or ZDP) in the API SM oil. In some of the information that is out there, the implication is that ZDDP has been outlawed, or totally removed from motor oil, which is simply not true. It is obvious that the amount of ZDDP has been reduced. What is not immediately clear is if the testing of the SM oil is applicable to older, flat tappet engines.

The Sequence III-D test for valve train wear was modified and developed over the years, and led to the III-E, III-F, and finally the III-G test. The current API SM oil classification with its reduced level of ZDDP uses the Sequence III-G test, and it is therefore is of particular interest. Sequence III-G evaluates cam and tappet wear using a GM 3.8L (231 CID) engine that has had the valve train replaced with the flat tappet valve train similar to that used by GM in the 1980s. [2] According to the ASTM engine assembly procedure, the engines are rebuilt using new parts, and the cams are installed with EF-11, an SAE 10W oil – not assembly lube. Test III-G is specifically "meant to simulate a flat tappet OHV push rod engine in a pickup truck pulling a loaded cattle trailer across the desert on a hot day." [2] Using unleaded gasoline, the engine runs a 10 minute initial oil leveling procedure followed by a 15 minute slow ramp up to speed and load conditions. It then operates at 125 bhp, 3600 rpm, and 150°C oil temperature for 100 hours, interrupted at 20-hour intervals for oil level checks. At the end of the test, all six pistons are inspected for deposits and varnish; cam lobes and lifters are measured for wear; and oil screen plugging is evaluated. The average cam plus lifter wear (maximum) is 60μm (0.06 mm). The III-F test for API SL/GF-3 oil was shorter (80 hours) with more frequent stops (every 10 hours), and the average cam plus lifter wear (maximum) was 20 μm.

Sequence IV-A tests for cam lobe scuffing and wear in an overhead cam engine. This test uses a KA24E Nissan 1994 2.4-liter, water-cooled, fuel-injected engine, 4-cylinder in-line, overhead camshaft with two intake valves, and one exhaust valve per cylinder. This engine uses "slider finger followers". Although it is not a "flat tappet cam" design, this type of valve train is particularly prone to valve train wear, and very sensitive to the amount of friction modifiers in the oil. The test consists of 100 one hour tests, and each test period consists of 50 minutes at 800 RPM and 10 minutes at 1,500 RPM. At the end of the test, each of the 12 cam lobes is measured at 7 locations for maximum depth of wear. Measurements of wear on all 7 positions of each lobe are added, then all 12 lobe measurements are averaged for the wear result. This result is the primary evaluation for the test. To pass, the average cam wear must be less than 90 μm (0.09 mm). The wear limit for API SL / ILSAC GF-3 was higher at 120 μm.

There is a lot more to the III-G test and the IV-A test than what I have described, but our focus is on the testing done on API SM oils that give some indication of the oils ability to protect older engines. Testing of the SM specification addressed multiple concerns, using a combination of new and older engines to make sure the oil not protected modern engines with roller tappets and roller rocker arms AND older engines with “flat tappet cams”. This issue of backwards compatibility was not ignored or swept aside as some articles seem to imply.

A thorough review of the test data and some 33 papers on oil, ZDDP and wear were pulled together in one SAE report. The authors “…suggest that 0.08% phosphorus, in the form of ZDP is more than adequate to protect both current and older engines from scuffing and wear.”[2] They went on to say “The data available also suggest that even lower levels of phosphorus, certainly as low as 0.05%, and perhaps as low as 0.03%, may be sufficient to provide scuffing and wear protection for engines in the field with phosphated camshafts.”[2]

So far, we have looked at the problems reported, oil and oil additives, the standards for oil and the organizations that set those standards, and we have traced the use of ZDDP as an additive and we have looked at the testing done before the level of ZDDP was dropped to its current level. Clearly, the testing done was intended to make sure older engines were protected. We have also looked at the SAE report that concluded that API SM oils have enough ZDDP to protect older engines, and that adequate protection would be available at even lower levels of ZDDP.

The question is, how does the real world experience of engine rebuilders, enthusiasts, collectors, and restorers stack up against all the data and well reasoned analysis that has led us to the current level of ZDDP, and lower levels of ZDDP in the future ?

Real World Experience

There have been increasing numbers of cam/tappet failures, especially in the last four or five years. The Engine Rebuilders Association (AERA) has been keeping records for the last ten years. In that period, there have been more reported cam/tappet failures, with the largest jump in numbers of failures after 2004. Of the failures reported, 25% were traced to poor break-in procedures. The other 75% were traced to use of "modern oil for the break-in." [10]

As a result, the AERA issued Technical Bulletin TB 2333R. Issued November 2007, it "…warns about the reduction of Zinc in gasoline engine oils which has been traced to many camshaft and flat tappet lifter failures. This information should be considered for any engine that uses a flat tappet design and should be referenced before initial engine start-up." [10] The Bulletin goes on to say "Adding additional Zinc for camshaft and lifter break-in by using GM Engine Oil Supplement (EOS) or using any supplant supplied from any of the aftermarket cam manufacturers. All camshaft manufacturers are aware of the reduction of Zinc and changes in engine oils formulations. For many years they have offered camshaft assembly lube and break-in lube for their products, so USE IT. Liberal amounts of this lube during assembly on all moving or rotating points will offer a front line defense as soon as the engine is rotated. GM recommends pouring a pint bottle of their EOS over the crankshaft before installing the oil pan." GM's Engine Oil Supplement (EOS) did contain significant amounts of ZDDP, and it was the most concentrated ZDDP supplement available. It was intended to boost ZDDP levels of oils that already contained EP additives. It was available for over 20 years, but unfortunately it was discontinued by GM in early 2007.

Crane Cams has published a number of documents that deal with camshaft break-in, failure, and lubrication. On their website, there is an article titled "Preventing Cam and Lifter Wear". It makes several points. "REMEMBER . . . the first 10 minutes are the most important in a new camshaft's life. Tests have shown that if there is no spalling or metal pick up during the first 10 minutes to one hour of operation, the cam will last a normal life."[30] They are very specific about assembly lube and the break-in oil. "There must be a moly coating between the cam lobe and lifter, in order to prevent metal-to-metal contact. Before installing your new cam, coat all lobes and the bottoms of each lifter with a moly disulphide based assembly lubricant…".[30] For oil, they recommend "… a high quality 30 or 40 weight oil, preferably a Pennsylvania base oil, or a high quality Pennsylvania based multi-viscosity oil, such as 10W-30 or 20W-50. Also, for extra protection, an antiwear additive (zinc dithiophosphate) must be added…".[30]

In another article on their website, "Reasons and Causes for Cam Failure", they begin by saying "Cam failure is rarely caused by the cam itself. The only things we can control during manufacture pertaining to cam lobe wear are lobe taper, lobe hardness and surface finish. Of all the damaged cams we have checked over the years, more than 99.99 percent have been manufactured correctly. Some people have the misconception that it is common for a cast iron flat tappet cam to occasionally have a soft lobe. We have yet to see a cast iron flat tappet cam that had a soft lobe. When the cast core is made at the casting foundry, all the lobes are flame hardened. That process hardens all the lobes to a depth below the barrel of the core. That depth of hardness allows the finish cam grinder to finish grind the cam lobes with a Rockwell hardness above 50Rc. The generally accepted hardness on a finished cast cam should be between 48Rc to 58Rc. All of the finished cams that we have checked are always above 50Rc hardness on the lobes. Many outside factors, or a combination of factors, can cause cam failures. We will list some of the factors we have determined that may cause camshaft failure." [28] Number one on the list is incorrect break-in lubricant, and they say "Moly Paste must be applied to every cam lobe surface, and to the bottom of every lifter face of all flat tappet cams.", and "…apply the Moly Paste to the distributor gears on the cam and distributor for all camshafts. For extra protection, an anti-wear additive should be added…" they make specific reference to the products offered by Crane in the document.

Crane also published their "Flat Tappet Camshaft Break-in Procedure", Installation Instructions 548E. It says, in part, "Due to the EPA's mandate for zinc removal from most motor oils, proper flat tappet camshaft break-in procedure is more critical than ever before. This is true for both hydraulic and mechanical flat tappet camshafts. As a point of interest, the most critical time in the life of a flat tappet camshaft is the first 20 minutes of "break-in" during which the bottoms of the tappets "mate-in" with the cam lobes. There are some oils with additive packages that are better for camshaft "break-in"… Do not use API rated “SL” or “SM” oil. CAUTION: We do not recommend the use of synthetic oils for “break-in”.” Crane lists two oils they like and suggest using their break-in additive. The implication of the “EPA’s mandate for zinc removal” is that the zinc is gone, and that is not strictly correct.

Piper Cams has a similar article, “The Rules of Successful Camshaft Installation”. The first two paragraphs read: “Research and experience has shown that most cams that wear out start to fail during the first few moments of operation. Many cams are irreparably damaged, even before the engine is started, because the basic rules of camshaft installation and 'break in' have not been followed. The cause of premature cam and follower failure is metal to metal contact between the follower and cam lobe. Should this contact occur due to lack of lubrication and excessive high pressure due to valve train interface shearing the oil film, then 'galling' will take place. When this happens, metal is transferred from the follower to the cam lobe or vice versa in a process comparable to welding. Microscopic high spots, which are present on all machined parts, become overheated due to friction and pressure and bond together, tearing sections loose from follower or lobe. These pieces of metal remain attached and create further local overheating during the following revolutions of the camshaft and lead to ultimate failure of the affected components.” They go on to say that the cam must be washed carefully without disturbing the phosphate coating, then liberally coated with Piper’s Cam Lube. They do not address the issue of oil, zinc, or ZDDP.

Competition Cams published a Tech Bulletin in 2005 entitled “Flat Tappet Camshafts”. “Recent changes in oil and engine technology are likely the cause of premature camshaft failure… Premature flat tappet camshaft failure has been an issue of late and not just with one brand or type of camshaft. In almost every case, the hardness or the taper of the cam lobe is suspected, yet most of the time that is not the problem. This growing trend is due to factors that are unrelated to camshaft manufacture or quality. Changes in today's oil products and “advanced” internal engine design have contributed to a harsher environment for the camshaft and a potential for failure during break-in.” [16] The article goes on to say a “major factor in the increase of flat tappet camshaft failure is your favorite brand of engine oil. Simply put, today’s engine oil is just not the same as it used to be, thanks to ever tightening environmental regulations. The EPA has done a great job in reducing emissions and the effects of some of the ingredients found in traditional oils; however these changes to the oil have only made life tougher on your camshaft. The lubricity of the oil and specifically the reduction of important additives such as zinc and phosphorus, which help break-in and overall camshaft life, have been drastically reduced. In terms of oil selection, we recommend a high “ZDDP”, Zinc Dialkyl Dithiosphosphate, content oil for the break-in procedure and regular operation.” [31] Comp Cams recommends the use of their assembly lube, and their break-in additive. It is interesting to note that they are encouraging the use of the break-in additive after the initial break-in: “While this additive was originally developed specifically for break-in protection, subsequent testing has proven the durability benefits of its long term use. This special blend of additives promotes proper break-in and protects against premature cam and lifter failure by replacing some of the beneficial ingredients that the oil companies have been required to remove from off-the-shelf oil.” [16] They do not say what is in the additive on the website, but I called them and they confirmed that the main ingredient is ZDDP at 1400 PPM.

If you review the literature being supplied with new cams and tappets, it is very clear that the manufacturers have identified the assembly lube and the oil used for start-up and break-in as critical. It is important to realize this is not just about the assembly lube and oil- they are also providing more detailed, specific instructions on how an engine should be assembled and broken in, and the list of things to do or check are getting longer.

Companies that make oil specifically for vintage applications are quick to point out that there is a lot more to oil than ZDDP, but they all are using more ZDDP than is found in the SM oils. I checked with half a dozen oil companies, and some of them either offer, or plan to offer, oils that are not API certified with ZDDP in concentrations that exceed the 0.08% maximum limit allowed for API certification.

What Does It All Mean?

There seems to be a fundamental disconnect here. On the one hand, we have engineers with decades of experience saying modern API SM oil with 0.06 - 0.08% (600-800 PPM) ZDDP should be fine for older flat tappet engines. On the other hand are the large number of companies (with their own engineers) and individuals (many of them respected professional mechanics with decades of real-world experience) who are convinced that 0.06 - 0.08% ZDDP is not enough.

We do not have the benefit of a test study done, for example, with 25 MGBs with identical rebuilt engines that were run on oil that was identical except for the amount of ZDDP. It is difficult to weigh the technical data available on the subject and relate it to the cars we own and drive. That said, I think we can draw a logical conclusion for our vintage British engines.

A modern API SM oil with 0.06 - 08% (600-800 PPM) ZDDP may be fine for engines that are broken in, but there is enough evidence to suggest that ZDDP at 0.14% to 0.015% by weight (1400-1500 PPM) can provide the addition protection needed to maximize the chances of a successful cam/tappet break-in.

After that initial 20-30 minute break-in period, change the oil and the filter. The oil you run after that will not need as much ZDDP. We suggest that 0.10 - 0.12% (1000 to 1200 PPM) ZDDP would be appropriate. It is high enough to provide additional protection without risking chemical corrosion.

After the first 500 miles, change the oil and the oil filter again, using the same oil (1200 PPM ZDDP) you used for the first 500 miles.

What you use after the first 1,000 miles will depend in part on how much you drive. If you can't drive your car on a regular basis, consider using oil formulated specifically for classic cars. They have a mixture of additives designed to deal with the moisture, corrosion, and acids in engines that sit for extended periods of time. Change you oil every 3,000 mile or every 6 months, which ever comes first. If you live where the humidity is high, or where there is a significant change in temperature from day to night, you will have more moisture collecting in the sump. To get rid of it, change the oil more frequently, up to four times a year.

If you drive your car more frequently, you have more options. Using a 20W-50 API SM oil with 0.08% (800 PPM) ZDDP ***may*** be just fine. By driving the car frequently I mean once a week for 30 minutes or more with the oil between 170°F to 200°F. This will minimize the amount of water and water vapor in the crankcase, and that will limit the corrosion and subsequent pitting of the cam lobes and lifters. If you are more conservative, a ZDDP level of 1000 to 1200 PPM will provide additional protection.

Our conclusions are not a substitute for real world experience. If you have never had a problem with a rebuilt engine or the oil you have been running, I wouldn't change a thing. If you use an API oil, be aware that the oil will change in the future as additive packages are fine tuned for modern engines. The SAE papers I have read indicate that the ILSAC-GF5 standards which will go into effect in 2009-10 will probably call for 0.05% (500 PPM) phosphorus[2], meaning the amount of ZDDP will be reduced some more. The change may not be obvious from the packaging. Read the labels, check the oil company website. If it is not clear, call them on the phone.

If you have had a problem with cams and/or lifters in a rebuilt engine, or if you are having an engine rebuilt, or are thinking about it, you should carefully weigh the information you have. Pay particular attention to the instructions on the cam and/or tappet manufacturer's website, and whatever instructions you received with your cam and/or tappets. Talk to the professionals. If you are having your engine rebuilt, the experience of someone that rebuilds six or more MG, Triumph or Healey engines is invaluable. They have a combination of parts, procedures, assembly lube and break-in oil that works for them. Take their advice. Recognize that changing their recipe may cause problems that they have not seen or experienced.

Finally, a cautionary note. As I pointed out earlier, it is known that ZDDP in high concentrations is actually harmful. In several reports ZDDP over 0.14% (1400 PPM) is described as providing increased protection against start-up scuffing, and causing increased wear in the long run. And at 0.20% (2,000 PPM), ZDDP will attack the grain boundaries in the cast iron tappets.[2] This is the chemical corrosion mentioned earlier. This corrosion leads to the loss of small pieces or chunks of metal or spalling, a process also described earlier. The craters or pits in the tappet foot are evidence of spalling, and they are distinctly different than abrasive wear patterns, although wear tends to obscure the corrosion damage. There is another problem with high levels of ZDDP. “Once ZDDP levels exceed 1500 to 2000 parts per million, the potential for burned ash accumulations in the ring lands and on the piston domes increases dramatically.”[11]

Because ZDDP is affected by the level and type of detergents in a particular oil, it is not possible to predict the performance of a specific oil mixed with a ZDDP additive because there is no data on this subject.

And finally - and I cannot stress this enough - using oil with ZDDP level above the 800 PPM level does not guarantee success. There are simply too many other factors involved. However, the right oil, when combined with careful selection of components, care and attention to detail during assembly, a good assembly lube, and a good prep, start-up, and break-in procedure, may tip the balance in your favor.

I hope that this long, dry article on oil has help make some sense out of the situation. The information presented here is offered, one enthusiast to another, in the hope that it will make it easier for you to decide what you need to do about the motor oil you buy for your British sports car.

Appendix: Collected Tips for Rebuilding a Vintage British Engine

Everything presented below has been compiled from information compiled from public sources. We are not providing instructions, and nothing we present here is a replacement for the specifications and procedures provided in the various factory workshop manuals. This information is general in nature, although specific examples are used to illustrate various points. It is hoped that by sharing this information we may stimulate thought and discussion on the issues raised, and perhaps reduce the number of camshaft and tappet related problems encountered in freshly rebuilt engines.

Product Selection

The cam and tappets you use must be considered together.
Tappets with a flat bottom or foot are generally an older OE design, and are only suitable for use with OE type cams with no taper to the lobes. You cannot use a flat-footed tappet with a cam that has tapered lobes. With flat-footed tappets, the tappet bore must be offset with respect to cam lobe or the tappets will not rotate.

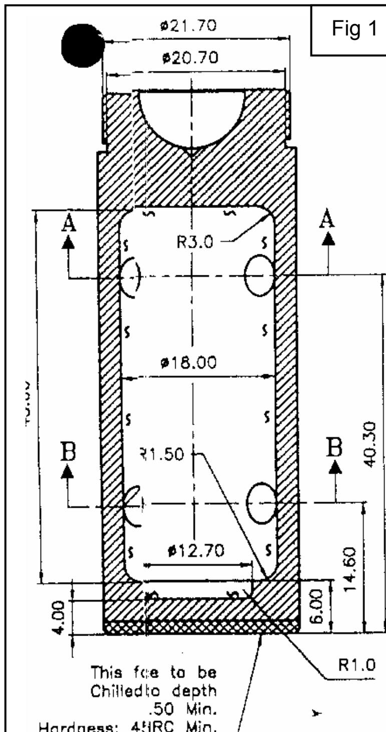
Tappets with a domed or curved foot are suitable for use with cams with tapered lobes. This design promotes rotation of the tappet. The curve of the tappets must be carefully matched to the taper of the cam. If they are not matched, the tappets may not rotate, or they may rotate too fast. Either case is going to cause problems.
The tappet bore may or may not be offset with respect to lobe of cam.

If you are not sure if your cam & tappets were made for each other, have them checked by one of the cam specialists like Elgin Cams or Comp Cams. If necessary, the tappets can be modified to match the cam.

If the cam and tappets are not phosphate coated or etched, consider having it done. The phosphate will trap oil, and it has been shown over and over again that phosphate will improve the odds of a successful break-in, even though the phosphate coating on the cam lobe will cause some wear on the foot of the tappet.

Some original tappets, like those used in the MG T-Series, have holes in the sides. (Fig 1) The hollow body of the lifter fills with oil from the rocker gallery. As the tappet drops down in the lifter bore, the lower holes are uncovered, and oil drains out of the tappet body, flowing over the camshaft. Some modern replacement tappets feature holes designed to improve oiling (picture), and the holes can be in the side or the foot of the tappet.

Fig 1



Section of an original Morris Garage blueprint for the T-Series Tappet.

Some cams, like the Crane cam for the T-Series, use a larger base circle than a stock cam. (Diagram needed) By increasing the base circle, the cam manufacturer can reduce the ramp angle and it allows the "point of the lobe" to be more rounded. Both of these are good. However, when used with tappets that have the holes in the side, the tappet may not drop down far enough to expose the oil holes. The oil will not drain out, and that reduces the oil flowing over the cam, decreasing lubrication and increasing heat build-up in the tappet and the cam. Moss modified T-Series tappets (picture) address this by elongating the lower oil holes.

The Engine Block - Tappet Bore

Tappet bores are critical, and often overlooked because the last cam/tappet combination performed "OK". That does not mean the tappet bores are fine- it means the tappets and cam wore in together, despite problems.

The actual position of the tappet bores in the block is critical. Perhaps because the casting and machining of older blocks was not terribly sophisticated, some vintage MG and TR blocks have been discovered to have the lifter bore centered, or nearly centered over the cam lobe. This placement is more critical with “narrow” cam lobes. You can check tappet bore-cam lobe relationship with a dummy lifter made out of aluminum. Machined like a tall tappet with a tapered point in the exact middle of the cylinder, this will show you where the middle of the tappet bore is in relation to the cam lobe. To use it, coat the lobes of cam with machinists blue, and install it. Rotate the cam one revolution with “dummy tappet” in each tappet bore in succession. Compare position of the line traced in the machinists blue on each lobe. If all the lines are offset toward one side of the lobe, and one is in the middle of the cam lobe, you found your problem. We do not have information on just where the middle of the tappet bore should sit; they should all be about the same. The point is, if you have one odd one, it is a potential problem. If you are not sure if you have a problem or not, take the block to a machinist with experience rebuilding engines like yours. Relocating a lifter bore is very difficult to correct. In theory, a machine shop could bore out the hole and fit a machined bushing with an offset hole, similar to sleeving a block. In practice this is very difficult and it can be expensive. It may be less trouble to get another block, although that I not necessarily easy or inexpensive either.

Tappet Bore Alignment, Size & Clearance

The bores must be checked for orientation; they must sit at 90 degrees to the long axis of the camshaft. Size and clearance: for example, Crane says the clearance should be 0.0005 (1/2 a thousandth of an inch) to 0.0035" (three and ½ thousandths of an inch). Below that minimum, there is not enough clearance for the tappet to move when the engine gets hot. Over the maximum, it's too loose.

If the tappet is too tight, they may not rotate properly when the engine gets hot, even though they are moving up and down. This can greatly increase the pressure on the foot of the tappet and it will quickly fail. If the tappet is too loose in the bore, or the bore is ovalized, the tappet can rock in the bore, and both the tappet and the cam lobe will fail.

Lifter Bore Oil grooves

Some cam/tappet manufacturers, like Competition Cams, are recommending that engine builders cut longitudinal grooves in the lifter bores to increase the flow of oil to the cam in GM and Ford engines. Comp Cam even sells the specialized tools to do the job. The grooves Increase oil flow to cam, which provides better lubrication and helps keep the cam/tappet interface cool by transferring heat away. WE are not in apposition to recommend this procedure, but suggest that you discuss this with your engine builder or machine shop.

Oil Pathways

The cam manufacturers are all in agreement that there should be no restrictions to oil flow in the block. You must have adequate oil flow to the rocker gallery, and adequate flow to the tappets. Anything that restricts that flow can create problems. For this reason, do not use oil restrictors, windage trays, baffles, and do not restrict or plug any oil return holes.

Valve Springs

Never install springs without checking the installed spring height and the spring pressure. Too much pressure can overload the cam and lifter, which will make it impossible to break them in together.

For a mild street cam, spring seat pressures should be 85 – 105 lbs. Radical or high performance cams may call for 105-130 lbs. There are two problems with high spring pressures. First, the load on the tappet foot is increased. Second, higher spring pressures will impede the proper rotation of the tappet during break-in. If the tappets do not rotate properly during the first ten minutes of the break-in, the damage is irreversible. If you plan on running higher spring pressures, don’t do it during break-in. Use a shorter ratio rocker are to reduce valve lift. If you are using dual valve springs, consider removing the inner spring during break-in.

The valve springs must be checked to ensure that coil binding does not exist at maximum lift. One company says there must be a minimum clearance of 1mm between the valve spring coils. Another says there must be an additional 0.060” (1.5 mm) travel left in the spring when fully compressed by the action of the cam. Make sure the springs are fitted at the correct installed height. It is important to ensure that the valve spring fits the retaining cap correctly and in some instances the cylinder head may need machining. Once the valve springs have been installed check both inner and outer springs for coil binding and ensure that the bottom face of the spring retaining cap does not contact the top of the valve guide or valve stem oil seal. Minimum clearance on full lift is .060. (1.5mm). If this clearance cannot be achieved the top of the guide may need to be modified.

Valve to Piston Clearance

After resurfacing the block, head, fitting new pistons and / or valves, it is important to check the clearance between the valve head and the top of the piston. It has been suggested that 0.08" intake and 0.100" exhaust are the minimum clearance needed.

Camshaft End Play

If the camshaft end play is specified, check it after the cam is installed and the bolts have been torqued. If it is excessive, the cam will move back and forth. In extreme cases, a cam lobe may come in contact with the adjacent tappet with disastrous results.

Other Engine Components

It is probably impossible to come up with a comprehensive listing of things to check or to consider. There are simply too many variables. Here is an example just to make the point.
Connecting rod design may make a difference to the camshaft. Most con rods have a hole at the big end facing the cam. Oil under pressure squirts out the hole and it splashes on the cam and tappets. On MGT Series con rods the hole is on the opposite side, directing oil toward the thrust side of the cylinder. We have been told that at least one T-Series engine builder is modifying the con rods to direct oil to the cam.
Be aware that there may be a combination of factors for your engine that may combine to make the situation worse (or better). Seek out professionals with experience rebuilding you particular engine
You need the benefit of their long experience.

Assembly Procedures

Replace the cam and tappets together. Never, ever use a new cam with used tappets. According to Crane, this is the number one cause of camshaft failure. A used tappet, once broken in, cannot be paired with another cam lobe no mater how perfect it looks. Even swapping two tappets in the same engine will not work. Cam lobe at tappets have to wear in together, and that can only happen with a proper break in. Generally, it is the cam lobes that take a beating.
While it is possible to use new tappets with a used cam that has been inspected by a machinist and given a clean bill of health, it is not recommended.

Assembly Lube

There are almost as many assembly lubes out there as there are oils. Increasingly, cam manufacturers are offering assembly lube either with new cams, or as a suggested product on their website. Any assembly lube offered by a cam manufacturer will be good, and you should consider using one. There are two general types. One is oil based, the other is more like a paste or grease. The oil based lubes use a base oil with a blend of anti-scuffing and anti wear additives, just like a motor oil. The concentration of additives is quite high. The thicker assembly lubes are like grease or a paste, and many seem to be based on molybdenum disulphide (MoS_2). or "moly" for short.

Moss offers Kent Cams "Cam Lube" (221-570). It is specifically a cam/lifter lube, and it is used to coat the cam/lifters liberally before assembly. It is like a thin grease and will stay where you put it. Kent does not provide technical information as to the composition. Kent provides it to minimize the chance of a failed cam.

Moss also offers Permatex "Ultra-Slick" assembly lube (221-565) is a tacky red oil-based lubricant gel that sticks to metal surfaces, forming a film that provides protection from scuffing and galling during start up. It is made from a base oil to which specific extreme pressure (EP) additives have been added. The technical information they have published does not specify the type and amount of any of the additives. It is used to coat all the moving parts in an engine - engine bearings, camshafts, lifters, valves, guides and rocker shaft assemblies - as it is assembled. It also has special rust inhibitors to protect all the metal surfaces during the rebuild and before the engine is fired. It exceeds all OEM specifications as an engine and bearing assembly lubricant.

When it comes time to pick an assembly lube, listen to your engine builder or your machinist. They probably have a favorite that they like based on experience. If you are rebuilding the engine yourself, and the cam you bought came with assembly lube or if the cam manufacturer makes a specific recommendation, we suggest that you follow their recommendations.

Break-in Procedures

The break-in procedure is essential to long life of the cam and tappets. Improper break-in can lead to catastrophic failure in 500-1000 miles. Cam and tappets wear in together during “break-in” very quickly. First 10-20 minutes of the break-in are critical. Once broken in, consider the individual cam lobes and tappets to be bonded pairs. You cannot swap tappets, even in the same engine.

Everything must be as close to perfect as possible, because it is essential that the engine fire quickly and run steadily at 1500 to 3000 RPM. Prolonged cranking on the starter and/or multiple restarts will lead to scuffing, and once that happens you are going to need another cam and a set of tappets. Do not think you will be able to “get it started and sort it out.” This is no time for assumptions and shortcuts. Think about the time, money and effort that has gone into the engine. Don’t blow it rushing the last step.

Ignition System

Have the distributor checked on a distributor machine to make sure it actually is working properly. Do not assume that the distributor is OK “because the car ran fine” 8 months ago. If the weights are sticking, the springs are broken, the shaft bushing is worn, or the diaphragm in the vacuum advance is damaged, the distributor must be rebuilt. With a known good distributor with the proper advance curve installed, set the point gap (or dwell angle), and install fresh plugs, properly gapped, with new or known good plug wires, Check the spark energy on all plugs. Make sure you have the proper firing order. Set the timing to the factory specification.

Cooling System

Fill the system with pure water and pressure test the system. Locate any leaks and correct them. Drain the system and re-fill with 50% antifreeze mixture. Pressure test again, just to be sure.

Fuel System

The fuel tank and all lines up to and including float bowls should have fresh, clean gasoline from a known good source. If the gasoline in your area has ethanol in it, be aware that it has a shelf like of 45-90 days. Go get some fresh gas if you have any question about the age of the gas in the car.

Oil System, Oil Pressure

Select the break-in oil of your choice. Look for ZDDP at 0.14%- 0.15% by weight (1400 – 1500 PPM) If you prefer, mix an API SM oil (0.08% or 800 PPM ZDDP) with a ZDDP additive to get a ZDDP level of 0.14-0.15%. Fit a new, top quality oil filter. Three technical papers (SAE 881827, SAE 881825 and SAE 95255) “…proved that removing additional particles in the 3 to 10 micron range will have the greatest effect in reducing engine wear. Particles in this range have traditionally been ignored, but this size range is very significant as a long-term wear factor.” Noria is a company specializing in lubrication technology, education and consulting> They have published numerous books and magazines dealing with oil and lubrication technology, and they had this to say about particle size and wear: “The films of oil that protect moving engine parts from wear are customarily 2-5 microns in thickness. This remains the same thickness, even when you use an additive for additional lubricity. Ergo, for example, as the pistons move up and down against the cylinder walls, particles that are as much as 3-10 times thicker than the protective oil film are squeezed between the piston and cylinder wall. These particles are aggressive abrasives, and thereby cause substantially accelerated engine wear.”[14] (2 to 5 microns = 0.002-0.005 mm)

To fill the galleries with oil and bring the system up to pressure, use a pressurized external oil tank. There is no better way to fill the oil system with the break-in oil. If you decide to use the starter motor to build oil pressure, you must remove the spark plugs, and stop the flow of fuel to and through the carburettors. Most importantly, TAKE THE TAPPETS OUT.
The engine at cranking RPM will not spin the cam fast enough to rotate the tappets. The tappet foot can easily be scored, and a scored foot will lead to tappet failure in 500-1000 miles. Because it does not happen immediately, there will be no obvious link to the real cause. Once you have oil pressure and oil flow through the rocker arms, replace the tappets and the spark plugs.

Start the Engine
If the engine does not start immediately STOP CRANKING! At cranking RPM, the tappets are not rotating The foot of the tappet will be scored by the cam lobe. It will fail in short order.
Figure out why the engine will not fire and correct it.

When the engine starts .
DO NOT LET IT IDLE
At idle, properly broken in tappets are rotating, but very slowly. New tappets may not rotate at all at that low RPM. Bring RPM up to 1500 and keep it between 1500 and 3000 RPM for 20 to 30 minutes.
Immediately after the engine fires and comes up to 1500 RPM, verify that the pushrods are rotating. This indicates that the tappets are rotating, which is absolutely critical. You can see the pushrods rotating with valve cover removed. Some shops have special valve covers with a section of the top removed, which allows the pushrods to be seen while controlling some of the oil slash.
If a push rod is not rotating, try rotating it by hand to get it started. (Use a glove).
If you cannot get it to rotate, SHUT THE ENGINE DOWN.
You must find out why the tappet is not rotating, and correct the problem.
There is no “fixing it later”. If the tappet does not rotate it will quickly fail, taking the cam with it.
If all the pushrods are rotating, after 20-30 Minutes running between 1500-3000 RPM, shut it down.
Perform the normal checks you would do at this point.

After the Initial Break-in Period
Change the Oil
Drain the oil and replace the oil filter with a new, top quality oil filter.
Which oil should you use after the initial 20-30 minute break-in period?
You have two options. You can use an oil formulated for vintage engines. They have the appropriate levels of ZDDP (0.12% or 1200 PPM seems to be an average). They also have additional detergents and anti corrosion agents to help protect the engines that tend to sit for long periods of time.
If you prefer, you can use an API SM oil with 0.08% ZDDP, and add ZDDP to it. Mix it carefully to obtain the desired 0.12% ZDDP by weight (1200 PPM). Remember that levels of ZDDP over 0.14% (1400 PPM) will cause chemical corrosion of the tappet and lead to increased wear over time.

Drive Your Car
If you can drive your car for 30 minutes with the oil between 170°F to 200°F once a week, and you change the oil and the filter every 6 months or 3,000 miles, you will minimize the corrosion pitting of the cam lobes and tappets due to moisture and acids in the oil. It is unclear what the minimum driving requirements are. Once a month may be enough, but we have not run across any data on this issue. If it is not practical for you to drive your car that often consider using oil formulated specifically for classic cars.

Checking for Wear
The oil in aircraft engines is checked periodically by looking for steel and iron particles trapped by the oil filter material, oil pump pickup screen, and the magnetic drain plug. Unless you are using an original canister type oil filter on your engine, checking the filter for wear particles is going to be difficult. If a magnetic drain plug is available for your application, use one. When I drain the oil, I run a powerful magnet through it to pull all the iron and steel particles out. You can get a sense of how the engine is doing partly by the amount of material you find, and partly by the relative amount found from one oil change to the next.

Used Oil Analysis (UOI)

You can send samples of your used oil to a company that will check it for you, and you will receive a report detailing what they find. This is very useful if you are managing a fleet of taxicabs or commercial trucks. Because a company running a fleet of vehicles has lots of data and a series of reports for the same vehicle, something out of the ordinary will tend to stand out. It gives the technicians a chance to spot a problem before a catastrophic failure occurs. If you have had problems with previous rebuilds, you might consider this option, but you will need to be diligent about sending in regular samples. Unfortunately, UOI cannot effectively monitor the level of ZDDP in your oil for reasons already discussed.

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