

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

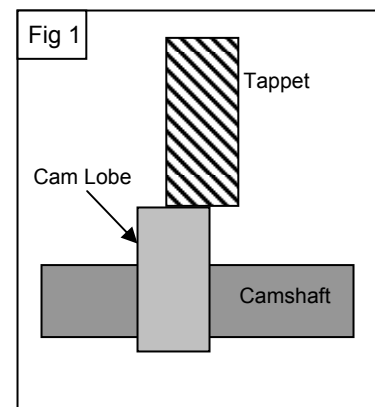
There is also an appendix which a collection of cam/tappet related tech tips on rebuilding and breaking in vintage British flat tappet cam engines.

48 **What Exactly is the Problem?**

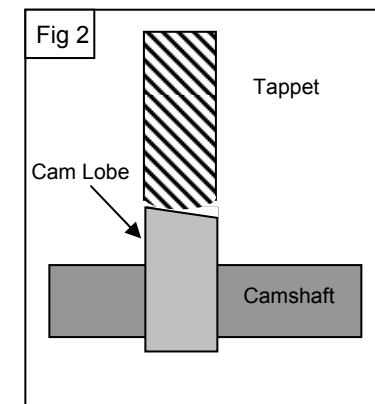
49 Before we dive in, we need to understand a little about the parts involved, just so we are all on the same
50 page. The problems associated with cams and tappets are due in part to the nature of the contact
51 between them, which is unique. Engine bearings are separated from the rotating shaft or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

58
59 The tappets must rotate or they will wear out quickly because the rotation of the tappet pulls a
60 “converging wedge” of oil into the area where the cam lobe and the foot of the tappet come together. The
61 oil film is the only thing preventing metal-to-metal contact. The continuous flow of oil also carries away
62 heat, which is critical to long cam and tappet life. The oil circulating through
63 the engine “may be 50°F (10°C) hotter than the crankcase oil.”¹³

64 Cams and tappets in older engines are lumped together as “flat tappet
65 cams” and you will see that term in any discussion of oil and classic cars.
66 This is referring to the design of the tappet, where the foot or bottom of the
67 tappet sits directly on the lobe of the cam, as opposed to “roller tappets”
68 which have – you guessed it – a roller bearing that rides on the lobe of the
69 cam. The term “flat” is perhaps misleading. It is true that the original
70 tappets used in early British engines (like the MGT series XPAG) were
71 “dead flat”, and the lobes of the cam were also “dead flat”, meaning the
72 lobe was the same height all the way across from front to back. (Fig 1) The
73 tappet rotates because it is offset with respect to the lobe of the cam. For
74 these engines the term “flat tappet cam” makes perfect sense. However,
75 not all cams and tappets are “flat”.



76
77 It was discovered that tappet rotation could be enhanced if the cam lobe
78 were tapered and the foot of the tappet was “domed” or “curved” like a
79 lens. (Fig 2) These tappets may or may not be offset. The taper of the cam
80 lobe is measured in ten thousandths of an inch, and the shape of the foot
81 of the tappet is often measured in diopters, like the lens in a pair of
82 glasses. The “dome” and the “taper” are very subtle, not generally
83 detectable with the naked eye. Fig 2 greatly exaggerates the curve and
84 taper. They dome and taper are also matched, one to the other; it is
85 important to use tappets that have a curved surface that is matched to the
86 taper of the lobes on a specific camshaft. For the T-Series, we sell a Crane
87 cam with a 0.0011” taper on the lobes. To match the cam, we offer
88 specially modified tappets which are crowned to match. Crane considers a
89 0.002” hemispherical crown on a tappet to be normal, but for the T-Series
90 cam, the tappets are crowned 0.0005” to 0.0008”



91
92 Even though cams with tapered lobes and tappets with a domed foot are not really “flat”, they are lumped
93 together with the cams and tappets that actually are flat under the general heading of “flat tappet cams
94 and tappets”.

95
96 Whatever the design, new tappets and cams have to wear-in” together during the initial break-in, usually
97 considered to be the first 20-30 minutes that the engine is run after a rebuild, and this is a very critical
98 period. The break-in is the key, because it does not take much to wear to trigger the failure of a lobe.
99 Once the surface of the cam lobe is worn just 500µm (0.5 mm, .0197 inches), the lobe will fail rapidly.¹

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

108 **Scuffing**

109 Scuffing is defined as “damage caused by solid-phase welding between sliding surfaces”²⁵, in this case
110 the transfer of metal between the camshaft and the tappets. “Microscopically, the scuffed surface
111 appears irregular, torn, with plastic deformation, and shows evidence of melting.”²⁵ Break-in scuffing, as
112 the name implies, occurs during break-in, and it is the result of direct metal-to-metal contact between the
113 cam lobe and the foot of the tappet. Scuffing, also called “galling”, can cause “spalling”, the second type
114 of damage.
115

116 **Spalling**

117 Spalling describes the damage where small chunks of metal are lost from the lobe of the cam or the foot
118 of the tappet. The foot of a chilled cast iron tappet has particles of iron carbide (very hard, very dense)
119 imbedded in a softer iron matrix. This type of surface is very resistant to wear in areas of high contact
120 stress, like the point of contact between the cam lobe and the foot of the tappet. If metal is transferred
121 from the cam lobe to the tappet (scuffing)², the transferred material can cause a very high load to be
122 applied to a very small area on the face of the tappet. The softer iron matrix may develop small cracks
123 around the harder iron carbides. Under high loads with areas of concentrated stress, small pieces of the
124 lifter foot will fall away, leaving a tiny pit or crater. Anything that causes highly localized loading of the
125 contact surface can cause spalling. If the lifter fails to rotate, or if debris in the oil winds up between the
126 foot of the tappet and the cam lobe you can have spalling. Minor scuffing and spalling will frequently heal
127 over during break-in, and it will not be discovered until the engine is torn down for a rebuild sometime in
128 the future. Spalling of the tappet foot will not necessarily affect the lobe of the cam. Teledyne Continental
129 considers spalling of less than 10% of the foot of a tappet to be acceptable. If the damage to the lifter foot
130 is extensive, the cam lobe can be damaged.²⁶
131

132 **Corrosion**

133 The third type of damage can be termed corrosion, and generally does not by itself cause problems that
134 lead to the tear-down of a freshly rebuilt engine. For many British cars, it is a serious issue because so
135 many of these vehicles are not driven frequently. It is enough of a concern to affect the choice of a motor
136 oil. Surprisingly, corrosion due to rust caused by water vapor in the engine can be found on an engine
137 that was rebuilt with well-oiled components, then bagged waiting for the restoration of the chassis. The oil
138 present in the engine will absorb moisture from the atmosphere. Normal operation of the engine will drive
139 off the moisture, but if it just sits, there will be corrosion.²⁶ Normal motor oil is designed to lubricate, not to
140 coat and protect metal surfaces from corrosion.³³ When the engine is fired, any surface rust on the cam
141 lobes or tappets will disappear, but any pitting will remain. The pitting and surface erosion found when the
142 engine is torn down next time may be confusing unless you know what you are looking at.
143

144 Because it takes time for the corrosion to form the pits, you can minimize this problem by driving your car
145 more frequently. You will need to drive it long enough for the oil to come up to temperature (170°F to
146 200°F), and you need to drive it long enough to reduce the moisture and acids in the oil. According to the
147 aircraft engine manufacturer Teledyne Continental, a minimum of 30 minutes is needed once the oil is up
148 to operating temperature.²⁶ If it is not possible to drive the car frequently, it is important to change the oil
149 more frequently than you normally would. I have not found specific recommendations for automotive
150 applications, but Teledyne Continental recommends that the oil and filter be changed four times a year,
151 not because the oil has broken down, but to eliminate “wear particles, combustion by-products, moisture
152 and acid buildup in the oil.”²⁶ You can also use oil designed for classic cars. They do a much better job of
153 protecting the metal surfaces inside the engine.³³ Just remember, when you do drive, drive it long enough
154 to bring the oil up to temperature and keep it there for at least 30 minutes.
155

156

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

160
161 Scuffing and spalling problems are much worse with high performance cams. The more radical the cam,
162 the more trouble they can be. Smokey Yunick, legendary NASCAR mechanic and innovator, reportedly
163 resorted to breaking in racing cams and lifters in multiple sets, looking for a set that survived the process.⁷
164 The focus of this article is on general principles and problems with engines built for use on the street
165 rather than the race track.

166
167 Shops specializing in British cars have been dealing with these problems for years, and most of them
168 have developed a set of procedures to minimize the chance of a cam/tappet failure. Having arrived at this
169 combination of parts, machine work, engine prep and lubricants, most of the specialists have contained
170 the problem, or at least kept it at a low level. Some have gone to considerable lengths to deal with this
171 situation, and it does not stop with the rebuild. Skip Kelsey of Shadetree Motors probably put as many
172 miles on a 52 MG TD as anyone. Skip bought his tappets from a supplier in the UK, and had experienced
173 a couple of tappet failures. He used to check the tappets in his engine every 3,000 mile or so. If he
174 thought one was starting to go, he'd replace it.

175
176 After talking to several of these specialists, it was clear that no two shops would agree on exactly what
177 the cause or causes of past problems had been. They all had their own ideas about what needed to be
178 done to prevent problems based on their personal experience. One thing common to every list was oil,
179 particularly break-in oil. Although the brand and type of oil varied, it was clear that oil was perceived to be
180 a problem, and they had selected a specific oil that they felt offered the best protection. This brings us to
181 our next topic of discussion – oil.

182 **About Oil**

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

185
186 Every manufacturer starts with a “base oil”. Base oils are divided into five groups (I, II, III, IV, V). Group I,
187 II and III are mineral oils, increasing in purity as you go from I to III. Some automotive oil is made using
188 Group I base oils, but more manufacturers use a Group II base which has better lubricating properties
189 and better stability. In the last 10 years, there has been an increase in the use of Group III base oils,
190 which represent the highest level of refined mineral oils. They have excellent lubrication properties, and
191 they are very stable. Some of the oil marketed as “semi-synthetic” or “synthetic” is made by combining a
192 Group 3 base with a selection of additives that improve the performance of the base oil. Group IV base
193 oils are chemically engineered and are truly “synthetic oils”. The Group IV base is augmented with
194 various combinations of additives to produce oil sold as synthetics or synthetic blends. Group V are also
195 pure synthetics, and they are generally used to produce additives rather than being used like other base
196 oils. The properties of the base oil are “fine tuned” to meet specific needs by the oil companies using a
197 wide selection of additives.²⁷ We will work our way through these properties and additives one by one,
198 starting with something familiar.

199 **Viscosity**

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

222
223 In contrast to the SAE viscosity, which is always measured at 0° F and 212° F, “Operating Viscosity” is
224 measured at the actual operating temperature of a specific engine. Visualize a chamber that can be
225 maintained at a specific temperature, say 195° F. In the chamber is a graduated container with a narrow
226 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
227 container is measured. The unit of measure is square millimeters per second, or “centistokes” (cSt).
228 Because the viscosity can be related to the actual operating temperature of a particular engine, some
229 consider the “operating viscosity” to be more relevant than the SAE viscosity. I have seen “Operating
230 Viscosity” on a couple of oil related websites, but it is usually given along with the SAE viscosity. The SAE
231 viscosity is much more common and gives us a standard we can use to select oil for our vehicles.

232 **Dispersants**

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

240 **Detergents**

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

249 **Anti-Oxidants**

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

255 **Friction Modifiers**

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

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

286
287 To complicate matters, the dispersants and detergents in the oil will have an effect on the ZDDP. In some
288 tests, oil with higher levels of dispersants had greater valve train wear. Wear can also be affected by the
289 detergent type and amount.² "Detergents... alter the chemical composition of the films."³ The article goes
290 on to say "Common detergents contain calcium ions, which are incorporated into the ZP [zinc phosphate]
291 films by replacing the Zn... on iron surfaces this causes... higher pressure and increased wear..."³
292 because the calcium cross-links are not as strong.³

293
294 On the plus side, ZDDP is also an excellent anti-oxidant, which will come up again later. ZDDP is not the
295 only friction modifier. Additives based on molybdenum are currently being used to reduce friction and
296 increase mileage. ZDDP is the main character in this story though.

297
298 Measuring ZDDP is tricky, and confusing. It is usually done by measuring elemental zinc and/or
299 phosphorus. The concentration, when it is provided, is usually given as parts per million (PPM) or as
300 "weight %". For example, 0.12% by weight is equivalent to 1200 PPM. Commonly, measurements are
301 done using a Rotating Disc Electrode (RDE) or Inductively Coupled Plasma (ICP) Spectroscopy. While
302 these are good for determining the level of ZDDP in fresh, unused oil, they do not work well on used oil.
303 Oil subjected to high heat in presence of water vapor will break down due to hydrolysis. You will still have
304 significant levels of zinc and phosphorus in the oil but it is not ZDDP. Fourier Transform Infrared (FTIR) is
305 better for measuring ZDDP depletion.⁵ Measuring ZDDP levels would not be an issue if the concentration
306 was printed on the label. Unlike food, the ingredients in the oil are not on the label in plain English. The oil
307 companies consider their formulas proprietary, and rightly so. More recently, some of the oil companies
308 have started listing the amount of zinc, phosphorus, or ZDDP in some of their oil, presumably as a
309 result of pressure from consumers.

310
311 There are other additives that go into the oil, but the five discussed above will suffice for this discussion.

312
313 So... we have a basic understanding of the major problem- cam and tappet failures- and a basic
314 understanding of the way motor oil is modified with various additives, and what the additives affect. To
315 understand what has happened to oil over the last 10 years, we need to know a little about how standards
316 for motor oil are developed and who has a say in setting these standards.

317 **Oil Standards - Where do They Come From?**

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

322
323 The major players are Ford, General Motors, Daimler Chrysler, the Japan Automobile Manufacturer's
324 Association, and the Engine Manufacturer's Association. This diverse group develops performance
325 standards, test methods, and restrictions in cooperation with the various engine and vehicle
326 manufacturers, the Society of Automotive Engineers (SAE), the American Society for Testing & Materials
327 (ASTM), and the American Chemistry Council. In addition to the organizations mentioned above, the
328 American Automobile Manufacturers Association (AAMA), and the Japanese Automobile Standards
329 Organization (JASO) also have a say about performance specifications for lubricants.

330
331 In 1992 the AAMA and JASO formed the International Lubricant Standardization and Approval Committee
332 (ILSAC). ILSAC, according to one source, was formed because of a concern that the API-SAE-ASTM
333 group might not be reacting quickly enough to changes in the industry, and there was concern about the
334 lag in developing more relevant standards for oils. ILSAC sets minimum performance standards for oil
335 used in gasoline powered passenger car and non-commercial light trucks.

336
337 ILSAC, API, SAE, and ASTM joined together and formed the Engine Oil Licensing and Certification
338 System (EOLCS). The EOLCS licenses oils approved through the ILSAC. The API provides the overall
339 administration of the EOLCS system, which brings us back to what I said a minute ago. The bewildering
340 array of groups know by three and four letter acronyms just listed is not complete, but we're going to
341 ignore the ACEA, ISO, AIAM and AAIA for now.

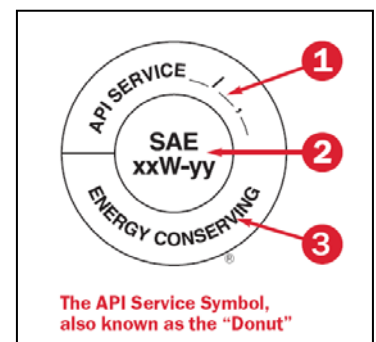
342 Now, about the standards. Companies that market oil that that meets the API standards can print the "API
343 Engine Oil Quality Marks", specifically the API Service Symbol (known as the "Donut"), and the
344 "Starburst" Certification Mark on the packaging or advertising for the oil. These symbols amount to the
345 "Good Housekeeping Seal of Approval". They establish the quality of the product and they provide useful
346 information anyone considering buying that quart of oil. Currently, more than 8,000 products in more than
347 50 countries carry these symbols.

348
349 **1. Performance Level:** Gasoline engine oil categories (for cars, vans, and light
350 trucks with gasoline engines) fall under API's "S" or "Service" categories. SM is
351 the current automotive grade, introduced in 2004. Diesel engine oil categories
352 (for heavy-duty trucks and vehicles with diesel engines) fall under API's "C" (for
353 "Commercial"), and "CJ-4" is the current commercial or diesel truck grade.

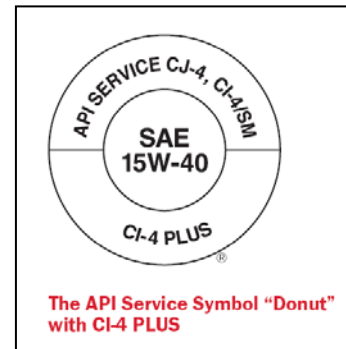
354 **2. SAE Viscosity Grade:** The measure of the oil's thickness and ability to flow at
355 certain temperatures as established by the SAE.

356 **3. Energy Conserving:** The "Energy Conserving" designation applies to oils
357 intended for gasoline-engine cars, vans, and light trucks. Widespread use of
358 "Energy Conserving" oils may result in an overall savings of fuel in the vehicle
359 fleet as a whole.

360
361 **The "Starburst Certification Mark".** Unlike the performance level on the
362 "Donut", which will show which standards the oil meets, the "Starburst" simply
363 means the oil meets the **current** International Lubricant Standardization and
364 Approval Committee (ILSAC) engine protection and fuel economy standards.
365 Although not as well known, every API classification since 1996 has had a
366 companion GF standard. For example, the API performance level in '96 was
367 "SH" and the ILSAC standard was GF-1. In 1997, the API performance level
368 changed to "SJ" and the ILSAC standard was GF-2. The current standard is
369 GF-4. The "GF" number will never appear in the "Starburst".
370



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



377
378
379
380
381
382

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

387
388 Many of you may not be familiar with the progression of API and the newer “GF” specifications, which
389 were developed by ILSAC to meet the government regulations regarding fuel economy and long-term
390 emission system performance and durability. It may make more sense if we look at the changes made to
391 the oil over time, and relate those changes to the problems that provided the impetus to come up with
392 newer, better oil. We will also trace the development of the procedures used to evaluate the level of
393 protection provided by motor oil. We will also trace the use of ZDDP over the years.

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

- 395
- 396 **1911 SAE Develops Oil Classification System**
- 397 • Based only on viscosity
- 398 **1942 First Use of ZDDP in Motor Oil**
- 399 • Not to protect the cam and tappets
- 400 • Added to control copper/lead bearing corrosion
- 401 • A low level of phosphorus (0.03% by weight or 300 PPM) was effective.²
- 402 **1947 First API Oil Types Defined**
- 403 • API designated three types of engine oils: regular, premium, and heavy duty.
- 404 • Generally, the regular oils were straight mineral oils.
- 405 • The premium oils contained oxidation inhibitors
- 406 • The heavy-duty oils contained both oxidation inhibitors and detergent-dispersant
- 407 additives.³²
- 408 **1952 Engine Service Classification System (ESCS)**
- 409 • Developed by API Lubrication Committee and ASTM
- 410 • ESCS considered gasoline and diesel engine oils separately
- 411 • Service Categories ML, MM, and MS for gas engines
- 412 • Service Categories DG, DM, and DS for diesel³²
- 413 • Oil companies rated their own product²
- 414 **1955 ESCS Revised by API & ASTM**
- 415 **(Mid 1950s)**
- 416 • Development of high performance engines in Detroit
- 417 • High lift camshafts created problems as well as lots of horsepower.
- 418 • “This came to light... when... engines that were developed on one API MS oil and then
- 419 factory filled with another API MS oil wore camshafts and lifters out within weeks of
- 420 delivery to customers.”¹
- 421 • Problems were overcome by
- 422 ○ using hardened cast iron camshafts and lifters
- 423 ○ phosphate etching the camshafts (which creates a surface that traps oil)
- 424 ○ increasing the level of ZDDP in the oil to 0.08% (based on the measured amount
- 425 of phosphorus). That corresponds to a level of 800 PPM.
- 426 ○ They also found that “raising the zinc above 14% would cause increased wear.”¹
- 427 **1958 First Tests Developed to Measure Oil Performance**
- 428 • Direct result of the problems with MS oil
- 429 • Five specific “Sequence” tests were developed by Ford, GM and Chrysler
- 430 • One Sequence Test can test for several different things
- 431 • Testing is intended to look at these issues:
- 432 ○ Engine Rust & Corrosion
- 433 ○ High Temperature Oil Oxidation (oil deterioration)
- 434 ○ Piston Varnish
- 435 ○ Engine Varnish
- 436 ○ Engine Sludge
- 437 ○ Cam & Lifter Wear
- 438 ○ Bearing Wear
- 439 • Two of these “Sequence Tests” focused on camshaft and lifter scuffing
- 440 • General intent: To assist oil companies in coming up with oils that actually worked.
- 441 **1960 ESCS Revised by API & ASTM**
- 442 • Sequence Tests were updated and used through the 60s
- 443 • Used by oil companies and automakers alike.
- 444

- 445 **1969-1970 New Oil Classification System Established**
- 446
- 447
- 448
- 449
- 450
- 451
- 452
- 453
- 454
- 455
- 456
- 457 **1971 Automotive & Oil Companies Adopt Common Performance Standards**
- 458
- 459
- 460
- 461
- 462
- 463 **1970s Problems with Oxidation**
- 464
- 465
- 466
- 467
- 468
- 469 **1970s Problems with Camshaft & Tappet Foot Wear**
- 470
- 471
- 472
- 473
- 474
- 475
- 476
- 477
- 478
- 479
- 480
- 481
- 482
- 483
- 484
- 485
- 486
- 487 **1980 -1988 API SF Oil (Obsolete)**
- 488
- 489
- 490
- 491
- 492
- 493
- 494
- 495
- 496
- 497 **1989 -1993 API SG Oil (Obsolete)**
- 498
- 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.
 - 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
 - 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
 - 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
 - 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
 - ZDDP % by weight ranged from 0.10% to 0.12% (1000-1200 PPM).

- 499 **1993 - 1996** **API SH** **ILSAC GF-1** **(Obsolete)**
500 • Two sources of information give different data on ZDDP concentration
501 ○ ZDDP % by weight unchanged at 0.10% to 0.12% (1000-1200 PPM).
502 ○ Zinc = 0.130%, 1130ppm (parts per million); phosphorous = 0.120%,
503 1120ppm
504 • API SH standards are the same as API SG standards
505 • The rules for “passing” each requirement (test) were changed¹³
506 • For API categories through SG, a single “pass” on each test was required.¹³
507 • Number of attempts and number of failures was not considered¹³
508 • Chemical Manufacturers Association (CMA) has applied a Multiple Test Acceptance
509 Criteria (MTAC)¹³
510 • For tests run twice, the data is averaged, and the averages must be a pass for each
511 parameter tested. For tests run 3 or more time, one test may be discarded, the rest of the
512 data is averaged, and the averages must be a pass for each parameter tested.
513 • To meet the stricter testing, formulas for the oil were adjusted by the oil companies
514 • As a result SH oils showed improvements over SG oils¹³
515 ○ Less rust
516 ○ Improved oxidation protection
517 ○ Less varnish
518 ○ Less sludge
519 ○ Less wear
520 ○ Better, fuel economy, although API SH has no energy conserving requirement
521 • First ILSAC specification (GF-1) implemented
522 • ILSAC GF-1 specifications **only** apply to 0W-X, 5W-X and 10W-X oils where X can be
523 20, 30, 40 or 50.
524 • API SH applies to **all** single and multi viscosity grade oils
525 • GF-1 requires an API SH oil to meet the Energy Conserving II (EC-II) requirements.
526 • EC-II oil provides a 2.7% fuel economy improvement over reference oil
527 **1997 - 2001** **API SJ** **ILSAC GF-2** **(Current, for 2001 & older engines)**
528 • phosphorus (ZDDP) level maximum 0.10% (1000 PPM)
529 • improved low temperature operation
530 • reduced high temperature deposits
531 • better foam control.
532 **2001- 2004** **API SL** **ILSAC GF-3** **(Current, for 2004 & older engines)**
533 • implemented July 2001
534 • phosphorus (ZDDP) level maximum 0.10% (1000 PPM)
535 • long-term emission system durability
536 • improved fuel economy
537 • reduced volatility
538 • improved deposit control
539 • better viscosity retention over the oils service life
540 • reduced additive depletion over the oils service life
541 • reduced oil consumption rates.
542 **2004 -** **API SM** **ILSAC GF-4** **(Current, for engines after 2004)**
543 • phosphorus (ZDDP) reduced to 0.060 -0.085% (600-850 PPM)
544 • improved oxidation resistance
545 • better deposit control
546 • improved wear protection
547 • improved performance at low temperatures over the life of the oil
548 • oil with the “Starburst” certification are energy conserving (possibly better mileage)¹²
549

550 **Testing and ZDDP Reduction in API SM Oil**

551 The level of ZDDP in oil has been reduced from a high of 0.10 - 0.15% (1000 – 1500 PPM) to 0.060 -
552 0.085% by weight or 600-850 PPM when the API SM and ILSAC GF-4 standards were implemented. This
553 is about the same as the 0.08% (800 PPM) level of ZDDP in oil back in the 1950s when ZDDP was first
554 introduced to prevent premature cam/lifter failures.²
555

556 The level of ZDDP was reduced to protect the catalytic converter. Catalytic converters have to be covered
557 by the automobile manufacturer's warranty, and the length of the warranty in terms of miles has been
558 increased significantly. Phosphorus is a know "poison" of catalytic converters, and to protect them, the
559 level of phosphorus in motor oils has been reduced in a cooperative effort between the auto makers, the
560 oil companies, and the groups that set the standards. Not all the ZDDP in oil was there to provide anti-
561 scuffing and anti-wear protection. Some of it functioned as an anti-oxidant. This secondary role of ZDDP
562 was taken over by new ashless and phosphorus free antioxidants, which made it possible to eliminate
563 some of the ZDDP. It is important to realize that while the reduction was done to protect the catalyst, the
564 **actual level** of ZDDP was not set solely based on the requirements of the catalyst.² Extensive testing
565 was done to determine how much ZDDP was required to provide adequate wear protection, and that is
566 what determined the level of ZDDP in the API SM/ILSAC GF-4 oil.
567

568 Even so, the latest API "SM" oils have been singled out as being "unsuitable for vintage applications".
569 Many of you have already read or heard that "SM oils were not made for older engines" or that the "EPA
570 and tighter emission regulations forced "them to change the oil", and "SM oil will kill your classic". The
571 reason cited is the reduction in zinc dialkyldithiophosphate (ZDDP, ZnDTP, or ZDP) in the API SM oil. In
572 some of the information that is out there, the implication is that ZDDP has been outlawed, or totally
573 removed from motor oil, which is simply not true. It is obvious that the amount of ZDDP has been
574 reduced. What is not immediately clear is if the testing of the SM oil is applicable to older, flat tappet
575 engines.
576

577 The Sequence III-D test for valve train wear was modified and developed over the years, and led to the
578 III-E, III-F, and finally the III-G test. The current API SM oil classification with its reduced level of ZDDP
579 uses the Sequence III-G test, and it is therefore of particular interest. Sequence III-G evaluates cam
580 and tappet wear using a GM 3.8L (231 CID) engine that has had the valve train replaced with the flat
581 tappet valve train similar to that used by GM in the 1980s.² According to the ASTM engine assembly
582 procedure, the engines are rebuilt using new parts, and the cams are installed with EF-11, an SAE 10W
583 oil – not assembly lube. Test III-G is specifically "meant to simulate a flat tappet OHV push rod engine in
584 a pickup truck pulling a loaded cattle trailer across the desert on a hot day."² Using unleaded gasoline,
585 the engine runs a 10 minute initial oil leveling procedure followed by a 15 minute slow ramp up to speed
586 and load conditions. It then operates at 125 bhp, 3600 rpm, and 150°C oil temperature for 100 hours,
587 interrupted at 20-hour intervals for oil level checks. At the end of the test, all six pistons are inspected for
588 deposits and varnish; cam lobes and lifters are measured for wear; and oil screen plugging is evaluated.
589 The average cam plus lifter wear (maximum) is 60µm (0.06 mm). The III-F test for API SL/GF-3 oil was
590 shorter (80 hours) with more frequent stops (every 10 hours), and the average cam plus lifter wear
591 (maximum) was 20 µm.
592

593 Sequence IV-A tests for cam lobe scuffing and wear in an overhead cam engine. This test uses a
594 KA24E Nissan 1994 2.4-liter, water-cooled, fuel-injected engine, 4-cylinder in-line, overhead camshaft
595 with two intake valves, and one exhaust valve per cylinder. This engine uses "slider finger followers".
596 Although it is not a "flat tappet cam" design, this type of valve train is particularly prone to valve train
597 wear, and very sensitive to the amount of friction modifiers in the oil. The test consists of 100 one hour
598 tests, and each test period consists of 50 minutes at 800 RPM and 10 minutes at 1,500 RPM. At the end
599 of the test, each of the 12 cam lobes is measured at 7 locations for maximum depth of wear.
600 Measurements of wear on all 7 positions of each lobe are added, then all 12 lobe measurements are
601 averaged for the wear result. This result is the primary evaluation for the test. To pass, the average cam
602 wear must be less than 90 µm (0.09 mm). The wear limit for API SL / ILSAC GF-3 was higher at
603 120 µm.
604

605 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
606 testing done on API SM oils that give some indication of the oils ability to protect older engines. Testing of
607 the SM specification addressed multiple concerns, using a combination of new and older engines to make
608 sure the oil not protected modern engines with roller tappets and roller rocker arms AND older engines
609 with "flat tappet cams". This issue of backwards compatibility was not ignored or swept aside as some
610 articles seem to imply.

611
612 A thorough review of the test data and some 33 papers on oil, ZDDP and wear were pulled together in
613 one SAE report. The authors "...suggest that 0.08% phosphorus, in the form of ZDP is more than
614 adequate to protect both current and older engines from scuffing and wear."² They went on to say "The
615 data available also suggest that even lower levels of phosphorus, certainly as low as 0.05%, and perhaps
616 as low as 0.03%, may be sufficient to provide scuffing and wear protection for engines in the field with
617 phosphated camshafts."²

618
619 So far, we have looked at the problems reported, oil and oil additives, the standards for oil and the
620 organizations that set those standards, and we have traced the use of ZDDP as an additive and we have
621 looked at the testing done before the level of ZDDP was dropped to its current level. Clearly, the testing
622 done was intended to make sure older engines were protected. We have also looked at the SAE report
623 that concluded that API SM oils have enough ZDDP to protect older engines, and that adequate
624 protection would be available at even lower levels of ZDDP.

625
626 The question is, how does the real world experience of engine rebuilders, enthusiasts, collectors, and
627 restorers stack up against all the data and well reasoned analysis that has led us to the current level of
628 ZDDP, and lower levels of ZDDP in the future ?

629 **Real World Experience**

630 There have been increasing numbers of cam/tappet failures, especially in the last four or five years. The
631 Engine Rebuilders Association (AERA) has been keeping records for the last ten years. In that period,
632 there have been more reported cam/tappet failures, with the largest jump in numbers of failures after
633 2004. Of the failures reported, 25% were traced to poor break-in procedures. The other 75% were traced
634 to use of "modern oil for the break-in."¹⁰

635
636 As a result, the AERA issued Technical Bulletin TB 2333R. Issued November 2007, it "...warns about the
637 reduction of Zinc in gasoline engine oils which has been traced to many camshaft and flat tappet lifter
638 failures. This information should be considered for any engine that uses a flat tappet design and should
639 be referenced before initial engine start-up."¹⁰ The Bulletin goes on to say "Adding additional Zinc for
640 camshaft and lifter break-in by using GM Engine Oil Supplement (EOS) or using any supplant supplied
641 from any of the aftermarket cam manufacturers. All camshaft manufacturers are aware of the reduction of
642 Zinc and changes in engine oils formulations. For many years they have offered camshaft assembly lube
643 and break-in lube for their products, so USE IT. Liberal amounts of this lube during assembly on all
644 moving or rotating points will offer a front line defense as soon as the engine is rotated. GM recommends
645 pouring a pint bottle of their EOS over the crankshaft before installing the oil pan." GM's Engine Oil
646 Supplement (EOS) did contain significant amounts of ZDDP, and it was the most concentrated ZDDP
647 supplement available. It was intended to boost ZDDP levels of oils that already contained EP additives. It
648 was available for over 20 years, but unfortunately it was discontinued by GM in early 2007.

649
650 Crane Cams has published a number of documents that deal with camshaft break-in, failure, and
651 lubrication. On their website, there is an article titled "Preventing Cam and Lifter Wear". It makes several
652 points. "REMEMBER . . . the first 10 minutes are the most important in a new camshaft's life. Tests have
653 shown that if there is no spalling or metal pick up during the first 10 minutes to one hour of operation, the
654 cam will last a normal life."³⁰ They are very specific about assembly lube and the break-in oil. "There must
655 be a moly coating between the cam lobe and lifter, in order to prevent metal-to-metal contact. Before
656 installing your new cam, coat all lobes and the bottoms of each lifter with a moly disulphide based
657 assembly lubricant. . .".³⁰ For oil, they recommend "... a high quality 30 or 40 weight oil, preferably a
658 Pennsylvania base oil, or a high quality Pennsylvania based multi-viscosity oil, such as 10W-30 or 20W-
659 50. Also, for extra protection, an antiwear additive (zinc dithiophosphate) must be added. . .".³⁰

660
661 In another article on their website, "Reasons and Causes for Cam Failure", they begin by saying "Cam
662 failure is rarely caused by the cam itself. The only things we can control during manufacture pertaining to
663 cam lobe wear are lobe taper, lobe hardness and surface finish. Of all the damaged cams we have
664 checked over the years, more than 99.99 percent have been manufactured correctly. Some people have
665 the misconception that it is common for a cast iron flat tappet cam to occasionally have a soft lobe. We
666 have yet to see a cast iron flat tappet cam that had a soft lobe. When the cast core is made at the casting
667 foundry, all the lobes are flame hardened. That process hardens all the lobes to a depth below the barrel
668 of the core. That depth of hardness allows the finish cam grinder to finish grind the cam lobes with a
669 Rockwell hardness above 50Rc. The generally accepted hardness on a finished cast cam should be
670 between 48Rc to 58Rc. All of the finished cams that we have checked are always above 50Rc hardness
671 on the lobes. Many outside factors, or a combination of factors, can cause cam failures. We will list some
672 of the factors we have determined that may cause camshaft failure."²⁸ Number one on the list is incorrect
673 break-in lubricant, and they say "Moly Paste must be applied to every cam lobe surface, and to the
674 bottom of every lifter face of all flat tappet cams.", and "...apply the Moly Paste to the distributor gears on
675 the cam and distributor for all camshafts. For extra protection, an anti-wear additive should be added..."
676 they make specific reference to the products offered by Crane in the document.

677
678 Crane also published their "Flat Tappet Camshaft Break-in Procedure", Installation Instructions 548E. It
679 says, in part, "Due to the EPA's mandate for zinc removal from most motor oils, proper flat tappet
680 camshaft break-in procedure is more critical than ever before. This is true for both hydraulic and
681 mechanical flat tappet camshafts. As a point of interest, the most critical time in the life of a flat tappet
682 camshaft is the first 20 minutes of "break-in" during which the bottoms of the tappets "mate-in" with the
683 cam lobes. There are some oils with additive packages that are better for camshaft "break-in"... Do not

684 use API rated “SL” or “SM” oil. CAUTION: We do not recommend the use of synthetic oils for “break-in.”
685 Crane lists two oils they like and suggest using their break-in additive. The implication of the “EPA’s
686 mandate for zinc removal” is that the zinc is gone, and that is not strictly correct.

687
688 Piper Cams has a similar article, “The Rules of Successful Camshaft Installation”. The first two
689 paragraphs read: “Research and experience has shown that most cams that wear out start to fail during
690 the first few moments of operation. Many cams are irreparably damaged, even before the engine is
691 started, because the basic rules of camshaft installation and 'break in' have not been followed. The cause
692 of premature cam and follower failure is metal to metal contact between the follower and cam lobe.
693 Should this contact occur due to lack of lubrication and excessive high pressure due to valve train
694 interface shearing the oil film, then 'galling' will take place. When this happens, metal is transferred from
695 the follower to the cam lobe or vice versa in a process comparable to welding. Microscopic high spots,
696 which are present on all machined parts, become overheated due to friction and pressure and bond
697 together, tearing sections loose from follower or lobe. These pieces of metal remain attached and create
698 further local overheating during the following revolutions of the camshaft and lead to ultimate failure of the
699 affected components.” They go on to say that the cam must be washed carefully without disturbing the
700 phosphate coating, then liberally coated with Piper’s Cam Lube. They do not address the issue of oil,
701 zinc, or ZDDP.

702
703 Competition Cams published a Tech Bulletin in 2005 entitled “Flat Tappet Camshafts”. “Recent changes
704 in oil and engine technology are likely the cause of premature camshaft failure... Premature flat tappet
705 camshaft failure has been an issue of late and not just with one brand or type of camshaft. In almost
706 every case, the hardness or the taper of the cam lobe is suspected, yet most of the time that is not the
707 problem. This growing trend is due to factors that are unrelated to camshaft manufacture or quality.
708 Changes in today's oil products and “advanced” internal engine design have contributed to a harsher
709 environment for the camshaft and a potential for failure during break-in.”¹⁶ The article goes on to say a
710 “major factor in the increase of flat tappet camshaft failure is your favorite brand of engine oil. Simply put,
711 today’s engine oil is just not the same as it used to be, thanks to ever tightening environmental
712 regulations. The EPA has done a great job in reducing emissions and the effects of some of the
713 ingredients found in traditional oils; however these changes to the oil have only made life tougher on your
714 camshaft. The lubricity of the oil and specifically the reduction of important additives such as zinc and
715 phosphorus, which help break-in and overall camshaft life, have been drastically reduced. In terms of oil
716 selection, we recommend a high “ZDDP”, Zinc Dialkyl Dithiosphosphate, content oil for the break-in
717 procedure and regular operation.”³¹ Comp Cams recommends the use of their assembly lube, and their
718 break-in additive. It is interesting to note that they are encouraging the use of the break-in additive after
719 the initial break-in: “While this additive was originally developed specifically for break-in protection,
720 subsequent testing has proven the durability benefits of its long term use. This special blend of additives
721 promotes proper break-in and protects against premature cam and lifter failure by replacing some of the
722 beneficial ingredients that the oil companies have been required to remove from off-the-shelf oil.”¹⁶ They
723 do not say what is in the additive on the website, but I called them and they confirmed that the main
724 ingredient is ZDDP at 1400 PPM.

725
726 If you review the literature being supplied with new cams and tappets, it is very clear that the
727 manufacturers have identified the assembly lube and the oil used for start-up and break-in as critical. It is
728 important to realize this is not just about the assembly lube and oil- they are also providing more detailed,
729 specific instructions on how an engine should be assembled and broken in, and the list of things to do or
730 check are getting longer.

731
732 Companies that make oil specifically for vintage applications are quick to point out that there is a lot more
733 to oil than ZDDP, but they all are using more ZDDP than is found in the SM oils. I checked with half a
734 dozen oil companies, and some of them either offer, or plan to offer, oils that are not API certified with
735 ZDDP in concentrations that exceed the 0.08% maximum limit allowed for API certification.

736

737 **What Does It All Mean?**

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

743
744 We do not have the benefit of a test study done, for example, with 25 MGBs with identical rebuilt engines
745 that were run on oil that was identical except for the amount of ZDDP. It is difficult to weigh the technical
746 data available on the subject and relate it to the cars we own and drive. That said, I think we can draw a
747 logical conclusion for our vintage British engines.

748
749 A modern API SM oil with 0.06 - 0.08% (600-800 PPM) ZDDP may be fine for engines that are broken in,
750 but there is enough evidence to suggest that ZDDP at 0.14% to 0.015% by weight (1400-1500 PPM) can
751 provide the additional protection needed to maximize the chances of a successful cam/tappet break-in.

752
753 After that initial 20-30 minute break-in period, change the oil and the filter. The oil you run after that will
754 not need as much ZDDP. We suggest that 0.10 - 0.12% (1000 to 1200 PPM) ZDDP would be
755 appropriate. It is high enough to provide additional protection without risking chemical corrosion.

756
757 After the first 500 miles, change the oil and the oil filter again, using the same oil (1200 PPM ZDDP) you
758 used for the first 500 miles.

759
760 What you use after the first 1,000 miles will depend in part on how much you drive. If you can't drive your
761 car on a regular basis, consider using oil formulated specifically for classic cars. They have a mixture of
762 additives designed to deal with the moisture, corrosion, and acids in engines that sit for extended periods
763 of time. Change your oil every 3,000 miles or every 6 months, whichever comes first. If you live where the
764 humidity is high, or where there is a significant change in temperature from day to night, you will have
765 more moisture collecting in the sump. To get rid of it, change the oil more frequently, up to four times a
766 year.

767
768 If you drive your car more frequently, you have more options. Using a 20W-50 API SM oil with 0.08% (800
769 PPM) ZDDP **may** be just fine. By driving the car frequently I mean once a week for 30 minutes or more
770 with the oil between 170°F to 200°F. This will minimize the amount of water and water vapor in the
771 crankcase, and that will limit the corrosion and subsequent pitting of the cam lobes and lifters. If you are
772 more conservative, a ZDDP level of 1000 to 1200 PPM will provide additional protection.

773
774 Our conclusions are not a substitute for real world experience. If you have never had a problem with a
775 rebuilt engine or the oil you have been running, I wouldn't change a thing. If you use an API oil, be aware
776 that the oil will change in the future as additive packages are fine tuned for modern engines. The SAE
777 papers I have read indicate that the ILSAC-GF5 standards which will go into effect in 2009-10 will
778 probably call for 0.05% (500 PPM) phosphorus², meaning the amount of ZDDP will be reduced some
779 more. The change may not be obvious from the packaging. Read the labels, check the oil company
780 website. If it is not clear, call them on the phone.

781
782 If you have had a problem with cams and/or lifters in a rebuilt engine, or if you are having an engine
783 rebuilt, or are thinking about it, you should carefully weigh the information you have. Pay particular
784 attention to the instructions on the cam and/or tappet manufacturer's website, and whatever instructions
785 you received with your cam and/or tappets. Talk to the professionals. If you are having your engine
786 rebuilt, the experience of someone that rebuilds six or more MG, Triumph or Healey engines is
787 invaluable. They have a combination of parts, procedures, assembly lube and break-in oil that works for
788 them. Take their advice. Recognize that changing their recipe may cause problems that they have not
789 seen or experienced.

790

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

800
801 Because ZDDP is affected by the level and type of detergents in a particular oil, it is not possible to
802 predict the performance of a specific oil mixed with a ZDDP additive because there is no data on this
803 subject.
804

805 And finally - and I cannot stress this enough - using oil with ZDDP level above the 800 PPM level does
806 not guarantee success. There are simply too many other factors involved. However, the right oil, when
807 combined with careful selection of components, care and attention to detail during assembly, a good
808 assembly lube, and a good prep, start-up, and break-in procedure, may tip the balance in your favor.
809

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

813 **Appendix: Collected Tips for Rebuilding a Vintage British Engine**

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

820 821 **Product Selection**

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

827
828 Tappets with a domed or curved foot are suitable for use with cams with tapered lobes. This design
829 promotes rotation of the tappet. The curve of the tappets must be carefully matched to the taper of the
830 cam. If they are not matched, the tappets may not rotate, or they may rotate too fast. Either case is going
831 to cause problems.

832 The tappet bore may or may not be offset with respect to lobe of cam.

833
834 If you are not sure if your cam & tappets were made for each other, have them checked by one of the
835 cam specialists like Elgin Cams or Comp Cams. If necessary, the tappets can be modified to match the
836 cam.

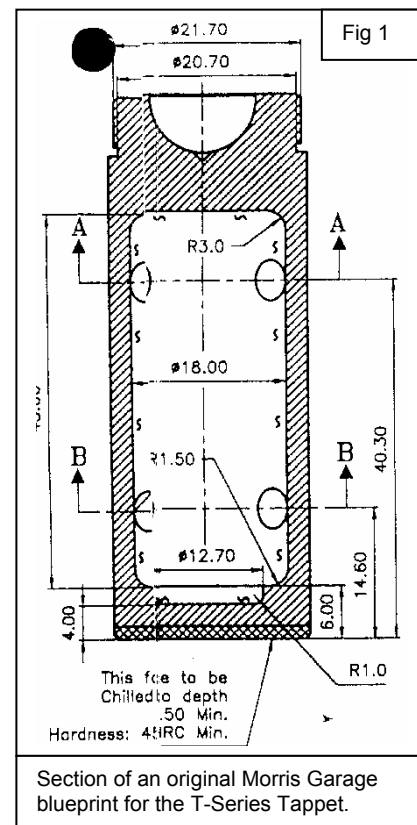
837
838 If the cam and tappets are not phosphate coated or etched, consider having it done. The phosphate will
839 trap oil, and it has been shown over and over again that phosphate will improve the odds of a successful
840 break-in, even though the phosphate coating on the cam lobe will cause some wear on the foot of the
841 tappet.

842
843 Some original tappets, like those used in the MG T-Series, have holes
844 in the sides. (Fig 1) The hollow body of the lifter fills with oil from the
845 rocker gallery. As the tappet drops down in the lifter bore, the lower
846 holes are uncovered, and oil drains out of the tappet body, flowing
847 over the camshaft. Some modern replacement tappets feature holes
848 designed to improve oiling (picture), and the holes can be in the side
849 or the foot of the tappet.

850
851 Some cams, like the Crane cam for the T-Series, use a larger base
852 circle than a stock cam. (Diagram needed) By increasing the base
853 circle, the cam manufacturer can reduce the ramp angle and it allows
854 the "point of the lobe" to be more rounded. Both of these are good.
855 However, when used with tappets that have the holes in the side,
856 the tappet may not drop down far enough to expose the oil holes. The oil
857 will not drain out, and that reduces the oil flowing over the cam,
858 decreasing lubrication and increasing heat build-up in the tappet and
859 the cam. Moss modified T-Series tappets (picture) address this by
860 elongating the lower oil holes.

861 862 **The Engine Block - Tappet Bore**

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



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

883 884 ***Tappet Bore Alignment, Size & Clearance***

885 The bores must be checked for orientation; they must sit at 90 degrees to the long axis of the camshaft.
886 Size and clearance: for example, Crane says the clearance should be 0.0005 (1/2 a thousandth of an
887 inch) to 0.0035" (three and 1/2 thousandths of an inch). Below that minimum, there is not enough
888 clearance for the tappet to move when the engine gets hot. Over the maximum, it's too loose.
889 If the tappet is too tight, they may not rotate properly when the engine gets hot, even though they are
890 moving up and down. This can greatly increase the pressure on the foot of the tappet and it will quickly
891 fail. If the tappet is too loose in the bore, or the bore is ovalized, the tappet can rock in the bore, and both
892 the tappet and the cam lobe will fail.

893 894 ***Lifter Bore Oil grooves***

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

901 902 ***Oil Pathways***

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

907 908 ***Valve Springs***

909 Never install springs without checking the installed spring height and the spring pressure. Too much
910 pressure can overload the cam and lifter, which will make it impossible to break them in together.
911 For a mild street cam, spring seat pressures should be 85 – 105 lbs. Radical or high performance cams
912 may call for 105-130 lbs. There are two problems with high spring pressures. First, the load on the tappet
913 foot is increased. Second, higher spring pressures will impede the proper rotation of the tappet during
914 break-in. If the tappets do not rotate properly during the first ten minutes of the break-in, the damage is
915 irreversible. If you plan on running higher spring pressures, don't do it during break-in. Use a shorter ratio
916 rocker to reduce valve lift. If you are using dual valve springs, consider removing the inner spring
917 during break-in.

918 The valve springs must be checked to ensure that coil binding does not exist at maximum lift. One
919 company says there must be a minimum clearance of 1mm between the valve spring coils. Another says
920 there must be an additional 0.060" (1.5 mm) travel left in the spring when fully compressed by the action
921 of the cam. Make sure the springs are fitted at the correct installed height. It is important to ensure that
922 the valve spring fits the retaining cap correctly and in some instances the cylinder head may need

923 machining. Once the valve springs have been installed check both inner and outer springs for coil binding
924 and ensure that the bottom face of the spring retaining cap does not contact the top of the valve guide or
925 valve stem oil seal. Minimum clearance on full lift is .060. (1.5mm). If this clearance cannot be achieved
926 the top of the guide may need to be modified.
927

928 **Valve to Piston Clearance**

929 After resurfacing the block, head, fitting new pistons and / or valves, it is important to check the clearance
930 between the valve head and the top of the piston. It has been suggested that 0.08" intake and 0.100"
931 exhaust are the minimum clearance needed.
932

933 **Camshaft End Play**

934 If the camshaft end play is specified, check it after the cam is installed and the bolts have been torqued. If
935 it is excessive, the cam will move back and forth. In extreme cases, a cam lobe may come in contact with
936 the adjacent tappet with disastrous results.
937

938 **Other Engine Components**

939 It is probably impossible to come up with a comprehensive listing of things to check or to consider.

940 There are simply too many variables. Here is an example just to make the point.

941 Connecting rod design may make a difference to the camshaft. Most con rods have a hole at the big end
942 facing the cam. Oil under pressure squirts out the hole and it splashes on the cam and tappets. On MGT
943 Series con rods the hole is on the opposite side, directing oil toward the thrust side of the cylinder. We
944 have been told that at least one T-Series engine builder is modifying the con rods to direct oil to the cam.
945 Be aware that there may be a combination of factors for your engine that may combine to make the
946 situation worse (or better). Seek out professionals with experience rebuilding your particular engine
947 You need the benefit of their long experience.
948

949 **Assembly Procedures**

950 Replace the cam and tappets together. Never, ever use a new cam with used tappets. According to
951 Crane, this is the number one cause of camshaft failure. A used tappet, once broken in, cannot be paired
952 with another cam lobe no matter how perfect it looks. Even swapping two tappets in the same engine will
953 not work. Cam lobes and tappets have to wear in together, and that can only happen with a proper break in.
954 Generally, it is the cam lobes that take a beating.
955 While it is possible to use new tappets with a used cam that has been inspected by a machinist and given
956 a clean bill of health, it is not recommended.
957

958 **Assembly Lube**

959 There are almost as many assembly lubes out there as there are oils. Increasingly, cam manufacturers
960 are offering assembly lube either with new cams, or as a suggested product on their website. Any
961 assembly lube offered by a cam manufacturer will be good, and you should consider using one. There are
962 two general types. One is oil based, the other is more like a paste or grease. The oil based lubes use a
963 base oil with a blend of anti-scuffing and anti wear additives, just like a motor oil. The concentration of
964 additives is quite high. The thicker assembly lubes are like grease or a paste, and many seem to be
965 based on molybdenum disulphide (MoS₂). or "moly" for short.
966

967 Moss offers Kent Cams "Cam Lube" (221-570). It is specifically a cam/lifter lube, and it is used to coat the
968 cam/lifters liberally before assembly. It is like a thin grease and will stay where you put it. Kent does not
969 provide technical information as to the composition. Kent provides it to minimize the chance of a failed
970 cam.
971

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

978 surfaces during the rebuild and before the engine is fired. It exceeds all OEM specifications as an engine
979 and bearing assembly lubricant.

980
981 When it comes time to pick an assembly lube, listen to your engine builder or your machinist. They
982 probably have a favorite that they like based on experience. If you are rebuilding the engine yourself, and
983 the cam you bought came with assembly lube or if the cam manufacturer makes a specific
984 recommendation, we suggest that you follow their recommendations.

985 **Break-in Procedures**

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

990
991
992 Everything must be as close to perfect as possible, because it is essential that the engine fire quickly and
993 run steadily at 1500 to 3000 RPM. Prolonged cranking on the starter and/or multiple restarts will lead to
994 scuffing, and once that happens you are going to need another cam and a set of tappets. Do not think
995 you will be able to "get it started and sort it out." This is no time for assumptions and shortcuts. Think
996 about the time, money and effort that has gone into the engine. Don't blow it rushing the last step.

997 **Ignition System**

998 Have the distributor checked on a distributor machine to make sure it actually is working properly. Do not
999 assume that the distributor is OK "because the car ran fine" 8 months ago. If the weights are sticking, the
1000 springs are broken, the shaft bushing is worn, or the diaphragm in the vacuum advance is damaged, the
1001 distributor must be rebuilt. With a known good distributor with the proper advance curve installed, set the
1002 point gap (or dwell angle), and install fresh plugs, properly gapped, with new or known good plug wires,
1003 Check the spark energy on all plugs. Make sure you have the proper firing order. Set the timing to the
1004 factory specification.

1005 **Cooling System**

1006
1007 Fill the system with pure water and pressure test the system. Locate any leaks and correct them.
1008 Drain the system and re-fill with 50% antifreeze mixture. Pressure test again, just to be sure.

1009 **Fuel System**

1010 The fuel tank and all lines up to and including float bowls should have fresh, clean gasoline from a known
1011 good source. If the gasoline in your area has ethanol in it, be aware that it has a shelf life of 45-90 days.
1012 Go get some fresh gas if you have any question about the age of the gas in the car.

1013 **Oil System, Oil Pressure**

1014 Select the break-in oil of your choice. Look for ZDDP at 0.14%- 0.15% by weight (1400 – 1500 PPM) If
1015 you prefer, mix an API SM oil (0.08% or 800 PPM ZDDP) with a ZDDP additive to get a ZDDP level of
1016 0.14-0.15%. Fit a new, top quality oil filter. Three technical papers (SAE 881827, SAE 881825 and SAE
1017 95255) "...proved that removing additional particles in the 3 to 10 micron range will have the greatest
1018 effect in reducing engine wear. Particles in this range have traditionally been ignored, but this size range
1019 is very significant as a long-term wear factor." Noria is a company specializing in lubrication technology,
1020 education and consulting> They have published numerous books and magazines dealing with oil and
1021 lubrication technology, and they had this to say about particle size and wear: "The films of oil that protect
1022 moving engine parts from wear are customarily 2-5 microns in thickness. This remains the same
1023 thickness, even when you use an additive for additional lubricity. Ergo, for example, as the pistons move
1024 up and down against the cylinder walls, particles that are as much as 3-10 times thicker than the
1025 protective oil film are squeezed between the piston and cylinder wall. These particles are aggressive
1026 abrasives, and thereby cause substantially accelerated engine wear."¹⁴ (2 to 5 microns = 0.002-0.005
1027 mm)

1028
1029
1030
1031

1032 To fill the galleries with oil and bring the system up to pressure, use a pressurized external oil tank. There
1033 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
1034 pressure, you must remove the spark plugs, and stop the flow of fuel to and through the carburetors.
1035 Most importantly, TAKE THE TAPPETS OUT.
1036 The engine at cranking RPM will not spin the cam fast enough to rotate the tappets. The tappet foot can
1037 easily be scored, and a scored foot will lead to tappet failure in 500-1000 miles. Because it does not
1038 happen immediately, there will be no obvious link to the real cause. Once you have oil pressure and oil
1039 flow through the rocker arms, replace the tappets and the spark plugs.
1040

1041 ***Start the Engine***

1042 If the engine does not start immediately STOP CRANKING! At cranking RPM, the tappets are not rotating
1043 The foot of the tappet will be scored by the cam lobe. It will fail in short order.
1044 Figure out why the engine will not fire and correct it.
1045

1046 ***When the engine starts....***

1047 DO NOT LET IT IDLE

1048 At idle, properly broken in tappets are rotating, but very slowly. New tappets may not rotate at all at that
1049 low RPM. Bring RPM up to 1500 and keep it between 1500 and 3000 RPM for 20 to 30 minutes.
1050 Immediately after the engine fires and comes up to 1500 RPM, verify that the pushrods are rotating. This
1051 indicates that the tappets are rotating, which is absolutely critical. You can see the pushrods rotating with
1052 valve cover removed. Some shops have special valve covers with a section of the top removed, which
1053 allows the pushrods to be seen while controlling some of the oil splash.
1054 If a push rod is not rotating, try rotating it by hand to get it started. (Use a glove).
1055 If you cannot get it to rotate, SHUT THE ENGINE DOWN.
1056 You must find out why the tappet is not rotating, and correct the problem.
1057 There is no "fixing it later". If the tappet does not rotate it will quickly fail, taking the cam with it.
1058 If all the pushrods are rotating, after 20-30 Minutes running between 1500-3000 RPM, shut it down.
1059 Perform the normal checks you would do at this point.
1060

1061 ***After the Initial Break-in Period***

1062 ***Change the Oil***

1063 Drain the oil and replace the oil filter with a new, top quality oil filter.
1064 Which oil should you use after the initial 20-30 minute break-in period?
1065 You have two options. You can use an oil formulated for vintage engines. They have the appropriate
1066 levels of ZDDP (0.12% or 1200 PPM seems to be an average). They also have additional detergents and
1067 anti corrosion agents to help protect the engines that tend to sit for long periods of time.
1068 If you prefer, you can use an API SM oil with 0.08% ZDDP, and add ZDDP to it. Mix it carefully to obtain
1069 the desired 0.12% ZDDP by weight (1200 PPM). Remember that levels of ZDDP over 0.14% (1400 PPM)
1070 will cause chemical corrosion of the tappet and lead to increased wear over time.
1071

1072 ***Drive Your Car***

1073 If you can drive your car for 30 minutes with the oil between 170°F to 200°F once a week, and you
1074 change the oil and the filter every 6 months or 3,000 miles, you will minimize the corrosion pitting of the
1075 cam lobes and tappets due to moisture and acids in the oil. It is unclear what the minimum driving
1076 requirements are. Once a month may be enough, but we have not run across any data on this issue. If it
1077 is not practical for you to drive your car that often consider using oil formulated specifically for classic
1078 cars.
1079

1080 ***Checking for Wear***

1081 The oil in aircraft engines is checked periodically by looking for steel and iron particles trapped by the oil
1082 filter material, oil pump pickup screen, and the magnetic drain plug. Unless you are using an original
1083 canister type oil filter on your engine, checking the filter for wear particles is going to be difficult. If a
1084 magnetic drain plug is available for your application, use one. When I drain the oil, I run a powerful
1085 magnet through it to pull all the iron and steel particles out. You can get a sense of how the engine is
1086 doing partly by the amount of material you find, and partly by the relative amount found from one oil
1087 change to the next.

1088 **Used Oil Analysis (UOI)**

1089 You can send samples of your used oil to a company that will check it for you, and you will receive a
1090 report detailing what they find. This is very useful if you are managing a fleet of taxicabs or commercial
1091 trucks. Because a company running a fleet of vehicles has lots of data and a series of reports for the
1092 same vehicle, something out of the ordinary will tend to stand out. It gives the technicians a chance to
1093 spot a problem before a catastrophic failure occurs. If you have had problems with previous rebuilds, you
1094 might consider this option, but you will need to be diligent about sending in regular samples.
1095 Unfortunately, UOI cannot effectively monitor the level of ZDDP in your oil for reasons already discussed.

1096 **References**

- 1097
- 1098 1 "Cam and Lifter Wear as Affected by Engine Oil ZDP Concentration and Type"
1099 Loren G. Pless, John J. Rodgers, Fuel & Lubricants Dept., Research Labs, General Motors
1100 Corp. SAE Report 770087, 1977
- 1101 2 "How Much ZDP is Enough?" R.M. Olree, (GM Powertrain),M.L. McMillan (GM R&D) SAE
1102 Technical Paper Series 2004-01-2986, October 2004
- 1103 3 "Interpretation of Experiments on ADDP Anti-Wear Films Through Pressure Induced Cross-
1104 Linking", N.J. Mosey ^a, T.K. Woo ^{a,b}, M. Karsai ^a, P.R. Norton ^a, G.M. Bancroft ^a, M.H. Müller ^a
1105 ^a Dept. of Chemistry, Univ. of Western Ontario; ^b Dept. of Chemistry, Univ. of Ottawa; ^c Dept.
1106 of Applied Mathematics, Univ. of Western Ontario
- 1107 5 "A Study of Motorcycle Oils", AMSOIL Power Sports Group, AMSOIL Inc., October 2005
1108 "Molecular Spectroscopy – A Precision Lubrication Tool?", Mark Barnes, Noria Corporation,
1109 Dave Wooton, Wooton Consulting, *Practicing Oil Analysis Magazine*, May 2003
- 1110 6 "Tribofilms Generated from ZDDP and DDP on Steel Surfaces: Part 2, Chemistry", Z. Zhang ^a
1111 E.S. Yamaguchi ^b, M. Karsai ^a, G.M. Bancroft ^a, X. Liu ^c, M.E. Fleet ^c, ^a Dept. of Chemistry,
1112 Univ. of Western Ontario; ^b Chevron Oronite Company LLC, Richmond Ca; ^c Dept. of Earth
1113 Sciences, Univ. of Western Ontario
- 1114 7 "Engine Oil Mythology", www.steelsoldiers.com; article attributed to one of the authors of
1115 "How Much ZDDP Is Enough?" without referring to the author by name. See ² above.
- 1116 8 "Flat Tappet Camshaft Break-In Procedure", Installation Instructions 548E, Revised 2/2008,
1117 Crane Cams, Inc.
- 1118 9 "Flat Tappet and Camshaft Lobe Lubrication", Technical Service Bulletin MO-2007-08-08,
1119 AMSOIL Inc, 8/3/2007
- 1120 10 "Camshaft Break-In Using Zinc for Flat tappet Camshafts", Technical Bulletin TB 2333R,
1121 AERA Technical Services Department, Engine Rebuilders Association, Nov. 2007
- 1122 11 "The Lost Lobe Chronicles", Dave Emanuel, *Engine Professional*, Jan-Mar 2008
- 1123 12 "Flat Tappet Camshafts & Oils", Dave Hagen, Mike Caruso, Steve Fox, *Engine Professional*,
1124 Jan-Mar 2008
- 1125 13 "Oil and Additives: The Difference between SH & SH Oils & Oil Testing",
1126 http://www.procarcare.com/icarumba/resourcecenter/encyclopedia/icar_resourcecenter_encyclopedia_fuels2.asp
1127
- 1128 14 "A Preliminary Study of Branded Lubrication Filters: Filtration Efficiency Comparisons",
1129 <http://www.systems-engineering-associates.com/>, February 2008
- 1130 15 "How Much Additive Do You Need?" <http://www.systems-engineering-associates.com/>,
1131 September 2007
- 1132 16 "Flat Tappet Camshafts", Tech Bulletin 11-28-06, Research & Development Department,
1133 Competition Cams, Inc. November 2006
- 1134 17 "Review of the Lubrication of Metallic Surfaces by Zinc Dialkyl-dithiophosphates". Mark A.
1135 Nichols ^a, Than Do ^b, Peter R. Norton ^a, Masoud Karsai ^a, Michael Bancroft ^a, ^a Dept. of
1136 Chemistry, Univ. of Western Ontario; ^b Atomic Energy of Canada, Ltd., Chalk River, Ontario,
1137 Tribology International, Volume 38, Issue 1, January 2005, pages 15-39
- 1138 18 Material Safety Data Sheet, Redline Motor Oils, Redline Synthetic Oil Corporation, Revised
1139 August 11, 2005.

- 1140 19 Material Safety Data Sheet, Castrol Syntec 20W-50, BP Lubricants USA, Date of Issue
1141 11/19/2007
- 1142 20 "Applications of Surface Analysis and Surface Theory in Tribology", John Ferrante, NASA
1143 Lewis Research Center, Cleveland OH, November 1988
- 1144 21 "Has Zinc Been Removed from Motor Oils?", Mobil 1 Product Guide, Mobil Oil Corporation,
1145 http://www.mobiloil.com/USA-English/MotorOil/Car_Care/AskMobil/Zinc_Motor_Oils.aspx
1146 22 "The Rules of Successful Camshaft Installation", Piper Cams,
1147 <http://www.v8engines.com/Acrobat/cam-installation.PDF>
- 1148 23 "Oil is Killing Our Cars!!!!", Keith Ansell, Foreign Parts Positively, Inc.
1149 http://www.svmgcc.org/tech_tips/oil_is_killing.htm;
1150 http://www.rlengines.com/tech/Oil_is_Killing_our_Cars.pdf
- 1151 24 "Lubrication", <http://webphysics.davidson.edu/faculty/dmb/PY430/Friction/lubrication.htm>,
1152 Wolfgang Christian, Gregor Novak, Department of Physics, Davidson College, Davidson NC.
- 1153 25 "Additives for Desired Chemical Properties", http://www.pantherlubes.com/tl_17.html, Panther
1154 Lubricants, Ltd.
- 1155 26 "Design, Operation, Maintenance and Warranty for TCM Camshafts and Hydraulic Lifters",
1156 Service Information Directive, SID 05-1, Teledyne Continental Motors, Inc. 1/04/2005.
- 1157 27 "The Evolution of Base Oil Technology Industry Focus", David C. Kramer, Brent. K. Lok, Russ
1158 R. Kurg, J.M. Rosenbaum, Chevron Texaco Global Lubricants, *Machinery Lubrication*
1159 *Magazine*, March 2003
- 1160 28 "Reasons and Causes for Cam Failure", Crane Cams, Inc.
1161 <http://www.cranecams.com/?show=reasonsForFailure>
- 1162 29 "Engine Oil Licensing and Certification System", API 1509, Sixteenth Edition, April 2007,
1163 American Petroleum Institute
- 1164 30 "Preventing Cam and Lifter Wear", Crane Cams, Inc.
1165 <http://www.cranecams.com/?show=article&id=2>
- 1166 31 "Flat Tappet Camshaft Failures (Hydraulic & Solid/Mechanical)", Tech Bulletin Part #255,
1167 Research & Development Department, Competition Cams, Inc. Revised 3/11/08
- 1168 32 "Tribofilms: Aspects of Formation, Stability, and Removal", Ardian Morina, Anne Neville,
1169 Institute of Engineering Thermofluids, Surfaces and Interfaces School of Mechanical
1170 Engineering, University of Leeds, Leeds (UK)
- 1171 33 "Corrosion, Wear and Corrosive Wear; the story of lubrication systems in large technology
1172 object storage and use", David Hallam, David Thurrowgood and Col. Ogilvie, National
1173 Museum of Australia
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189



Moss Motors, Ltd.

440 Rutherford Street, Goleta, California 93117
In the US & Canada Toll Free (800) 667-7872 FAX (805) 692-2510 (805) 681-3400

Moss Europe Ltd.

Hampton Farm Industrial Estate, Hampton Road West, Hanworth Middlesex, TW13 6DB
In the UK: 020-8867-2020 FAX:- 020-8867-2030