A Lubrication Problem

Amongst the multitude of engines in use on the farm is a twin cylinder Petter Diesel which provides the motive power for a Benford concrete mixer. (Photo 1)

Photo 1: Big Mixey had seen better days, but he had seen worse days too. Life on the farm was more relaxed than it had been in the concrete factory. There was always something of interest happening, and his efforts were invariably much appreciated. The arm and bucket of his friend Big Dog the excavator, are seen at the right of the picture.

In common with many of the machines I use, the mixer was bought as scrap. It had spent a hard working life in a local concrete factory which manufactured items such as lintels and septic tanks. After a lot of chiselling to remove several hundredweight of encrusted concrete, it was possible to carry out the necessary repairs to the drum.

The mixer had originally been fitted with a winch and scoop for loading the hopper. The winch had been removed for repair and the scoop was in a sorry state. We had no suitable location for stockpiles of aggregate in any case, so it became our custom to load the hopper by hand.

Photo 2: Following a day of concreting with Little Mixey young Jim inspects the completed manhole while Bill finishes removing the last of the shuttering.

The engine itself started readily, and although it had neither air filter nor proper silencer, it could be relied upon to do its day's work. Needless to say the Petter always produced clouds of smoke, and drank oil as enthusiastically as diesel. My primary concern was to use the Benford for its intended purpose, and over the years, many hundreds of tons of concrete were mixed. The Benford became known as "*Big Mixey*" in contrast to "*Little Mixey*". When they were children, the boys had used Little Mixey many times, and it had accompanied us from Glasgow. (Photo 2)

There is no pleasure in working against the weather, and as the evenings drew in, Big Mixey settled into his long Winter hibernation. The next time we would require a substantial amount of concrete would be the following Spring.

When I next opened the engine cowling, Big Mixey had a surprise in store for me. A Wagtail had taken up residence beside the Petter. The presence of her nest with several chicks in it gave us all pause for thought.

Starting the engine would have meant certain death to the brood. The mother was watching us anxiously. We needed to get on with our day's work, and she needed to get on with hers. There was nothing for it. We loaded the nest, complete with its contents, into a plastic bucket. This was positioned beside the cab of Big Dog where mother Wagtail could see it. (Photo 3) We turned our attention to Big Mixey and commenced concreting. The mother Wagtail passed no remarks and resumed her duties.

Photo 3: Five hungry pairs of eyes stay alert for the arrival of the next beakful of grubs. Despite the smoke, noise, and constant activity, the mother Wagtail came and went without paying any heed.

At the end of the day, after Big Mixey was washed down, we returned the nest, still in the plastic bucket, to its place under the cowling. (Photo 4)

Photo 4: The bucket with the now empty nest sits close to where the nest had originally been built.

Within a couple of weeks, the wagtail chicks flew the nest, apparently none the worse for their adventure.

After a number of years use, Bill took it into his head to give Big Mixey's engine a decoke. One thing led to another, and the engine ended up being fitted with new pistons, big end shells, and small end bushes (Photo 5). Oil seals and gaskets were also renewed.

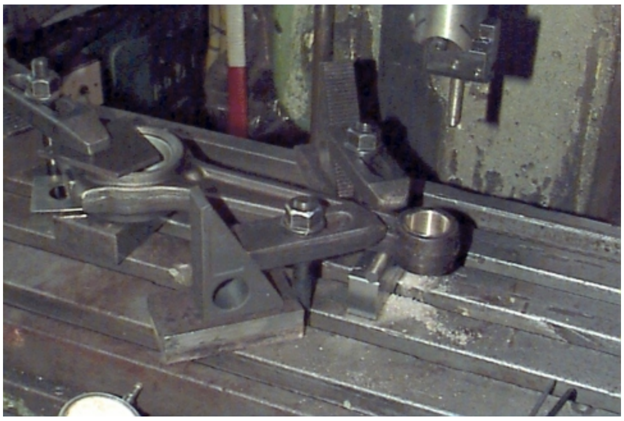


Photo 5: One of the Petter conrods has its small end bored to size on the Cincinnati Mill

The Petter was far from being fully reconditioned, but the boys adapted a complete air filter system taken from a scrap Volvo (Photo 6) and fitted a silencer which had been recovered from a Daimler V12. Big Mixey was hob-nobbing with the vehicular aristocracy.

The rebuild improved the performance of the Petter, but not by as much as I had hoped. There was still quite a lot of smoke from the exhaust, and the reduction in noise was not great. It seemed that the engine's contribution to the total noise level was minor compared to that from the drum.

Photo 6: With Bill at Drotty's controls, the carcass of a thoroughly disreputable looking Volvo, stripped of everything of value, commences its final journey.

Eventually, my son Mike bought himself a modern concrete mixer which he could take on site with him. Thereafter, Big Mixey was neglected.

About two years passed before the need arose for a volume of concrete which would justify the use of Big Mixey.

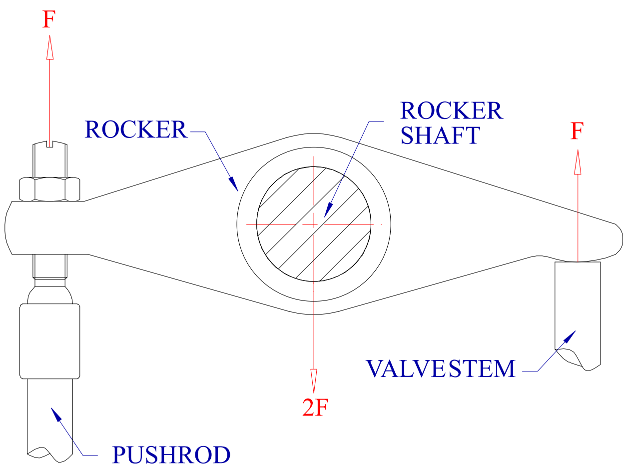
For the first time in our experience, the Petter gave us some trouble. The engine ran well enough for a time, but then started to produce more smoke than usual and began to slow down. It sounded as though the engine was about to seize. Hearing the change in engine note, my son promptly shut down the Petter. We checked the oil, which seemed to be at a reasonable level. Then we noticed that there was a lot of oil around the rocker boxes.

The day's work was definitely not going to be plain sailing. Having started the pour, we had to carry on. Settling down to engine maintenance was not a practical proposition. We decided to let the engine cool for a while and then try it again. The planned concreting was completed by proceeding on the basis of intermittent running. At the end of the day we were too tired to consider carrying out any engine maintenance.

Some time elapsed before I got round to investigating the lubrication problem. I started the engine briefly, and ran it with one of the rocker covers removed. Before I knew what had hit me, my face and hands were spattered with droplets of well used engine oil. Evidently, there was too much of the substance reaching the rockers. It was an elegant demonstration of the First Law of Lubrication Dynamics which states: "*Oil will always flow to where it is least required.*"

The Petter lubrication system is fitted with a pressure relief valve on the crankcase adjacent to the oil filter. Oil for the rockers flows via a banjo connection on the valve.

The intention of the design seems to be one of providing a variable distribution of oil between the crankshaft and rockers. The rockers were worn to such an extent, that there was insufficient back pressure from them. Consequently the rockers were being flooded with oil, while the big ends and main bearings were suffering from oil starvation. The situation was exacerbated by the limited rate at which oil from the rocker boxes could drain back down to the sump. Oil was making its way past the well worn valve guides to emerge as smoke in the exhaust. Reduced oil level in the sump, combined with low crankshaft oil pressure, was not conducive to smooth operation.



Drawing 1: The popular design of pushrod type valve gear is such that the bearing load is carried by the lower half of the rocker shaft.

The obvious solution was to repair or replace the worn rockers and rocker shafts.

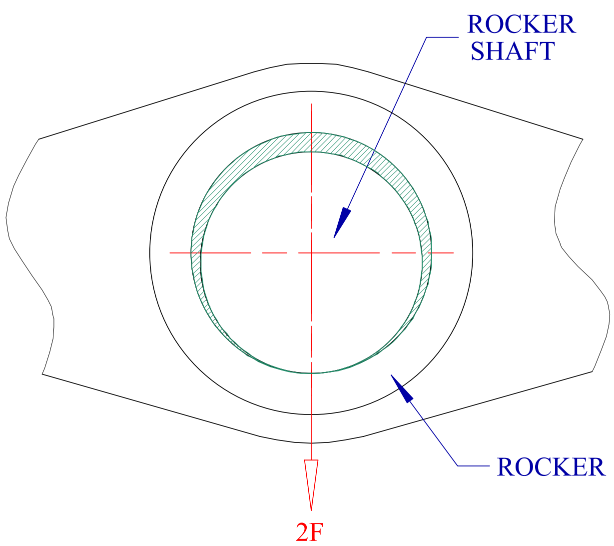
I would then have been the proud owner of a hard worked concrete mixer with a partly reconditioned engine, sporting pristine valve gear. Expenditure on improvements to the engine had already reached a level comparable to the sum I had paid for Big Mixey in the first place. I was reluctant to part with more hard cash. The problem prompted me to devote time to a consideration of the valve gear design. (Drawing 1)

In theory, the slipper face of the rocker which operates on the valve stem cannot support transverse load. In practice, some transverse load will be transmitted. Similarly, the ball and socket arrangement and long pushrod minimise transverse loads. The rocker describes an arc, so there will be a small amount of transverse loading at the pushrod end. To a very good approximation, the principle loading is in the direction shown by the arrows. The force reaches its maximum value during acceleration at valve opening, when inertial forces act in addition to the force of the valve return spring. The peak force is greatest at high engine RPM.

Importantly, the upper half of the rocker bush and rocker shaft are only subjected to the weight of the rocker itself. The reaction force is distributed around the circumference on the lower half of the rocker shaft. It is greatest in the direction shown in Drawing 1.

Although the rocker may oscillate through an angle of perhaps 30 degrees, the direction and distribution of the force on the rocker shaft remain essentially unchanged irrespective of variations in magnitude. From the point of view of the rocker, the direction of the reaction varies cyclically.

Between the mating faces of the shaft and rocker the motion is purely sliding in nature. As regards lubrication, rocker design poses specific problems. Consider the situation where there is no wear in the shaft or rocker.



Drawing 2: Clearance between the shaft and rocker permits the lubricant to be displaced from the area where it is most needed. An oscillating component does not benefit from induced hydrodynamic lift to the same extent as one which rotates continuously.

There will nevertheless be some clearance between the two components. Drawing 2 illustrates the situation in grossly exagerrated form.

The oil pressure establishes a film of lubricant in the clearance. The clearance, however small, means that the diameter of the rocker bush is slightly larger than the diameter of the shaft. The moment the valve begins to open, the forces tend to reduce clearance in the lower half of the assembly and increase the clearance in the upper half. Consequently, the oil film will taper in thickness as shown, being thinnest where the force is highest. The increased clearance at the top of the shaft also facilitates oil release from the rocker. This permits displacement of oil from the lower half at the times when it is most needed. Viscosity of the oil limits the extent of the effect.

Bearing design calculations based on knowledge of the hydrostatic pressure of the lubricant together with the projected area of the bearing need to include a generous factor of safety.

On the overhead valve gear of an upright engine, gravity assists lubrication. An inverted engine is at a disadvantage in this respect. If oil is introduced into the assembly illustrated at any point other than the bottom of the rocker shaft, it may not serve much useful purpose at all.

A downward pointing oil passage enables the establishment of an oil film during the period in which the valve is fully closed and tappet clearance is available. However, arranging for the oil passage to be at the bottom of the rocker shaft reduces the effective bearing surface at the point where the highest forces are applied. In principle, force is transmitted through the oil in the passage with the lubricant forming a hydraulic bearing surface. The fact that there is no metal present at that point should not matter.

However, the actual localised pressures may exceed the engine oil pressure. Under such circumstances, flow will cease at those instants when the highest forces occur, prompting a momentary reversal of flow. The lubricant then finds an additional avenue for escape in the supply passage, increasing the probability of metal to metal contact.

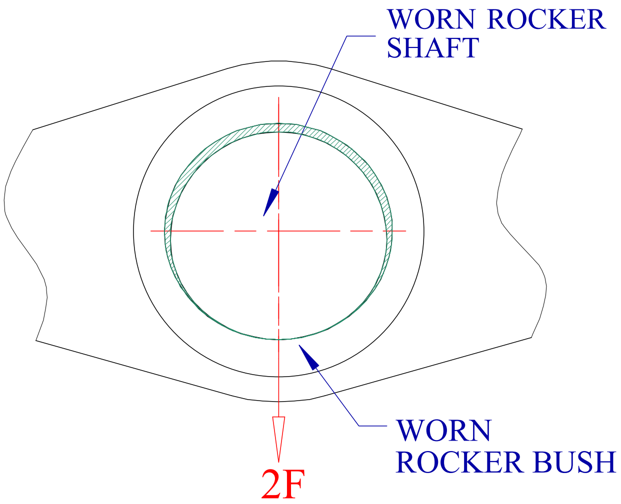
Similarly, inclusion of an oil groove in the shaft or bush, intended to increase the ease with which oil can reach the mating surfaces, increases the rate at which lubricant can be excluded by the applied force, as well as reducing the total available bearing surface.

Metal to metal contact manifests itself as shaft wear in the high pressure region. The result is visible on typical worn valve gear.

The approximately ellipsoidal form of the bearing surfaces in heavily worn valve rocker components is illustrated in Drawing 3. The flatter surface of the worn shaft and bush is in some respects equivalent to having a larger diameter bearing and represents a more favourable load bearing area than does a perfectly cylindrical form of small diameter. In addition, the gap which exists between the widest point of the shaft and the bush permits the mating faces to undergo rolling motion in combination with sliding action.

The combined motion can be expected to be less destructive to the wearing faces than the purely sliding motion characteristic of new components.

The additional freedom of movement in the rocker motion makes analysis of the dynamic behaviour more difficult to say the least. Few designers would be enthusiastic about presenting such a bearing profile as original equipment design.



Drawing 3: The approximately ellipsoidal form of a worn shaft and bush represents a more favourable load distribution than is obtained from small cylindrical components.

It is also easier to manufacture shafts and bushes which are cylindrical in form than it would be to produce some mathematically optimised bearing surface. In this case, natural wear and tear apparently go some way to carrying out a design optimisation process of sorts.

Any configuration of lubrication system for a rocking mechanism would be a compromise. On the other hand, the rockers do not undergo any reversal in the general direction of the applied force during operation. The same cannot be said of big ends or small ends. The force reversal which occurs at the end of each stroke produces the characteristic "*Knock*" indicative of excessive wear in these components.

In the case of main bearings, the absence of force reversals cannot be guaranteed. For example, an inverted engine may produce brief periods of force reversal in the main bearings near the point of ignition.

The fact that there would be no force reversal at the rockers led me to conclude that retaining the worn components would be unlikely to hinder engine performance in any significant way. Adjusting the tappet clearance would result in the wear showing up as an increase in clearance at the top half of the rocker shaft. The weight of the rocker would bear on the valve stem and pushrod instead of being carried by the rocker shaft.

However, the weight of the rocker is small in comparison to the dynamic loads. Provided an adequate supply of oil reached the valve gear, there was little advantage to be had from replacing the rocker shaft and bushes. The solution was less than ideal, but appropriate.

Niceties of the lubrication requirements for the rockers did not alter the fact that back pressure was needed in order to direct oil to the big end and main bearings. The solution adopted was to take advantage of the banjo bolt itself.

All that I required to do was convert the axial oil passage into a through hole. This was tapped to match a setscrew. The setscrew was turned down to a diameter slightly less than that of the oil passage in the banjo bolt. (Photo 7).

Photo 7: The modified banjo bolt and setscrew.

The position of the setscrew then determined the extent to which the transverse oil passage in the banjo was occluded. Clearance between the bore of the axial oil passage and the setscrew diameter ensured that oil to the rockers could not be shut off entirely.

Once the banjo was refitted to the relief valve, the setscrew was adjusted to restrict oil flow to the rockers. (Photo 8).

Photo 8: The banjo reinstalled in the relief valve of the Petter. Oil flow to the rockers was easily controlled by adjusting the setscrew.

Engine performance improved as a result of the modification. There was no longer any sign of excess oil at the rocker boxes, and there was a reduction in the amount of smoke produced.

Big Mixey was delighted with the new arrangement.

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