BY **GARY LEWIS**, **DEMA ELGIN** AND **RICH OLIVIER**

Valve Train Stability

Why doesn't the valve do what it's supposed to do?

When building performance engines, we often ask a production engine to go well beyond where it was intended to go, both in output and in RPM. Since we did not design the engine, we are limited to selecting improved components and otherwise doing the best we can with what we have.

In regard to the valve train, we do have much more information available to us as a result of the camshaft analysis tools now widely available. This data tells what the valve should do as it travels through the cycle from opening, to wide open and on to closing. Add a rocker arm or follower ratio and superimpose that valve open curve over the cam lobe lift curve and there will be another clean, somewhat taller curve showing the motion of the valve through the same open cycle. In a perfect world, the valve motion would match the data generated curve but in reality, the actual valve motion will be different than predicted (see Fig.1).

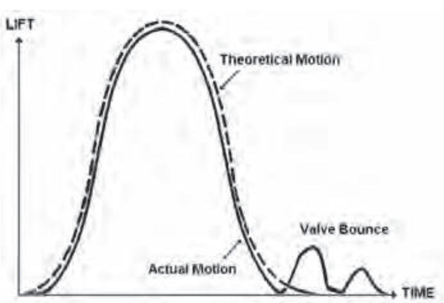
The data does not however tell us what other factors are acting on the valve and what the valve actually does. First of all, in real life, there is something called "compliance" to consider. This term describes movement, flexing and compression of valve train components in action. Some of the factors in compliance are very slight but when combined, they explain why the valve open curve varies from predictions. Let's walk through a list of what else has to be considered.

1. Cam bearing clearance – These bearings require oil clearance to keep the bearing alive but the cam moves within the limit of clearance and this movement takes away from theoretical valve action. Instead of precisely following the intended cam lobe or curve, the valve loses lift with some slight shift in valve timing points.

2. Camshaft defection – In addition to the movement in bearings, the camshaft also bends under the valve spring loads causing another loss in lift with added stress on the camshaft.

3. Hydraulic lifters – There is always at least some internal hydraulic leakage as compressive loads are applied to lifters. This causes another loss in lift and some changes in the designed valve curve.

4. Pushrods – In pushrod engines, these components actually compress especially as we add valve spring pressure to production components. Again, a loss in lift and a change in the curve. More importantly, the pushrods may permanently compress or possibly flex and then rebound. If they rebound, the action will induce another shock through the valve train including valve springs.



1 **Fig.1: Theoretical compared to actual valve open curve.**

5. Rocker arms and rocker followers – Rockers, and their mounts, flex under valve spring loads. Increasing spring pressure and higher rocker ratios can increase the flexing, especially in combination with production components.

6. Valves and valve guides – Poor rocker geometry coupled with excessive valve stem-to-guide clearance can change the actual valve opening and closing points.

For sealing, longevity and performance, as with any engine, the first requirement is to build the complete engine, including the valve train, to specifications.

How does this affect engine building?

Basically, we need to choose each component in the valve train from camshaft bearings on through the valve train to the valve to stabilize the valve train at high engine speeds and to avoid engine failure.

1. Camshaft bearings – To limit the movement off the center of rotation, plain bearings should not wear or deform to maintain the required oil clearance at continuous high engine speeds. Roller bearings with minimum clearances are sometimes retrofitted.

2. Camshafts – If we had the option, we would probably choose camshafts with more and larger bearing journals so that we could have tall cam lobes and a large core diameter. However, we are not designing the engine but instead limited to making the best of what we have. Stiffness can be maintained by avoiding grinding cam lobe base circles too far undersize to maintain the existing core diameter. Also, valve spring pressures should be adequate to control valve action but not so excessive as to exert unnecessary loads on the camshaft.

3. Cam lobe profiles – The valve action generated by the cam lobe should ideally be smooth and not allow shocks to the valve train on opening or closing or launch the valve over the nose. Shocks to the system not only stress individual components but also release energy into valve springs that can cause them to surge or oscillate.

4. Lifters or followers – With flat tappets, lifter bores should be square with the camshaft centerline and offset to one side of the cam lobe to promote rotation. Roller tappets should also align squarely with the camshaft centerline so that the roller does not contact on one edge. Alignments need to be checked and blueprinting may be required to avoid early failure.

5. Pushrods – Pushrods should be stiff but also light. This typically means tubular construction with alloy materials and thick walls.

6. Rocker arms and mounts – Rocker arms should also be stiff and light in weight especially at the valve end. Adding weight at the valve end, along with the weight of valves and spring retainers, adds to required spring pressures and to stresses on all valve train components. Rocker studs or capscrews can be replaced with larger diameter or stiffer pieces. Rockers may also be shaft (fulcrum) mounted for greater stability.

7. Valves – Valves are selected for size, weight and flow characteristics. For stability, lighter valves means that we can control the valve action with less spring pressure.

8. Springs and retainers – There are numerous variations in spring design including multiple springs, different alloys, round or ovate wire, and progressively wound springs or conical springs. Aside from providing the required pressures, springs must remain stable at high engine speeds without the surging or oscillating that causes a loss of valve control. Spring design is absolutely critical and must be carefully matched to the total valve train and RPM range of the engine.

Failures and Solutions

Cam Bearings and Related Problems – Cam bearing and camshaft bearing journals should be in perfect alignment and run within the specified oil clearance. For assembly, first check bearing bores and cam journals for specified diameters and for wear. If these components are right, oil clearance will be correct and the next potential problem is alignment. Although bearing bores can be misaligned, by far the most common problem is a bent camshaft. Don't assume that because the camshaft is new, it is straight. Things happen and you will find both new and used camshafts bent. They can be checked and straightened in minutes by any competent machinist (see Fig.2). Do not scrape bearings to obtain free rotation as this can lead to a major loss in oil pressure and engine failure.

Camshaft Breakage – Starting with the most extreme failure first, camshafts can break given a set of perfectly wrong conditions. To head off such failures, look for sharp fillets adjacent to journals and lobes and for "chatter" or poor surface finishes on the core diameter (see Fig.3). These cause stress concentration and opens the camshaft up for failure. Not visible is the possibility of hardness going too deep into the core making the camshaft brittle. Any combination of the above conditions and camshafts will snap.

Lobe and Lifter Wear – As in every situation, lubrication is critical. In today's world, this means searching for oil with good anti-scuff properties. This is generally associated with ZDDP content. Also in every case, break-in is important. Best practice is to use good oil, possibly with a ZDDP additive. Next, to assure good oiling during break-in, run the engine at approximately 2000 RPM for the first 30 minutes. For highly stressed camshafts in performance engines, it is also helpful to reduce spring pressure during break-in by changing springs or by

Fig.2: Straightening a camshaft

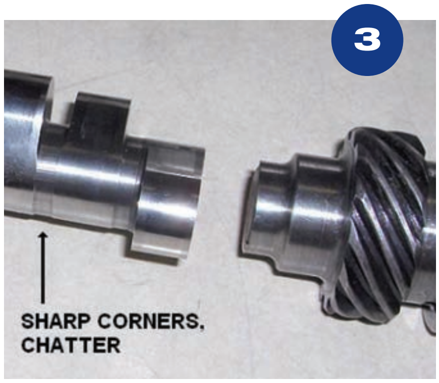


Fig.3: Poor finishes and sharp corners increase odds of breakage

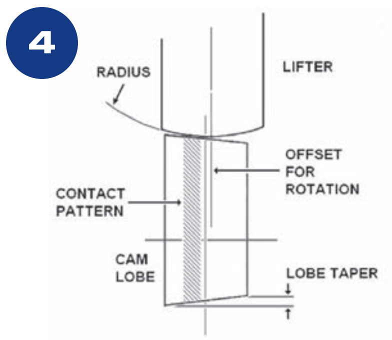


Fig.4: Correct flat tappet assembly

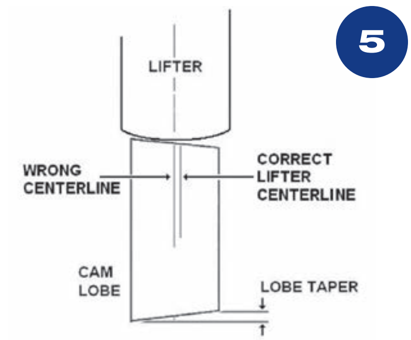


Fig.5: Incorrect assembly causing non-rotation

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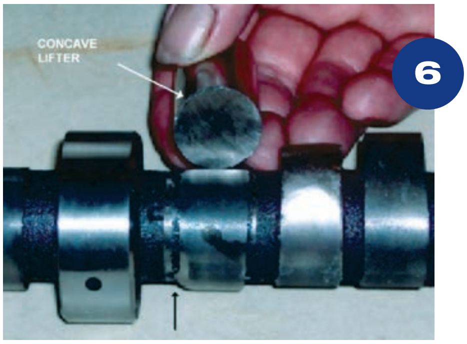

Fig.6: Wear caused by non-rotation

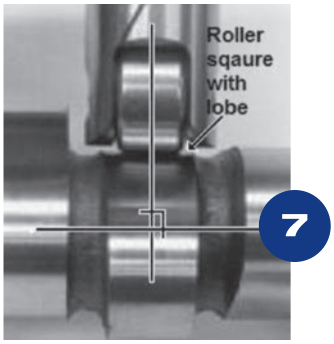

Fig.7: Correct cam-lifter angle

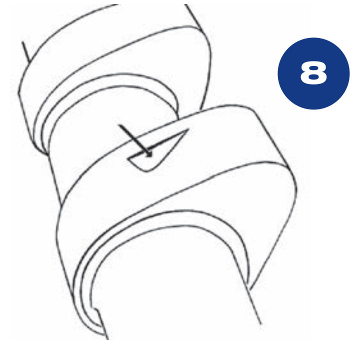

Fig.8: Look for edge-wear on the opening side caused by a misaligned roller

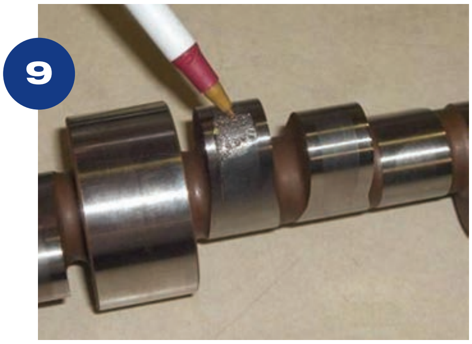

Fig.9: Damage caused by roller failure

Fig.10: Cam drive gear wear

removing extra springs from double spring assemblies.

For flat tappet camshafts, causes of lobe and lifter wear include non-rotation of lifters and misaligned or out-of-position lifter bores (see Fig.4). Lack of rotation for flat tappet lifters can be caused by improper lobe taper on cam lobes or lifter bores incorrectly positioned over the cam lobes (see Fig.5). Check for potential problems by installing a clean and well oiled cam and lifter set in the block and turning the cam over with a speed handle. The lifters should rotate and, if they don't, look down through the lifter bores and see if the bores are offset correctly relative to the cam lobe. The blue-printing of lifter bore locations is sometimes necessary. Also measure the lobe taper and check the direction of the taper. Failure to rotate lifters causes catastrophic wear (see Fig.6).

Roller lifters have a slightly different set of potential failures. One is associated with incorrect lifter bore alignment relative to the camshaft centerline (see Fig.7). The two centerlines should be 90-degrees to each other when viewed from the side. If the roller contacts the cam lobe on one edge due to misalignment, the lobe will wear especially on the opening side (see Fig.8). This also damages the axle and bearings in roller and can cause the roller to badly damage the cam lobe (see Fig.9). Again, the blue printing of lifter bores may be necessary.

Of course good design and proper assembly is basic to the whole question. Lifters or followers should stay in contact with the cam except for the time on the base circle. To do this requires a design with good ramps and controlled seating velocities, especially on valve closing. This also requires running the proper lash adjustments and properly selecting valve springs. Always consult with your cam grinder or manufacturer on spring requirements. Deal with the valve train as an assembly and not as a collection of separate components.

Wear at Drive Gears – Cams fail not only because of lobe wear but also because of wear on drive gears (see Fig.10). When gear centerlines are not at the same height, the normal "rolling" action of gears in mesh changes to a "sliding" action greatly adding to wear. Also keep in mind that this gear set is often heavily loaded by the need to drive the oil pump (one reason to keep oil pressure within reason).

One common cause for wear is the lowering the distributor drive gear below the centerline of the cam gear causing a change from rolling to sliding contact. In engines where the distributor installs through the intake manifold, surfacing cylinder heads, blocks and manifolds lowers the distributor deeper into the assembly. To correct for this requires shimming the distributor or drive gear back up into position.

Another cause for wear is incompatible materials in mesh. For example, steel cams and iron distributor gears. Problems in this area can be avoided by checking with your cam grinder or manufacturer and running bronze or composite distributor drive gears. Bronze gears are compatible with steel cams and composite gears are compatible with all materials. Gear wear can also be reduced by directing oil onto the gears but caution is required to prevent reducing oil to other parts of the engine.

Pushrods – The entire valve train benefits by improving stiffness including of course,

Fig.11: Louis tool used to elongate

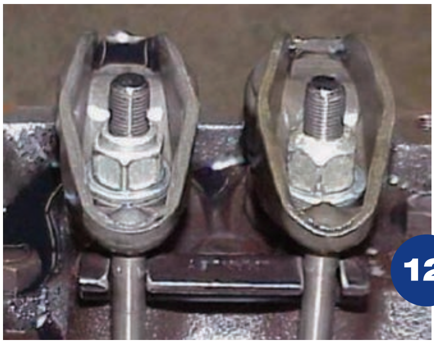

Fig.12: Pushrod guide plates with studs pushrod slot

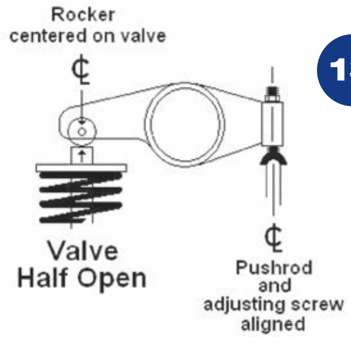

Fig.13: Correct rocker and pushrod geometry

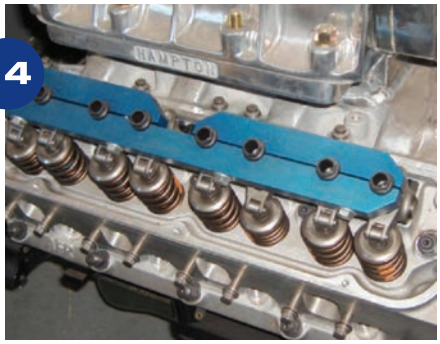

Fig.14: Stud girdle installed

Fig.15: Fulcrum mounted roller rocker

the pushrod. To keep weight down, this means using tubular pushrods with thicker walls. There may be a slight increase in weight over stock tubular pushrods but weight is less critical on this side of the system than on the valve side. Alloy steels are preferred not just for strength, but also for resistance to wear at the rocker arm ends or on the sides where they pass through guide plates.

Beware when changing to higher rocker arm ratios. Ratios are increased by moving the pushrod end of the rocker arm inward towards the center of rotation. This sometimes moves the pushrods into contact with the pushrod slots through the cylinder head. The slot may need to be elongated (see Fig.11) or opened up completely and pushrod guide plates installed (see Fig.12).

Rocker geometry is affected by both valve stem installed height and by pushrod length. It may necessary to use an adjustable pushrod to help find the length of pushrod that makes the geometry come out right. The geometry is right when the rocker is centered, or slightly past center, over the valve stem in the half open position and the pushrod and adjusting screw are also in alignment (see Fig.13).

Rocker Arms and Mounts – A good rocker arm is light, rigid and stable over the valve stem and pushrod. As for weight, we not concerned so much with total weight but with weight over the valve end. This is because of the direct effect on required spring pressures. We would prefer less spring pressure to reduce loads on the total system but we have to close that valve and keep lifters or followers in constant contact with the cam. Adding weight to the valve side of the system, including the valve end of the rocker arm, requires added valve spring pressure.

Stability of the rocker assembly is improved by using larger, stiffer rocker arm mounting studs. Stud girdles help distribute the loads acting on rocker studs and greatly stiffen the assembly (see Fig.14). Changing to fulcrum or shaft mounted rocker arms is also possible (see Fig.15).

Springs – Springs are a crucial component of the system but they are also very complex. In the space of this short article, we will cover some basics that are most helpful to engine builders. First of all, when it comes to springs, more is definitely not necessarily better. Excessive spring pressures cause deflection, wear and valve recession and are to be avoided. On the other hand, too little spring pressure and followers do not stay in contact with the cam and the resultant pounding causes failure.

Generally, it is safe to add seat pressure, measured when the valve is closed, but care is required not to go too high in the valve open position. Keeping component weights down, especially on the valve side of the system, helps reduce the required spring pressure. Keep in mind that the spring's job is closed the valve and keep the rocker arm, pushrod and lifters in contact with the cam.

On teardown and reassembly, watch for the usual suspects including variations in the free length of valve springs, warped springs and variations or incorrect spring pressures. Watch for shiny spring seats or spring shims on teardown as these indicate that the spring has been oscillating and moving around in assembly. Install progressively wound springs with the tight end against the spring seat or spring breakage or failure is almost certain.

On spring selection, there multiple designs to choose from; conical springs, ovate wire, variable alloys, internal or friction dampers and multiple springs to

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Fig.16: A lightweight steel retainer

name a few. At the design level, valve train weights, stiffness, RPM levels and required longevity are all considered. What does all this mean to us? If we buy a cam kit including springs, be sure that the kit is selected exactly for the intended use. Otherwise, consult with the cam grinder or manufacturer for specific spring recommendations. Failure to do this could cost you an engine.

Keepers and Retainers – Retainers are available in aluminum, titanium and steel. Aluminum is light but has a limited life cycle and if not changed in time, they will release aluminum particles into the oil circulation. Titanium retainers are light and strong but can flex under extreme spring loads. Steel retainers are strong and available in high strength alloys and somewhat lighter designs (see Fig.16). For combined strength, rigidity and longevity, consider steel.

Next to be considered are valve locks or keepers. To keep keepers from pulling through retainers under extreme conditions, upgrade from retainers with 7 degree keepers to retainers with high strength 10 degree keepers.

Summary

Some of topics mentioned are worthy of their own separate discussions. Valve springs and cam design are examples of complex and separate topics. Covered here are high points that we hope you, as engine builders, will find helpful. Should you be interested in developing these topics further, let us know through AERA.■

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