Understanding your... CRANKSHAFT PART ONE

We've all got one in our engines, whether Lambretta or Vespa, two-stroke or four. But have you ever wondered what they do, how they do it and what advantages might be had from fitting an aftermarket crankshaft? Well dear reader, we're here to enlighten you further...

What does it do?

In the simplest terms a crankshaft converts the reciprocal (up and down) movement of the piston into rotary movement to drive the ignition system on one side and the transmission on the other.

On Lambrettas that is the crankshaft's sole purpose, however, Piaggio gave the crank a secondary role on all rotary valve Vespas (i.e. every manual two-stroke after the 180SS), which is to control the opening and closing of the inlet port into the crankcase.

Why is the crankshaft important?

The crankshaft is the beating heart of your engine – possibly the most vital component of all to have in tip-top condition. If your crank fails then the chances are that you will be stranded with an unrepairable scooter, at least until it has had expensive open-heart surgery. Therefore, the best advice when undertaking any engine rebuild or tune is to ask whether the crankshaft you plan to use is up to the job. If you aren't sure then get it professionally checked. If the answer is 'no', then either get your current one rebuilt with a new rod kit, or buy a better crankshaft. Which of these is the more cost effective solution varies from scooter model to model, and according to the cost of a crankshaft rebuild in your area.

What does the crankshaft consist of?

Most two-stroke cranks consist of a pair of webs, a crankpin, big end bearing and con rod. In this case the big end also has two shims which aren't used on all cranks.

In two-stroke applications the crankshaft is very simple: usually two separate crank-webs pressed together on to a common crankpin. Connecting the crankpin to the piston is the logically named 'connecting rod' or 'con rod' for short. One end of the con rod is big (the end that attaches to the crank and known as the 'big end') and I'll leave you to guess what its small end is called which attaches to the piston.

Modern two-strokes use steel roller bearings at each end of the con rod: caged rollers at the big end, and a caged needle bearing at the little end to connect to the piston's gudgeon pin. Roller bearings are chosen because they are best able to cope with the harsh operating conditions inside an engine where the fuel-mixed lubrication arrives in a very hit and miss manner.

Early, small capacity two-strokes (e.g. Li Series 1 or early Vespa 50) sometimes used plain phosphor bronze bushes in the small end of the con rod. These are even more sensitive to poor lubrication and have a maximum rev limit of around 7000rpm in a two-stroke. Plain bush-type bearings (shells) are however still common in four-stroke engines where they can be constantly lubricated by engine oil. Hard-plated bushes in modern four-strokes operated with pressure-fed lubrication run almost silently and can have an extremely long service life.

Modern two-stroke crankshafts usually now have a shim either side of the big end bearing to prevent friction against the crank webs and to centralise the con rod. Early Lambretta cranks did not use shims at the big end to centralise the rod. Instead they used shims on the gudgeon pin to do the same job. This can make piston assembly a bit of a game: somewhat like trying to unlock your front door with the wrong key while blind drunk.

Crank alignment

I mentioned that the crank webs are pressed together on to a common crankpin. This is the only way they could be assembled using a single-piece con rod and bearing. Four-strokes sometimes use a one-piece crankshaft with a two-piece con rod that bolts together at the big end.

On a two-stroke the pin-web joint is a tight interference fit which must be aligned accurately and scientifically for the ends of the crankshaft to run true. The method by which split cranks are aligned looks somewhat less than scientific to the naked eye: basically the webs are hit with a large copper hammer to align them, then checked and hit again if necessary. Two-stroke crank assembly is truly a black art that few people are able to do, and even fewer can do it to the highest standard.

Unlike a single piece four-stroke crankshaft, a two-stroke crank will only have perfect shaft alignment if it is assembled and trued perfectly. In the real world this is difficult to achieve, so most manufacturers specify an acceptable assembly tolerance which can be measured as 'run-out' at the ends of the shaft using a dial gauge. It is important to keep run-out to a minimum because if the crank is out of line it will increase engine vibration and wear out the bearings more rapidly. A very badly out of line crankshaft may allow the flywheel to rub on the stator.

What is acceptable run-out for a scooter crankshaft? Some new shafts are supplied true to 0.002in (0.050mm), however, most good engineers aim to get the run-out at the farthest end of the crank to below 0.001in (0.025mm), which can take a great deal of assembly adjustment (read 'hitting with a hammer').


This is the set-up required to measure run-out: a dial-gauge and balance wheels. V-blocks may also be used.

Crankshaft balance

Without some form of balancing, every movement of the piston in your engine would transmit such severe vibration that bits of your body would fall off, never mind bits of your scooter. Vibration is not only expensive in terms of dentistry, but it also saps power. All the energy that should be transmitted to the wheel is being wasted in shaking your fillings out.

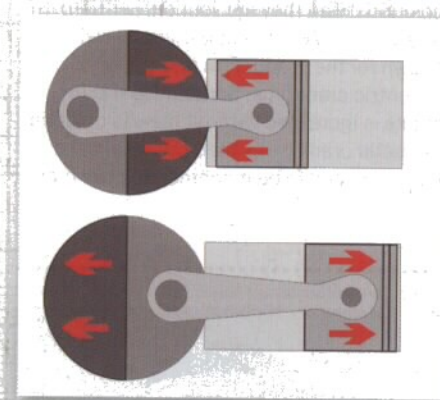
The way that single-cylinder engines are balanced is to counter-weight the crankshaft webs so they are heavier opposite the crankpin. When the piston is moving up, the crank weights should be moving down, and vice versa. Only they aren't, because a linear movement cannot perfectly be opposed by a rotating one. What is more, when the piston is halfway down the bore, the weighted mass of the crankshaft is now at 90-degrees to the barrel and making the engine vibrate in a different plane to that of the piston movement.

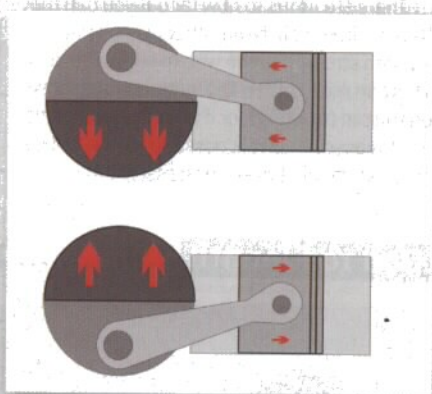
What should now be obvious is that it is impossible to perfectly balance a single cylinder engine with a single rotating shaft. That is one of the reasons why most car or bike engines are two, four, six or eight cylinders. All these configurations can be laid out so that the vibrations of one piston are largely cancelled out by another. More modern single cylinder engines often use a counter-rotating balance shaft to nullify vibrations, but this is both wasteful of power and not perfectly effective.

While it is impossible to iron out all vibration from a single cylinder engine, it is possible to improve the balance of a crankshaft so that it is smoother in a particular rev range, and when used in conjunction with a specific weight of piston.

At this point you should be able to spot some other problems in the 'one size fits all' approach to scooter crankshafts. If you buy a Lambretta GP 'race' crankshaft off the shelf, this might get used with anything from a light 52mm 125cc piston operating at 5000rpm right through to a heavy 72mm 250cc kit piston operating at 8500rpm and everything in between. There is no way that it could be balanced to suit every configuration which is why, in many cases, Lambrettas vibrate sufficiently to entertain ladies of a certain disposition.

Component balancing is a whole subject on its own, and hopefully one we will revisit in a future article.


At bottom dead centre and top dead centre the masses of the piston and the heavy sides of the crank web produce forces designed to oppose one another, in order to cancel vibration in the horizontal plane.


When the piston is mid-stroke the mass of the crank webs now causes vibration in the vertical plane. Perfect engine balance is impossible in this simplistic configuration.

Stroke

The long-stroke crank on the right has larger diameter webs and requires crankcase machining to suit.

Crankpins (L-R): solid, hollow, eccentric.

The stroke of a crankshaft is the distance (usually) in millimetres that the piston travels up and down the cylinder. This is double the measurement from the centre of the shaft to the centre of the crank pin (big end).

One possibility to increase the cubic capacity of an engine is to increase the stroke, which is done by moving the centre of the crank pin further from the centreline of the shaft. Moving the pin outwards by 1mm increases the stroke by double that amount: i.e. 2mm. Thus a 58mm stroke Lambretta crank would become 60mm stroke. This change can be achieved by boring the hole for the crankpin closer to the perimeter of the web, which is how most 60mm stroke Lambretta cranks are made.

There are limits to how far out you can move the crankpin hole before there is no longer enough strength in the web to support the pin. This can mean either the webs coming loose on the pin (twisting), or if the interference fit is increased, then it is possible for the webs to crack at the pin hole during assembly.

One way to increase stroke even further is to make a crank with larger diameter webs. Increased web diameter – as is common on many of the 54mm stroke smallframe cranks – requires the casings to be bored out to accommodate. This presents other problems, in that machining can make the casings thin and weaker.

The other solution to increasing stroke is to use an eccentric crankpin. These are specially machined pins which have the big end bearing surface machined eccentrically off-centre compared to the rest of the pin. Production of these pins is quite involved which is why they are so expensive, but if you want to increase the stroke of a crank without modifying the crankpin hole positions then they are your only option. Readspeed, Worb5 and MB are all well known for the production and use of eccentric crankpins. Sometimes if the stroke is increased without the use of larger diameter crank webs then the crankcase may still need to be machined to offer more clearance for the big end of the con rod. However, this may only need to be a narrow channel cut into the cases rather than the full-width surgery needed to run larger diameter webs.

Changing the stroke of a two-stroke engine is not something that should be undertaken lightly, because it can have a massive effect on port timings and engine performance. If you fit a crankshaft with 3mm greater stroke then you must space the cylinder head away by 1.5mm so that the piston doesn't hit the cylinder head. You could get the engine running with a 1.5mm packing plate under the barrel, or you could leave the barrel in the normal position and fit an extra 1.5mm of head gasket, or you could use a combination of packers/gaskets. Which route you chose will have remarkably different power delivery (it will be much revvier than standard using the base gasket, and less revvy with the thick head gasket), so it is vital to calculate the port timings in advance.

Con rod length

Con rods lengths are given centre-to-centre. Measure as shown and add half the diameter of each bearing hole to calculate the stated length.

QUICK TIP: *If you use a PC there is a free tool available at www.lambrettabook.com which calculates port timings from stroke, rod length and port height measurements.*

A common misconception is that a longer con rod means longer stroke. In fact it makes no difference at all to the stroke. On a 58mm-stroke crank then the piston would still travel 58mm with a longer rod, but the upper and lower limit positions would be changed.

If you fit a 5mm longer con rod then simply fitting a 5mm packing plate under the barrel, should get you back to square one with the same engine capacity and all the same port timings?

Well, almost...
Fitting a longer con rod with the same piston and a packer under the barrel still has a small effect on port timings, but the more noticeable effects will be a reduction in crankcase compression (because there is now more volume below the piston) and a reduction in side-loads on the piston skirt as it descends which can reduce wear and ease vibration.

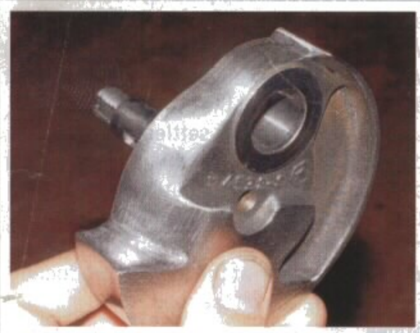
For these reasons crankshafts with longer than standard con rods are sometimes specified for some high-end performance kits such as Falc, Parmakit and the AF RB20.

There are other reasons to use different length con rods. Simply having a decent quality con rod to use can be reason enough. Before the advent of the affordable 'race' crank there were two options for tuned motors: either use a standard crank that may not survive any longer than the first little pig's straw house, or fit an exotic (often Japanese) con rod conversion. For Lambretta riders in the 1980s and 90s these conversions offered the opportunity to use quality con rods, bearing and big-end shims, and eliminated the need for those annoying piston shims.

Standard Lambretta rods come in unusual lengths: 107mm for all Li series with the exception of TV175 at 116mm long. The motorcycle con rod conversions that British tuners developed were rarely exactly the same lengths – 110mm, 115mm or 120mm – but as they were often used in conjunction with motorcycle piston conversions which had their gudgeon pin holes in different positions then it hardly mattered. Cylinder heights could always be adjusted by machining gasket faces or with packing plates.

Nowadays the rise of off-the-shelf race cranks means that this old-school con rod substitution is less sought after, but that need not be the case. Any of the recent Lambretta 'race' cranks with a 22mm pin can be rebuilt with a Japanese con rod and quality big end bearing to offer a reliable crankshaft, often for a fraction of the cost of a completely new one.

Vespa rotary inlet timing



It is far better to get a crank stripped in order to extend the timing or simply to polish and 'gas flow' the inlet side web.

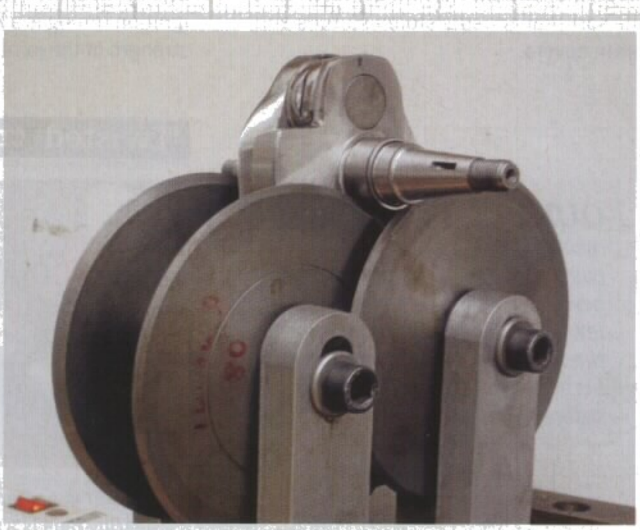
Three Vespa crank webs: standard (right), gas flowed but original timing (centre) and heavily modified with extended inlet timing (left).

The Vespa design of having a cutaway in the crank web and using the outside face of the web to open and close the port is an ingenious one. Unlike the piston-port design of a Lambretta it allows the inlet timing to be asymmetric – in other words the port can be open for a greater duration (in degrees) after top dead centre (TDC) than it is before TDC.

Not only is asymmetric timing more efficient – because the port is only open when there is enough vacuum to draw fuel in – but there is another advantage. On a Vespa the incoming fuel, air and oil mix has no option but to travel past the big end of the crankshaft, thus delivering more thorough lubrication. This is why Vespas only needed 2% oil mixture when Lambrettas often specified 4%, and also why crankshaft failures are so much rarer on Vespas.

The downside of this layout is that the inlet port must be quite narrow and is obstructed slightly by the crankshaft even while fully open. This is the basis behind what Vespa owners are sold as 'gas-flowed cranks', where the inlet-side crank web has been smoothed and polished. In actual fact most gas-flowed cranks also have an increased cut-away to extend the inlet port open duration. As with any tuning modification this has its pros and cons. Whether extended inlet duration suits your engine is rather dependent on what sort of tuning you are doing. Longer inlet timing

This gas-flowed Vespa crank is visibly off-balance.



This crank is better because the crankpin sits at 12 o'clock

A custom crankshaft for reed valve engines produced by Scooter & Service in Hamburg.

will generally give you more power at higher revs, but may sacrifice power and clean carburation at lower revs.

Then there is the question of reed-valve conversions. These permit the opening of the inlet port way beyond the normal sealing pad so that the crank no longer controls the inlet timing. This doesn't alter the fact that the crankshaft is still partially obstructing the inlet port for much of the time; which is why many tuners modify their reed valve Vespa cranks by chamfering the inlet web in one way or another.

Whatever, the pros and cons of increased-duration or reed valve cranks, very few of these are actually balanced properly again afterwards, which is likely to lead to increased vibration. Wolle from German tuning house Scooter & Service demonstrated this by placing a cut crank on a set of knife-edged balancing wheels. Without a piston fitted the crank should rest with the counter-weights at the lowest point and the crankpin at the top, but the unbalanced cut crank settled about 45-degrees off-centre. That might be okay for a cement mixer perhaps, but is not ideal for a tuned scooter. By contrast the S&S-modified crankshaft balanced perfectly with the crankpin at the top and produced far less vibration on the road.

Sticky

CRANKSHAFT PROBLEMS

Damaged keyways

This sort of damage to a flywheel taper means the crank is only really fit for the scrap metal man. Hit him with it if he is the sort that accepts stolen statues and drain covers.

Heavy flywheels used with revvy engines, or indeed any flywheel used with an insufficiently tight flywheel nut, can result in a sheared flywheel side Woodruff key. The results of this are rarely pretty: enlarged keyways and alternating high and low points on the shaft and the flywheel taper where they have friction-welded together and then been torn apart.

In theory the Woodruff key is not supposed to lend any mechanical strength to the flywheel-crankshaft joint. Its purpose is to serve to accurately align them to ensure the ignition timing is a known constant. The strength of the joint comes from friction between the cone of the flywheel boss and the tapered shaft of the crank. As such these surfaces must be absolutely free of any high-points that prevent the cone and taper meeting over a large area.

A temporary repair may be achieved by filing down the high points and then using valve grinding paste to lap one surface to the other. When both surfaces are evenly matt in finish then your work is done. If the Woodruff key slot is damaged then you may be able to glue it into position (and allow to dry) before fitting the flywheel as a roadside bodge, but really the crank should then be renewed at the earliest opportunity.

***QUICK TIP:** Readspeed recommends using the grinding paste trick to 'lap' together any new flywheel or crankshaft. Only a few turns are required to improve the fit of the components. Clean both components thoroughly before installation.*

'Twisted' crankshafts

Uneven wear marks on a flywheel-side bearing face is a useful indicator of a twisted crank.

If you want to avoid twisting a crank then the best way to fit one is to pull it into position.

With a crank extractor tool it is also possible to push Lambretta cranks out without hitting them. A construction technique for this tool featured in issue 307.

If one of the webs moves out of alignment on the crankpin then this is commonly known as a twisted crank. It is unusual for original crankshafts in standard engines to twist, but as you increase the power output of the engine then the limitations of the original design soon become apparent. Basically the crank webs are narrower than is really required to securely grip the crankpin on highly tuned motors.

Causes of twisted cranks include:

- Poor quality crankshaft
- Piston seizure
- Sudden shock (e.g. missed gear at high rpm)
- Drongo damage (e.g. big hammer used to fit crank)
- Excessively heavy flywheel or piston used on tuned engine

Potential solutions to twisted crankshaft problems include:

- Rebuilding the crankshaft using Loctite High Strength Retainer in the web/pin interface. The crank builder must avoid getting any Loctite into the bearing.
- Welding the crankpin to the webs. The very act of welding has a tendency to pull the crank out of true so this needs to be done by an expert or by laser.
- Using a lighter flywheel on a tuned motor.
- Using a very slightly oversized crankpin to increase the interference fit into the webs. Both Taffspeed and MB Developments made such pins in the past.
- Using a crankshaft with a larger overall diameter web to offer more 'meat' around the crankpin hole. The casings must obviously be bored out to accommodate a larger diameter crankshaft.

Bearing failure

The pitted surface in this small end eye means this crank is only good as a paperweight until it is fitted with a new rod kit. And not even a very good paperweight...

Pitting on the big-end eye of this Vespa rod means it is scrapped. With no oil slots to look through it is much harder to spot big end damage on Vespa cranks.

Crankshaft bearing failure is normally signalled in advance by a knocking noise if it is the big end bearing that is failing, or more of a rattle if it is the small end. Worn out main bearings may knock or rumble. Worn out bearings may be caused by simple wear and tear – lots of miles or high rpm – but insufficient lubrication kills them most rapidly through friction and overheating. Most of the motorcycle conversion con rods have large lubrication holes at the little end and large slots at the big end to allow oil to reach the bearings. By contrast some original Lambretta cranks and many of the original Vespa rods are very restricted in access for oil to reach the bearings.

On cranks with slotted rods a damaged big end is sometimes visible. Look for bearing rollers that have gone from shiny to matt, or sometimes have turned blue through heat discolouration.

QUICK TIP: *An out-of-line crank will probably make its presence known with increased engine vibration, but you can also test for it simply by putting the pointed end of a Phillips screwdriver into the recess machined into the end of the crank with the engine running. If the crank is out of line then this can be felt as strong side-to-side vibration in the shaft of the screwdriver. Twisted cranks often cause the inside of the flywheel to rub the stator plate, more so in one direction than the others.*

Damaged threads

You only have to see how cranks are trued to understand that brutal bashing to fit or remove them is not a great idea, and can knock them out of true. However, there are other problems associated with merrily hammering away like a submariner on leave: namely that that you can end up with a funny shape to the end of your shaft if you aren't careful.

Slightly damaged threads may be repaired with a thread file. More severe damage may need filing and use of a thread tap. Extreme mushrooming to the shaft (matron!) demands extreme surgery: maybe even cutting off the last thread with a hacksaw and then re-tapping.

Sticky

Thanks to: Harry Barlow (Pro Porting), Jerome Read (Readspeed), Wolle (Scooter & Service) and Mark Broadhurst for help with this feature.

Next month: how crankshafts are rebuilt.