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ZPlus™ Tech Brief #12

ZDDP and Engine Break-in

History

"…by 1958, as reported by Larson; The compound type zinc dialkyl dithiophosphate has gained wide acceptance in the United States for high quality motor oils. Two out of three of the major United States automobile manufacturers either require zinc dithiophosphate at about 1% of an 80% concentrate in the initial fill in new automobiles or require qualification tests which only zinc dithiophosphate can pass."[1]

This quote speaks volumes about OEM (Original Equipment Manufacturer) car companies conclusions 50 years ago regarding the use of ZDDP in the initial fill oil, but what is the situation today? We have analyzed the break-in oil supplied with numerous major manufacturers, and found contrary to the OEMs' claims that ZDDP is now much less necessary than it was historically, many break-in oils installed at the factory are loaded with ZDDP. Specifically the higher-performance engines of today seem to be filled at the factory with a high level of ZDDP. This indicates that in the viewpoint of OEMs, the inclusion of ZDDP is still mandatory for high-performance engine break-in.

ZDDP was originally blended into engine oils as a potent anti-corrosive and anti-oxidative additive. Early fuels were high in sulfur, and the resulting blow-by from combustion contributed a large amount of sulfuric acid and moisture to the oil. ZDDP eliminated much of the corrosion problem which had plagued the automotive industry up to that point. An additional problem with early oils was the rapid oxidation of the highly unsaturated base oils, but fortunately ZDDP displays a strong antioxidant action. Improved oil refining and a move to base oils consisting of more highly hydrogen saturated molecules would eventually reduce but not eliminate the base oil oxidation problem. By the 1940s and the advent of higher-power engines, it was observed that oils with ZDDP would also greatly prolong the life of high-wear components, such as the cam and lifter.

These highly beneficial characteristics of ZDDP have resulted in the incorporation of ZDDP in virtually all automotive engine oils for the last 70 years. The fact that the one economical additive can perform triple duty has ensured its continued use.

The recent catalytic converter life mandate by the EPA has led to declining ZDDP levels in most API rated oils. In order to replace the functionality of the ZDDP, additions are now made to the additive package to control corrosion and serve as antioxidants. In order to deal with the lower antiwear agent concentration, a few approaches have been taken to ensure new car compatibility: substitution of roller cam followers for flat cam followers, and the addition of different anti-wear agents, such as boron to augment the lowered ZDDP level in the oil. Unfortunately, since part of the remedy for the reduced ZDDP levels was the redesign of new engines, the newer oils no longer represent a complete lubrication package for older high-performance and classic engines, especially during break-in.

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[1] Spikes, H., Tribology Section, Department of Mechanical Engineering, Imperial College, London SW7 2AZ, UK, The history and mechanisms of ZDDP, Tribology Letters, Vol. 17, No. 3, October 2004

What is Break-In?

Modern engine parts are manufactured to extremely tight tolerances, so you may think they would not require break-in in order to fit correctly. Certainly modern rings and bearings for example, far outperform those of 50 years ago in precision of initial fit. In general, the very nature of break-in (which could more accurately be called "*wear-in*") is that pairs of parts which have bearing surfaces need to wear from their as-assembled shapes into mating shapes which spread the contact pressure over a larger area. If you consider that the oil film which separates and lubricates the parts once they are broken in can be less than a micron (.0000394″) thick, the need for break-in is obvious. There are no engine parts which are manufactured to such tight tolerances, so each bearing system is designed to wear and self-align slightly to achieve this high degree of mating precision. Once this close mate is achieved, the two bearing surfaces are held separated by the oil, and the break-in process is essentially complete. In this way, break-in can be a self-limiting process, if the two surfaces are protected from galling or damage during the wear-in process. For many engine bearing systems, ZDDP serves this role. Different engine parts achieve break-in in different ways, so let's examine some of them.

Crankshaft, Crankpin, and Camshaft Bearings

These bearing systems utilize thin-wall bearing inserts, which by themselves have very little structural rigidity and rely on precise seating in precision machined bores. These bores are usually positioned in substantial areas of the engine block which give the bearing system its needed rigidity. This ensures the bearing is both round and concentric with the journals under load. The precision necessary in a hydrodynamic bearing is not achievable with conventional machining techniques. (*If you are interested in a more thorough explanation of hydrodynamic lubrication, read ZPlus™ Tech Brief #11, IC Engine Lubrication.*) In order to get an idea of the magnitude of precision which would be needed, let's say that currently available close tolerance machining will result in journal and bearing bore surfaces that are coaxial, and within 0.0005″ of all design specifications. The hydrodynamic oil film which separates the bearing and journal in an IC (Internal Combustion) engine crankshaft bearing can be as thin as 0.000059″! To ensure proper clearances of this magnitude would require a degree of accuracy in machining over ten times better than the 0.0005″ tolerance.

Fortunately, bearing manufacturers have technology to deal with this need for extreme precision. During the first few moments of operation with new bearings, the crankshaft journal will effectively wipe and flatten the bearing babbitt coating, deforming tight spots flat, and effectively reforming the surface more concentric with the journal. Since these inserts are usually coated with only 0.0005″ to 0.002″ of babbitt, the crankshaft bearing can tolerate very little initial misalignment without wiping the babbitt coating completely off of the tight spot on the bearing insert. This is the reason why there is a requirement for extreme precision in machining and cleanliness during block and crankshaft preparation. Due to the need for an extremely tight mating between the back of these inserts and the bores in which they are seated, it is always recommended the bearing inserts and the bores they seat in be totally dry and free from even the smallest speck of debris.

We have read recently some are recommending oiling the back of the bearings to eliminate something called "*micro-welding*," which is a small spot where metals have adhered due to heat and pressure. Oiling bearing backs is not recommended for a number of reasons. In order to verify absolute cleanliness the back of the insert and bearing bore must be dry. The presence of an oil film will attract debris during assembly, and the oil film will hide particles which can cause a tight spot on assembly. When a bearing is disassembled after use, if there is a spot that looks like a micro-weld has occurred, it is a sure sign that there was debris present on assembly.

We have also heard some are recommending sanding or steel-wooling the bearing surface of inserts. The surface characteristics of a bearing insert are carefully controlled by the manufacturer to optimize break-in characteristics, and removing the babbitt increases the chances of wear-through of the coating.

The optimum lubricant for crankshaft and crankpin bearings would be a heavy-weight oil or fully soluble grease which could maintain a hydrodynamic film until the oiling system began delivering engine oil to the bearing. It is important NOT to use a Molybdenum Disulfide, Graphite, or Calcium Carbonate loaded Calcium Sulfonate base grease in the bearings. The solid particles in these greases can be larger than the hydrodynamic oil film is thick, and they can cause scuffing of bearing inserts and journals during the initial break-in phase.

Piston Rings and Cylinder Walls

There is an initial wear-in period for piston rings and cylinder walls where the asperities of each will penetrate the oil film. With time these contact points wear down, become broader, and spread the contact pressure over a larger area. This process will continue until the contact area is large enough to keep the contact pressure below that which would penetrate the hydrodynamic oil film. Once this has been accomplished, the rings are effectively seated. This does not mean there is no blow-by at this point. It merely means that the contact pressure of the rings is not high enough to penetrate the oil film on the cylinder walls, and further wear is extremely minimal, so break-in is essentially complete. During this process, if there was not an anti-wear agent like ZDDP present, the rubbing metals could form micro-welds and gall. When this occurs, metal is torn out of the contact area, making scars which will not permit smooth ring operation or a proper seal. The presence of ZDDP causes a sacrificial anti-wear film to form on the moving parts, and lessens the chances of damage to them during this initial period.

After break-in and during full power operation, further wear-in of the top and bottom edges of the rings and bores can occur due to high cylinder pressures and resulting ring dishing. Hydrodynamic lubrication requires movement of the two bearing surfaces relative to each other, and the rings stop moving relative to the bore at TDC (Top Dead Center) and BDC (Bottom Dead Center). This means that due to both ring tension and pressure energizing, the oil film between them rapidly squeezes out when they slow and stop, potentially permitting contact. At BDC there is less of a problem, since the cylinder pressure is relatively low, so the rings are not pressurized against the bore nearly as strongly as they are at TDC. Also, on the down-stroke, the oil scraper rings have redistributed an oil film for the compression rings to ride on. At TDC, the compression rings run in advance of the oil film. These factors put together can create wear at the top of the bore. If the rings were correctly sized, yet there is significant blow-by after the initial break-in, the rings or cylinder have an out-of-round condition which is preventing complete annular sealing.

The sliding velocity of the piston is too high to use a highly viscous lubricant like a grease or gel. The extreme viscosity will cause the piston and rings to flutter as cavitation occurs in the grease film. The optimum assembly lubricant for the rings and cylinder walls is a medium weight engine oil. If the engine has to sit for extended periods of time after assembly, the oil will collect at the upper compression ring and be re-distributed when the engine is initially cranked.

Cam Lobes and Lifter Feet

Break-in of the cam and lifter interface has several phases.

Phase #1 - The first phase is in the initial 10 to 30 seconds, during which the only lubrication is the assembly lube. If incorrect lubricant is used, or if this assembly lube is easily displaced from the contact path around the cam lobe, then severe and irreversible damage can quickly be done. Particularly in applications which use non-phosphated cams, incorrect lubrication during the first few seconds can cause galling and eventually result in destruction of the cam lobe and lifter foot. During this first phase with phosphated cam lobes, the phosphate coating acts as a mild abrasive, helping lap the lifter foot and cam lobe into mating surfaces which have contact points broad enough to support EHD (Elasto-HydroDynamic) or boundary lubricating films without puncturing the film. The microscopic pits in the phosphate coating also act as a lubricant reservoir, helping to ensure that some lubricant will be present at the cam and lifter contact until engine oil arrives to replace it.

Phase #2 - The second phase is when the engine oil begins dissolving and diluting the assembly lubricant. In the process it carries away the abrasive debris of the wear-in process for the cam and lifters. By the end of phase two, the two surfaces have completed most of the break-in. From this point on, a combination of EHD oil film lubrication and boundary lubrication utilizing the anti-wear agent ZDDP becomes the major wear determinants. This phase begins in the first 30 seconds of initial running after an engine build, and lasts until the assembly lube is thoroughly dissolved and washed off the cam and lifters. This can be as short as one minute, or as long as one hour, depending on the characteristics of the assembly lubricant and cam surface treatment. In general, the slower the break-in, the more chance there is for the contact patch on the cam and lifter to properly mate without damage.

Phase #3 - The third phase is essentially the rest of the engine life. If the break-in period was successful and the contact patch between the flat lifter and cam broad enough, then the contact patch will be stable for hundreds of thousands of miles with low additional wear. This is thanks to a combination of EHD and boundary film anti-wear lubrication using ZDDP. There are some conditions which can conspire against this, like a radical cam profile with excessively steep entrance ramps, or excessive spring pressure. In these cases, even the best break-in procedure and lubricants will not keep the cam and lifter from rapid wear. Aggressive cam profiles and extreme spring pressures of this type can typically be found in racing motors. In this application, life is not the number one design criterion, so the rapid wear is considered an acceptable compromise.

The optimum lubricant will have as high viscosity as possible without being displaced by contact pressure to the side of the developing contact patch. Due to the rubbing nature of the contact, it is important to have an antiwear agent like ZDDP during both break-in and extended life operation. Ideally the grease would cling to and re-apply itself to the contact area as the cam rotates.

Break-in Methodology

Many texts have been written which offer good break-in methods. Historically, the suggested break-in procedure was optimized for flat-tappet engines, due to the overwhelming numbers of that type of engine. Since 1996 or so, the numbers of flat-tappet engines being offered by major automotive manufacturers has plummeted in response to declining ZDDP levels in oil. As a result, currently recommended engine break-in procedures are split between flat-tappet and roller-tappet engine types, with the majority of flat-tappet recommendations coming from the aftermarket. If you are breaking in a flat-tappet engine, you MUST use the flat-tappet break-in procedure or risk serious damage to the cam and lifters.
A comprehensive and correct break-in process for a flat-tappet engine consists of two essential parts: engine assembly and initial operation.

IMPORTANT! If you are rebuilding an engine with roller tappets, please follow your manufacturer's recommendations. Also, the assembly and break-in steps which follow are recommendations, and are to be used in conjunction with all manufacturer's recommendations. If in doubt, contact your engine or engine part manufacturer for specific instructions!

A successful engine build requires attention to manufacturer's recommendations, cleanliness of work area, and the proper pre-lubricant for each internal assembly.

The following suggestions concentrate on the cam and lifter procedures. Correct procedures for assembling the other moving assemblies can be obtained from the vendors of those parts. Keep in mind that cam manufacturers offer flat-tappet cams of an extremely wide variety. The life expectancy of these cams decreases as you move to more aggressive ramps and operate at higher valve spring pressures and engine speeds. There are flat-lifter racing cams, which have a very short life expectancy, even if all the best procedures and lubricants are used during assembly and break-in.

Engine Assembly

Clean all new parts. This may seem redundant, as new parts usually come pre-cleaned, oiled, and individually packed, but there is a rub: The substance they are coated with is generally not designed as a break-in lube. It is designed to keep corrosion from occurring during shipment and storage, and since it is oily or tacky, it picks up debris from the package and elsewhere. This means you should thoroughly clean all parts with mineral spirits and dry to ensure the surface is clean. You should then lubricate all moving parts with the appropriate assembly lube.

Lifter Bore and Cam Lobe Alignment

A stable contact pattern between the cam lobe and lifter is dependent on the exact cam geometry, the lifter foot radius, and the individual lifter bore to cam lobe alignment in the block. All factors affecting the alignment must be set before break-in, including axial position of the cam. This means the cam thrust button or other axial travel limiter must be set in its correct position before beginning break-in. The exact alignment between the cam lobe and lifter foot is different between each of the lifter bores in a single engine, and even between the same lifter bore position in otherwise identical blocks. The contact between the cam lobe and lifter pair is unique to each lifter bore and cam lobe pair. Use ONLY new lifters with a new cam. If re-using a cam, all lifters MUST be put back in the bores they came from. If any cam-bore or lifter-bore rework or sleeving has been done to a block, a new cam and set of lifters must be installed. The cam and lifter pre-break-in service offered by some vendors does not position the lifter during its break-in procedure in the exact position it will be in the target engine, so we do not recommend using them. Due to machining tolerances and variations from block to block, a used cam and lifter set CANNOT be swapped from one block to another without a strong chance of failure.

Lubrication Specific to Lifter Feet and Cam Lobes

The break-in process between a cam lobe and flat lifter is best facilitated by a specialized lubricant specifically designed for the purpose. Unlike other moving parts in a new engine, the cam lobe and lifter contact is designed to be operated in a EHD or boundary lubrication mode. Before the contact patch has a chance to be gradually and smoothly polished, the potential for severe damage is high. Many cam lobes are chemically phosphated after the final grinding, which results in a matte textured surface designed to facilitate lapping of the lifter foot to the cam contour. The lifter foot itself has a swirl-polished finish, the asperities of which will be removed during break-in. By definition, this means metal will be removed from both cam and lifter. This metal is in the form of extremely fine particles, which can accelerate surface damage if there is not a lubricating film thick enough to keep them from scoring or galling the surface.

This film must remain intact until connecting rod oil splash begins to wash the lapping debris into the sump, and replace the cam assembly lubricant as the main lobe-to-lifter lubricant.

General-purpose assembly lubricants do not have the optimum characteristics for the cam and lifter interface break-in. The optimum lubricant would have a highly polar chemical makeup including anti-wear agents, not extreme-pressure agents, as well as high viscosity and body to keep the lubricant on the cam as long as possible before oil wash-off. Although the lubricant is expected to stay on the contact patch between the cam and lifter, it must also eventually totally dissolve in hot oil. It is this need for these very specific characteristics that led us to design ZPaste™.

We decided to test break-in lubricants to see which were best suited to the specific break-in needs of the cam lobe and lifter interface. Although there are many cam break-in lubricants being sold, their performance can be categorized by either mineral or synthetic base oil with a lithium thickener, or a calcium base, either with additives like molybdenum or ZDDP. We have tested many general-purpose and cam specific break-in lubricants. For this paper, we chose three popular products which are representative of the choices available.

Cam Break-In Lubricant Testing

For studying the first phase of cam break-in, a Chevrolet 350 small block engine, shown in figure 1, was modified in order to test different cam assembly lubricants and document the initial phosphate wear-in. This engine was chosen for its wide applicability and readily available low-cost OEM parts.

Since this test is just to observe the first phase of the cam and lifter wear-in, there is no need for any thermal control; phase one occurs before the engine has come to operating temperature. This meant we did not have to operate the engine in an internal combustion mode, or provide for any heated coolant circulation. We mounted a commercial-duty 3-phase motor on the bell housing and coupled it to the lower timing sprocket. The sprocket is mounted on a driveshaft running in oilite bushings clamped in the front and rear main bearing bores. We then closed off the rest of the main bearing oil holes, as shown in figure 2. In order to study just the effect of the assembly lubricant without any engine oil during phase one, we needed to minimize the oil from being spread onto the cam and lifter feet. In order to keep oil from the lifter bore from dripping onto the lifter feet, we inverted the engine.

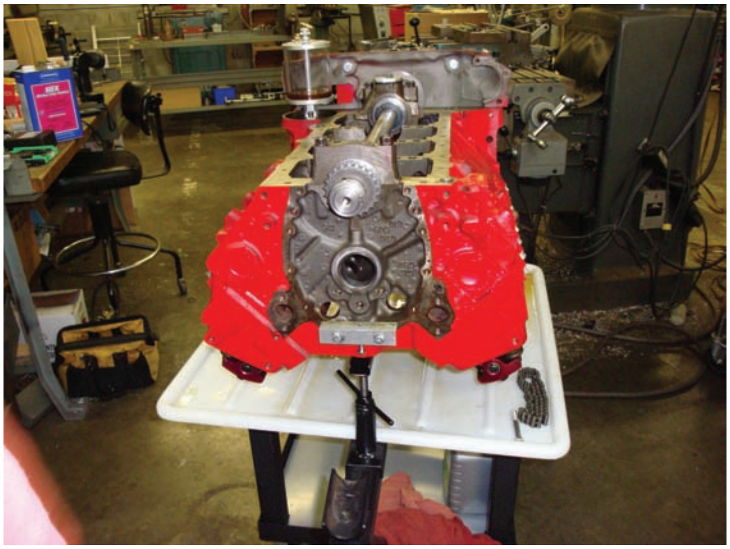

figure 1 - Modified, Inverted Chevrolet 350

figure 2 - Drive Shaft and Plugged Main Bearing Oil Holes

figure 3 - Clean and Dry Camshaft Installed into Bore

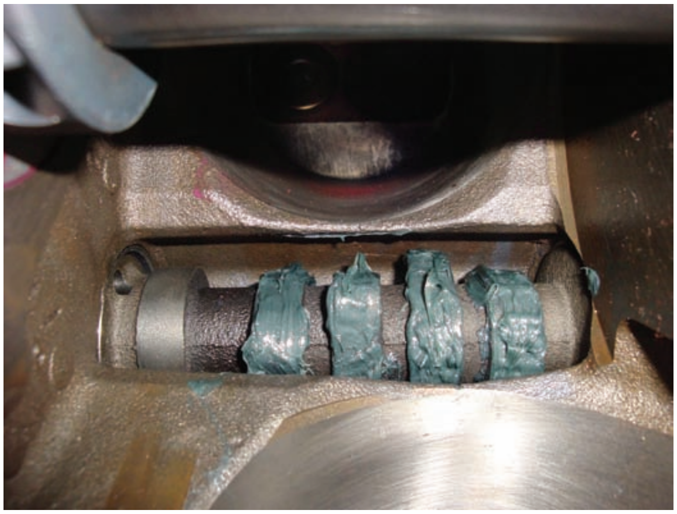

figure 4 - Lubricant #1 on Cam Lobes #1 & #2

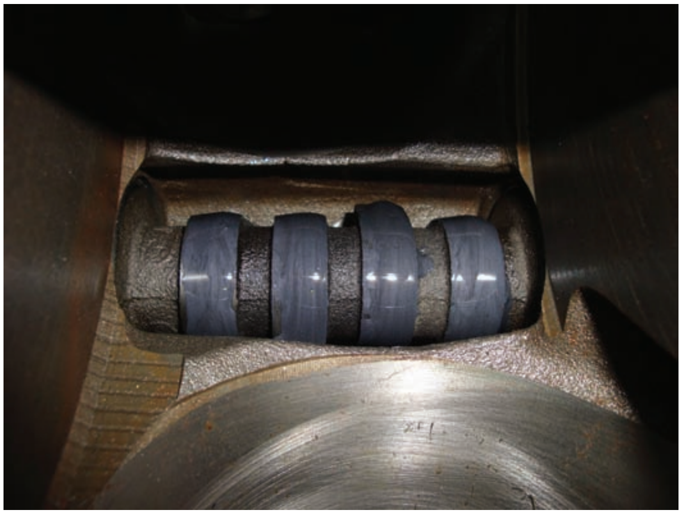

figure 5 - Lubricant #2 on Cam Lobes #7 & #8

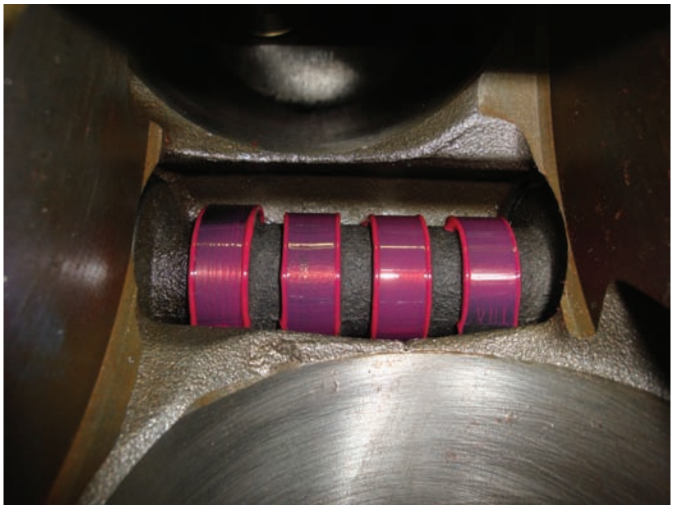

figure 6 - Lubricant #3 on Cam Lobes #9 & #10

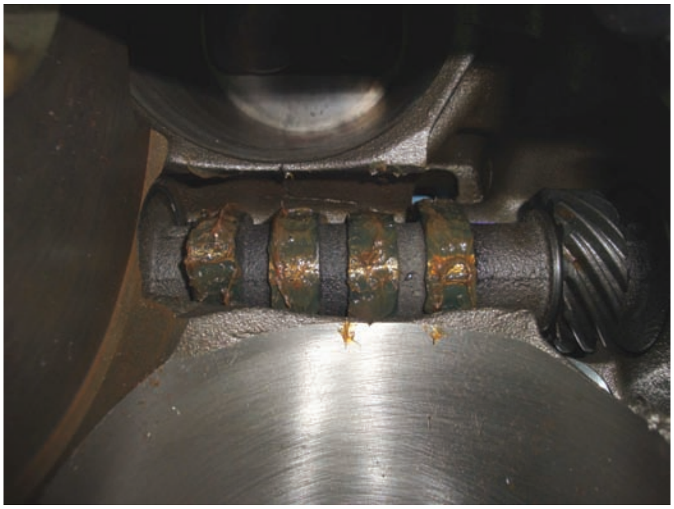

figure 7 - Lubricant #4 on Cam Lobes #15 & #16

The oiling system was extensively modified to allow for full lifter and cam bearing lubrication in an inverted configuration, but all other oil paths were blocked.

Since we wanted to get as close an approximation to a stock high-performance engine wear-in scenario, we chose a solid-lifter GM camshaft and GM/Delphi mechanical (solid) lifters.
In order to eliminate any potential issues with lubrication of the rockers, we mounted needle-bearing 1.5:1 ratio rockers. We chose a valve spring set which delivered 325 pounds of pressure at the specified lift of 0.283″. This spring pressure multiplied by the rocker ratio gave 488 pounds of lifter foot force at full lift.

There are high-performance springs available which have higher lifter foot pressures, but we were attempting to emulate cam wear-in for a stock high-performance engine, not a racing engine. In order to give each assembly lube a chance to perform as the manufacturer intended, we completely cleaned the camshaft and lifters with MEK (Methyl Ethel Ketone) and a soft bristle brush to remove any traces of oil or other lubricant. We then installed each lifter with no lubricant or oil. As shown in figure 3, we installed the camshaft completely un-oiled as well.

Once the camshaft was within ½″ of its final position in the bore, we placed several drops of 30 weight oil on each cam bearing journal, then spun the camshaft into place. Although the cam bearings are fully lubricated by the modified oiling system in this engine, we wanted the journal and insert surfaces to have an initial oil film to prevent any galling until the hydrodynamic lubrication was established.

We decided that in order to keep the size of the electric drive motor to a minimum, we would only use half of the 16 cam lobes. The pictures in figures 4 through 7 show the different lubricants we tested after coating the cam lobes, but before we cleaned off two lobes. In order to prevent any lubricant splash from causing cross-contamination between different

					Temperatures in °F						
Lifter Position	Lubricant	New Consistency	Color	Hot Oil Solubility in Minutes & Residue	30 Sec.	1 Min.	2 Min.	5 Min.	10 Min.	30 Min.	Cam/Lifter Appearance
#1 (1E)	ZPaste™	Tacky, Thick	Grey	10 - Slight MoS_2 dust	74	89	114	150	175	204	10 - Phosphate still intact
#2 (2E)	ZPaste™	Tacky, Thick	Grey	10 - Slight MoS_2 dust	74	91	116	154	175	208	10 - Phosphate still intact
#7 (3E)	US Lubricant	Runny	Black	2 - Left black chunks	76	88	110	140	205	320	1 - Sparks and smoke
#8 (4E)	US Lubricant	Runny	Black	2 - Left black chunks	77	87	108	138	197	285	2 - Scored and galled
#9 (5E)	Edelbrock	Runny Gel	Red	2 - No residue	76	90	112	135	170	250	7 - Smooth but scuffed
#10 (6E)	Edelbrock	Runny Gel	Red	2 - No residue	76	90	113	138	174	255	7 - Smooth but scuffed
#15 (7E)	Joe Gibbs	NLGI 2 Grease	Amber	5 - Some amber pieces	74	90	112	136	170	230	8 - Smooth but scuffed
#16 (8E)	Joe Gibbs	NLGI 2 Grease	Amber	5 - Some amber pieces	74	90	114	140	168	240	8 - Smooth but scuffed

figure 8 - Cam Lubricant Test Results

lubes, we only used one lubricant per two cam lobes associated with a single "V" cylinder bank.

Once the cam chain and drive sprockets were installed, we coated each of the cam lobes with the different lubricants, as shown in figures 4-7. We then adjusted valve lash for the 8 cam exhaust lobes under test at the base circle to the recommended specification. Finally, the lifter oiling system was enabled and full oiling in each lifter gallery verified. We then took initial pictures and temperature readings using a non-contact Fluke thermometer.

The 3-phase motor used maintains a steady 1730 rpm, which is close to the initial engine break-in speed recommended by cam manufacturers. The variable speed recommended during break-in is largely designed to properly break-in the rings. The constant motor speed is not a problem for the purposes of this test.

In order to push the lubricants further to differentiate between their performance, we decided to run an extended test. The test routine consisted of running the engine for 30 seconds, stopping and taking a temperature measurement of one of each of the different lubricant coated lobes, then restarting. We performed this procedure at the following intervals: 1, 5, 10 and 30 minutes. Keep in mind, this was a harsher test than cam assembly lubricants will have to endure in normal service. It does, however, magnify the differences in performance between them in the first break-in interval before splash lubrication. The initial ambient temperature was 72 degrees. The results of this test are summarized in the table of figure 8. We did not notice any severe wear occurring with any of the lubes until after the 5 minute point. This is longer than it would normally take for oil splash to reach the cam lobes.

As would be anticipated, the two lubricants with the highest viscosity fared the best overall. One of the basic principles of lubrication is; all other conditions being equal, the higher the viscosity of the oil or grease, the greater the film thickness. The real difference between the assembly lubricants was revealed during inspection at the end of the test.

Cam and Lifter Lubricant Test Summary

Referring to the pictures in figures 9 through 14, when you compare the original cam lobe appearance between the new lobe in figure 9 and the ones used in the test in figures 11 through 14, you will see the amount of wear and scuffing varied widely between the products.

In figure 9, a new, unused cam lobe is pictured. Notice the phosphated coating is uniform on the entrance ramp and nose of the cam lobe.

Figure 10 is a 50x view of the phosphated coating, showing the microscopic pits which help retain lubricant during initial start-up.

In figure 11, Cam Position #1 - The ZPaste™ allowed for very gradual break-in. On the ZPaste™ cam lobes, the phosphate coating had been burnished, but not worn completely through anywhere on the contact patch. The metal high spots between the phosphate patches looked smooth to the extent of the 50x magnification. The associated lifters had very faint circular halos showing where the contact area and rotation had rubbed them. There was still a grease film evident on the entire cam lobe. There was no scuffing anywhere, and if you note the fine lines running down the ramp of the lobe, they are remnants of the initial cam profile grinding before phosphating. This means the wear at this point was less than the average surface finish left by the grinding process.

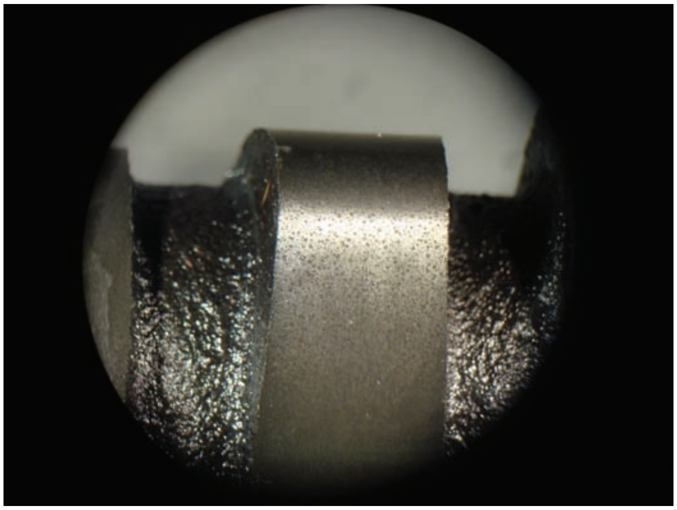

figure 9 - New Unused Cam Lobe

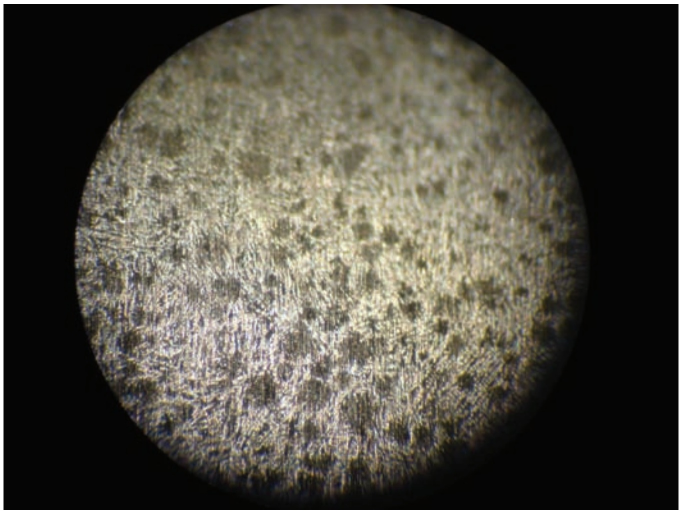

figure 10 - 50x Phosphate Magnification

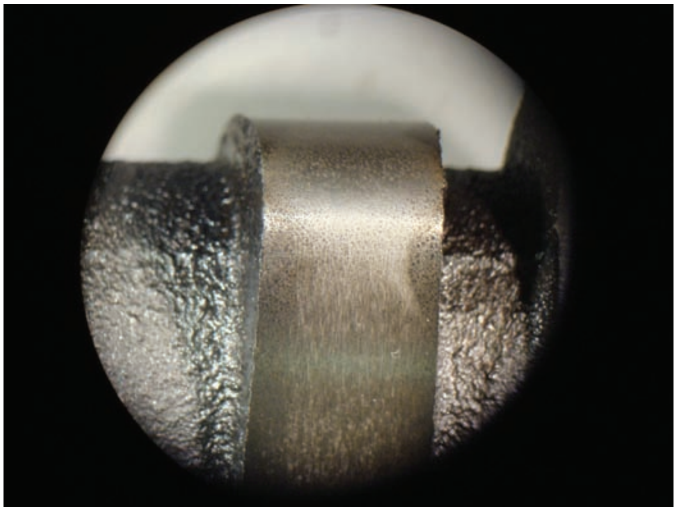

figure 11 - Cam Lobe #1 After Test

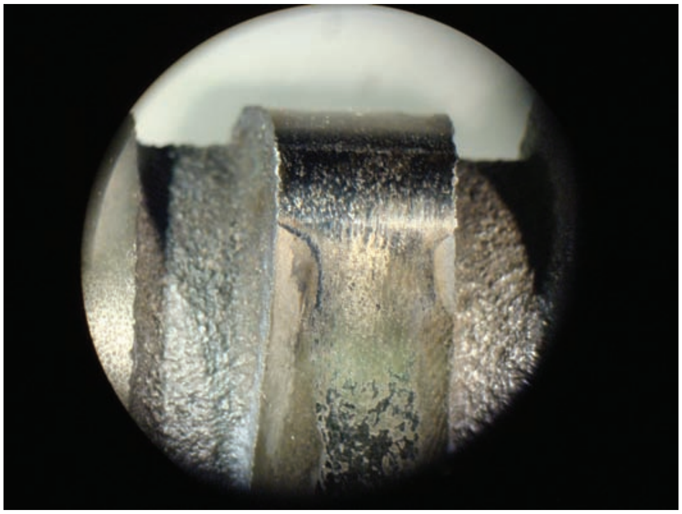

figure 12 - Cam Lobe #7 After Test

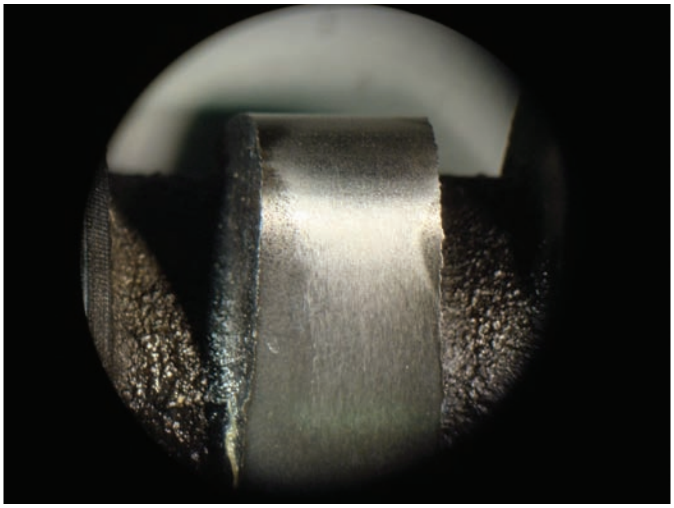

figure 13 - Cam Lobe #9 After Test

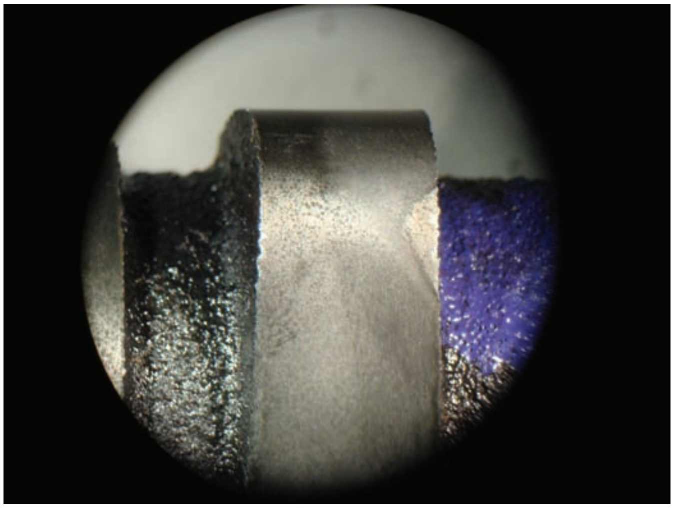

figure 14 - Cam Lobe #16 After Test

In figure 12, Cam Position #7 - The U.S. Lubricants lube had entirely disappeared around the 20-minute point and the cam lobe was hot and wearing rapidly. The associated lifters had circular halos showing where the contact area and rotation had rubbed them. Lobe and lifter #7 were discolored and throwing sparks and smoke at the end of the test. The surface of the cam shows the extreme wear and scarring.

In figure 13, Cam Position #9 - The Edelbrock lube allowed for significant, but smooth wear to the cam lobes and lifter feet, with scuffing evident at the end of the test. The grease was not in evidence near the nose of the cam, but was still in evidence at the base circle. The associated lifters had very slight circular halos showing where the contact area and rotation had rubbed them. The surface near the nose of the cam had a significantly large contact patch established, but very little wear or scuffing.

In figure 14, Cam Position #16 - The Joe Gibbs lube was significantly better at long-term protection, and its cam lobes looked better than #7 or #9, but scuffing was still evident at the end of the test. The associated lifters had very slight circular halos showing where the contact area and rotation had rubbed them. The contact patch near the nose of the cam lobe did not have any visible grease coating. The wear is concentrated in a smaller area than that of the Edelbrock lobe, indicating better performance, but there is still slight scuffing occurring along the primary contact path.

With all of the lubes, other than the ZPaste™, there was complete removal of the phosphate coating near the nose of the cam lobe, indicating fairly rapid wear. Since all of the lubes seemed to protect for the first 5 minutes or so, what is the difference? One of the biggest differences and a major concern to an engine builder is the consistency of the lubricant. After an engine is built, it may be days or even months until it is first started. In this case, the thinner lubricants will run off of the cam, especially in summer storage. Some of the thicker lubricants, when let sit for expended periods, will slump or separate. When this happens the base oil will run off, leaving the thickener, which is not as good a lubricant. ZPaste™ has a proprietary formulation which will not separate or slump in any storage environment, ensuring that proper lubrication is present even after a year or more in storage.

The ZPaste™ kept a film of lubricant on the cam lobe longer in our testing, and encouraged the growth of a ZDDP anti-wear film. There are a few ways to tell when ZDDP has been making an anti-wear film: one is high-tech, and involves ablative de-sputtering and X-ray spectroscopy of the lifter foot to find the presence of the phosphate glass. Another easier method is to monitor the coefficient of friction during operation. We noticed the two cam lobes with the ZPaste™ had temperatures which ran 10°-15° higher after the first few minutes until the 5-minute point, when the grease film of the other lubricants was displaced. This is due to the ZDDP film, which while reducing wear to the base metals, is not as low a friction film as grease or oil. Of course this friction also helps to ensure proper lifter rotation. After the 5-minute point, all the lubricants other than the ZPaste™ showed greater friction and resulting temperature rise. This indicates that the unique film properties of ZPaste™ allowed it to establish an effective film which displayed stable anti-wear characteristics.

You can be sure ZPaste™ will protect the lobe in ANY normal break-in scenario until the engine break-in oil begins to gradually wash it off the cam lobes. It is important to note in all cases, regardless of what lubricant you use when assembling your flat-tappet cam and lifters, adequate ZDDP must be present in the break-in oil to ensure proper break-in, as well in each oil change thereafter. ZPaste™ helps here as well, when applied at approximately 1 gram per lobe and fully dissolved in the oil, it will contribute a useful 65 ppm of phosphorus in the form of ZDDP to 5 quarts of oil.

Reducing Lifter Foot Pressure for Break-in

Most high-performance valve trains incorporate multiple valve springs with a combined high spring rate in order to achieve stable high-rpm operation. Often two actual springs will be used as reaction elements to keep the valve closed, and a third element called a "*damper*" placed inside of these. The two springs will have different characteristics in order to diffuse any resonance which could result in unstable valve return pressure. The damper is an additional low-tension element designed to absorb some of the vibrational energy which is imparted to the springs by rapid valve operation.

Prior to break-in of a high-performance engine, it is recommended with most break-in lubricants to remove the inner spring of a dual-spring setup to ease lifter foot pressure. Alternately, some break-in recommendations suggest using a lower-ratio rocker arm. In either scenario, the lower pressure on the lifter foot allows for a more gradual lapping of the contact surface, with less chance of the metal particles generated during this operation causing damage to the mating surfaces. The single spring approach lowers the lifter foot pressure at the cost of valve-controlling spring pressure, which is not a problem at the low rpms of break-in. Use of low-ratio rocker arms during break-in will maintain spring pressure but sacrifice lift, which is also not a problem during break-in. Combining the two can reap additional benefits not achievable with either individually.

For our analysis we are using a cam/spring set supplied by Isky Cams which uses the p/n 201035 camshaft with 1.5:1 rockers in conjunction with a 6005 Dual Spring with Damper setup, which has a 275 pounds per inch spring rate. We are using the specifications of the 905-D outer spring of the dual spring set for the calculations where the inner spring has been removed. Figure 15 summarizes the options available in our example to reduce lifter loading.

Method	Spring Pressure at Rated Lift (pounds)	Spring Pressure with Valve Seated (pounds)	Lifter Foot Pressure (pounds)	Difficulty (1-easy) (10-hard)	Cost (10-$$$) (1-$)	Percentage Drop in Lifter Foot Pressure	Desirability (1-least) (10-most)
Dual-Spring Setup 1.5:1 Rocker Arms	279	135	418	1	1	0	1
Outer Spring Only 1.5:1 Rocker Arms	200	95	300	8	1	28.2	5
Dual Spring Setup 1.2:1 Rocker Arms	251	135	301	5	8	28	7
Outer Spring Only 1.2:1 Rocker Arms	179	95	215	10	10	49	10

figure 15 - Methods of Reducing Lifter-Foot Pressure for Break-In

It is important when evaluating the spring pressure at rated lift data in figure 15, to remember this spring setup will only be asked to control the valve operation between 2000 to 3000 rpm. Even the lowest pressure option in the chart is sufficient to control valve float at 3000 rpm with no load on the engine. This lowest pressure option, while it is the most expensive and difficult to perform, gives a large 49% drop in lifter foot pressure which will help ensure the most gradual and gentle initial cam lobe to lifter foot contact lapping. Remember, the point of flat-tappet break-in is mating the cam and lifter foot to spread out the contact pressure to an area wider than the initial point contact. It is during this initial phase that any galling or severe scuffing could spell rapid deterioration for the two. We believe that if the highest quality cam assembly lubricants are used, any of these lifter-foot pressure reduction methods will achieve good results during the break-in process.

Adjusting Valves

In engines with mechanical lifters, the valve lash determines the gap between the foot of the lifter and the base circle of the cam lobe. If the lash is tightened, the point of initial contact between the lifter foot and the cam lobe moves down the leading ramp towards the base circle. In order to assure good break-in and reduce the potential of galling of the cam or lifter foot during break-in, it is important to make sure the valve lash is set to final running specification during break-in. If you are installing a hydraulic flat lifter, follow the manufacturer's recommended lifter piston pre-load. If you are installing a flat solid lifter, adjust valve lash to recommended specifications.

The Correct Oil for Break-in

Our recommendation is based on an oil change immediately after the initial break-in period of 45 minutes or so. For initial start-up and break-in, fill the oil sump with conventional non-synthetic oil and ZDDP additive. Period. Our testing of many factory fill oils shows the major automotive manufacturers specify an initial break-in oil fill for high-performance engines with ZDDP levels which can result in a phosphorus level of over 2000-3000 ppm. The break-in oil they specify is meant to remain in the engine for up to 4000 miles, so it is also heavily fortified with detergent. Our recommendation is to use a conventional oil, and then add the equivalent of 1200-1400 ppm of ZDDP additive.

The break-in oil will only be in the sump for less than an hour, so a high level of detergent is not necessary to maintain cleanliness of the engine or oil. The detergent molecules compete with ZDDP for bonding sites on the fresh metal being exposed by the break-in, so the less detergent during this period the better. Detergent and ZDDP also serve an important role of increasing the polarity of the oil, which increases its attraction to the metal parts being broken in. By keeping the ZDDP level high during break-in, you are increasing the bonding of the oil film to the metal.

We agree with recommendations to avoid synthetic oil for the initial break-in of flat-tappet engines for the following reason:

you need to ensure the lifter will be getting sufficient traction on the cam lobe to induce rotation. Synthetic oils have greater cohesion and, in some cases, less adhesion than do most conventional oils. This can make the oil film on the cam too slippery to induce lifter rotation. In some engines such as the Buick V6, certain lifter positions are known for higher than normal wear due to insufficient lifter rotation. It is helpful in these engines to use ZPaste because the ZDDP content will improve the adhesion of the oil at the cam and lifter interface, and ensure adequate lifter rotation. The extra film strength, high heat, and low temperature pour point characteristics of synthetic oil are also not needed at this time.

There are no additional additives other than ZDDP needed for break-in. Do NOT add an oil “fortifier” which contains long chain polymers. You can identify these by characteristics like high viscosity or webbing between parts. The long chain molecules in these additives trap air bubbles, causing loss of viscosity and lubrication.
Remember, aerated oil has very little film strength compared to a solid film of de-gassed oil, for a very simple reason: The oil is what provides the load-bearing film, not the air, and a bearing filled with aerated oil is only partly filled with oil. It is one of the reasons that even straight weight oil has a de-foaming additive in it. Let it do its job.

Setting Timing

Before attempting to start the engine, make sure the timing is set to allow for quick starting. The longer the engine is turning over without running at speed, the less assembly lubricant will be left in critical areas like the camshaft for the actual start. Consult your manufacturer’s recommendations for the correct specification.

Breaking In Your Engine Using Propane

One of the most beneficial steps an engine builder can take to ensure correct break-in is to perform initial start-up with propane. The major automotive manufacturers have been breaking in engines with propane for many years. Propane’s high octane rating of 110 to 120 gives a good safety margin from detonation for most any engine designed to run on gasoline. The easiest way to do this is to purchase a propane carburetor setup and couple its outlet to the gasoline carburetor air horn, or throttle body inlet in the case of fuel-injected motors. There are propane carburetors available from companies like Impco at reasonable prices. Using propane eliminates one of the biggest dangers to normal break-in: washing down the oiled, newly honed cylinder walls with condensed gasoline. Using propane also eliminates the initial priming needed with carburetor engines, or fuel rail priming needed with fuel-injected engines. Since propane break-in is performed using an external propane carburetor, the mixture has a better chance of being close to the optimum stoichiometric air-to-propane ratio of 15.6:1, and you eliminate the worry about gasoline carburetor jetting or fuel-injection engine management calibration. When specifying a propane carburetor, remember you will not be operating the engine at high power levels, so you will not need a propane carburetor rated at the full power output of the engine. The propane carburetor will automatically adjust its mixture for the no-load, part-throttle, mid-rpm operation of break-in.

Prime Fueling System

If you are not using propane, make sure the fuel system is primed before attempting to crank and start the engine to minimize cranking time. This is relatively trivial with a fuel-injected engine, but many classic vehicles have carburetors with engine-driven fuel pumps. For these engines, it is often possible to take a very small hose or funnel and fill the carburetor bowl through the bowl vent. Take extreme care not to overfill the bowl, usually just an ounce or two will fill the bowl enough to cover the fuel jets, which are at or near the bottom of the bowl. DO NOT pour gasoline directly into the intake in an effort to prime. This fuel will wash the lubricant from the fragile newly-honed and oiled cylinder bores and piston skirts, greatly increasing the chance of scoring and galling in the first few minutes of operation.

Pre-Pressurize Oiling System

There are as many different ways to pre-pressurize the oil system as there are engine builders. In general, as long as the oil pump is being driven WITHOUT turning the engine over, the goal will be achieved. There are a few factors to consider, namely: In some engines with distributor-shaft driven oil pumps, a distributor body MUST be in the engine block during oil priming. This is because the engine oiling passages connect to the distributor shaft bushing assembly, and leaving the distributor body out of the block can bleed off oil pressure.

Run-In

After the oil pressure has been pumped up and the fuel system is primed, immediately start the engine, and bring the engine speed above 1500 rpm. Continually vary the rpm between 2000 and 3000 and watch the temperature gauge. An engine makes a lot of noise at these rpms, even with no load, but don't worry about doing damage. If you correctly assembled the engine with the proper lubricants, this is the best way to optimize the hydrodynamic oil films during this critical period.

After 30 to 45 minutes of mid-range rpm, no-load operation, you can be assured that hot oil splash has replaced your cam lobe assembly lubricant, and your cam is well on its way to being properly broken-in. Your rings will have rubbed against the cylinder walls over 75,000 times back and forth and should have minimal blow-by. The crankshaft and crankpin bearings will have been seated and formed.
The engine can then be used in a normal fashion for its intended purpose, although most people recommend not using the engine at full power for several hundred miles.

This last point is the subject of some debate, but consider the fact that peak cylinder pressures are not achieved until the engine is under load, and it is clear that some additional ring break-in occurs when the car actually hits the road. Of course, some people swear by a run-hard break-in, and they are welcome to do it to their own engines. Our experience, and the suggestion of most automotive engineers who actually research and design the engines, is to be methodical and moderate in your approach to break-in.