The Black Mystic Art of Cam Timing!

Part One

By Peter Shearman

INTRODUCTION

Like Electric's many people think that cam timing adjustment is a 'Black Art'. They think that you have to be some sort of a Magician or Semi-God to be able to do it! Like most things in life experience is the best teacher and the only way to get experience is to have a go yourself.

Year ago (many!) I didn't have a clue how to adjust Dellorto carburettors but by watching someone do it, asking questions and finally trying it for myself I learned how. If you are willing to have a go then you will always learn something. Even if you make mistakes, and we all do, you will learn from them.

I wasn't game to try cam timing until a couple of years ago when I rebuilt the 900 engine. Before I tried it I did a lot of reading and watched it done on a belt drive at a service day before finally tackling it myself. Like Desmo shimming it isn't very hard you just have to give yourself plenty of time to take it slowly and double check all your figures. The good thing about cam timing is that even if you completely mess it up you can always go back to the standard factory timing marks and start again **but** don't try running the engine until you are sure the timing is where you want it!

This article is devided into three instalments. The first explains the role of valve timing starting with the basics and moving on to more complex explantions. The second part describes how to measure your existing valve timing and the final part gives a guide on how to change the valve timing

BASIC FOUR STROKE PRINCIPLES

For those with little knowledge of what goes on in a four stroke engine this first section will cover the simplified basics of operation including the part that valve timing plays in the four stroke cycle. If you already know all this just move on to the advanced section.

A four stroke engine crankshaft rotates twice (2 x 360° = 720°) for each cycle of operation. During this cycle the piston moves up and down the bore twice which gives us four strokes! When the piston is at the top of its stroke this is called Top Dead Center or **TDC** for short. When the piston is at the bottom of its stroke this called Bottom Dead Center or **BDC** for short. TDC and BDC are reached twice during each cycle of operation.

During these two rotations of the crankshaft the camshaft only goes through **one** rotation. This is achieved by driving the camshaft at an overall 2:1 reduction ratio from the cranshaft. The camshaft controls one valve cycle which covers two rotations of the crankshaft so whilst the crankshaft goes through 720° the camshaft only goes through 360°. You need to remember this relationship when it comes time to move the camshaft to change the timing.

Valve timing is usually given using two figures. The first is the number of crankshaft degrees degrees before/after TDC/BDC that the valve completely closes. This gives rise to further abbreviations of, **BTDC** (Before Top Dead Center), **ATDC** (After Top Dead Center), **BBDC** (Before Bottom Dead Center) and **ABDC** (After Bottom Dead Center).

Four stages are passed through for each four stroke cycle and these are listed below in simplified terms to explain the basic four phases involved. We will go into these phases in greater detail in the 'Advanced' section. Let's start at TDC at the end of the compression stroke.

POWER At TDC (Compression) the spark ignites the compressed mixture resulting in a burning of this mixture to create the power to drive the piston down the cyclinder. Both valves must remain closed for this power stroke.

EXHAUST At BDC the inlet valve must remain closed and the exhaust valve must be open whilst the piston in on the up stroke. This movement forces the burnt gases out past the exhaust valve to the exhaust port and the exhaust system.

INTAKE At TDC (Exhaust/Overlap) the exhaust valve must be closed and the inlet valve must be opened. The pistons downward movement causes a pressure below atmospheric in the cyclinder which allows atmospheric pressure to feed the air/fuel mixture past the inlet valve and into the engine via the inlet port.

COMPRESSION At BDC the exhaust valve must remain closed and the inlet valve must be closed. Whilst the piston is on the up stroke the air/fuel mixture is compressed dramatically ready for ignition by the spark plug. The cycles repeats with the power phase next.

If an engine was set up like this with valves opening and closing at TDC and BDC it would run at low revolutions but such basic valve timing is not good enough for an engine to develop any usable power. If you have grasped the basics and want to know more it's time to move on to what happens in a real motor.

ADVANCED CAM TIMING THEORY

I found a diagram helpful in understanding what is happening. With reference to figure 1, I have divided the two crankshaft rotations into two circles joined at TDC this should be followed as a 'Figure of Eight' through the various cycles.

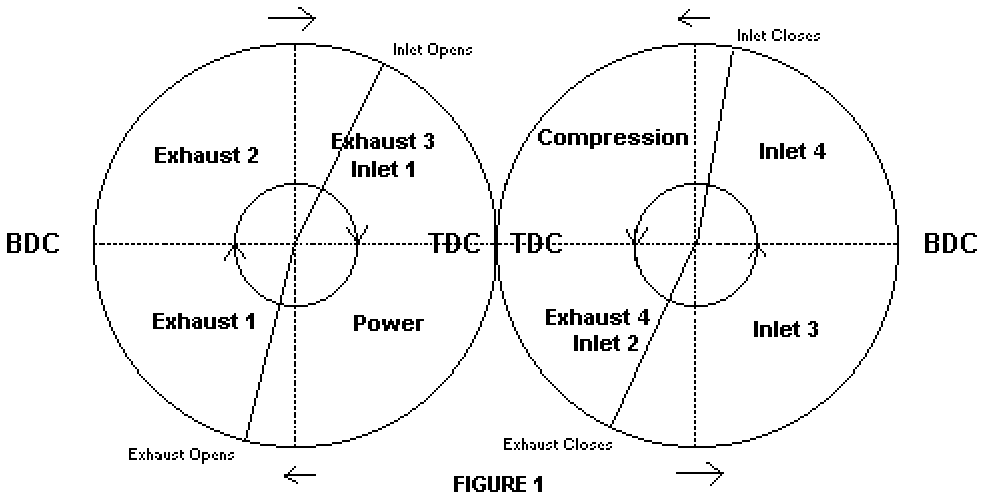

FIGURE 1

Starting at TDC compression follow the left hand circle clockwise until you return to TDC exhaust. Then follow the right hand circle anti-clockwise back to TDC compression. I have divided each circle into four 90° segments giving eight phases for the purpose of our advanced discussion. The actual degree settings for cam timing will be discussed later on.

We start at TDC compression. As discussed previously both valves are closed and the air/fuel mixture has been compressed into a small area. Because the mixture takes a finite time to become completely ignited we must start the ignition before the piston gets to TDC. I won't get into ignition timing in depth here but suffice to say the faster the crankshaft rotates the further before TDC the mixture needs to be ignited. The net result of this is to ensure that the maximum push of the fully burning mixture peaks just as the piston starts its downward stroke regardless of piston speed.

POWER For the first 90°-100° ATDC both valves remain closed whilst the mixture burns causing pressure to rise pushing the piston down on its power stroke.

EXHAUST 1 At around 80° BBDC the exhaust valve starts to open. The main reason for opening the exhaust valve earlier than BDC is so that it will be fully opened by the time the piston reaches the start of the upward exhaust stroke. Most of the power from the burning mixture has been used at this point so there is virtually no loss of power by opening the valve early. Also we can use the small amount of combustion power left to begin the exhaust phase early even though the piston is still moving down.

EXHAUST 2 & 3 From BDC to TDC the exhaust valve is wide open and the rising piston is forcing the burnt gasses out of the cylinder

INLET 1 At around 60° BTDC the inlet valve starts to open. As for the early opening exhaust valve we do this to give the inlet valve a chance to be fully open by the time the piston is reaching its maximum downward velocity and it gives a head start to filling the cylinder with fresh air/fuel mixture. By the time the inlet valve is fully open the exhaust gasses are moving fast out through the exhaust port and the inertia of this column of gas causes a slight depression in the cylinder which allows atmospheric pressure to feed in the fresh mixture. Exhaust systems are designed with this in mind and the term 'Extractors' is fairly self explanatory when you understand what is happening in the engine.

INLET 2 & 3 From TDC Exhaust/Overlap to BDC the inlet valve is wide open and the piston rapidly moving down creates a depression allowing atmospheric pressure to feed fresh mixture into the cylinder.

EXHAUST 4 The exhaust valve remains open till around 60° after TDC. This is done to purge the exhaust gasses. The rapidly moving incoming mixture not only fills the cylinder but forces the last of the exhaust gasses out through the closing exhaust valve until the returning exhaust pulse stalls the flow. The swirling air/fuel mixture at this point also provides some cooling for the hot exhaust valve.

INLET 4 From BDC to around 80° ABDC the inlet valve remains open. Although the piston is now moving upwards the inertia of the incoming air/fuel mixture is stronger and results in a mini super charging effect where the mixture is initially compressed into the cylinder.

COMPRESSION After the inlet valve closes at around 100° BTDC the rising piston continues to compress the fresh air/fuel mixture in readiness for ignition and the start of a new cycle.

When you realise that this full cycle happens around 70 times per second at high revolutions you can appreciate that cam timing is a very critical factor when designing an engine. The timing figures are dependant on the camshaft(s) which are ground specifically to suit the type of engine.

As you can imagine many factors effect the factory setting of cam timing such as, the intake and exhaust systems, fuel type used, compression ratio, maximum RPM of the engine, piston and combustion chamber shapes, torque and maximum power conciderations, fuel economy, etc.

MORE TERMS & CONSIDERATIONS

Nearly all cam timing figures rely on having a known clearance between the rockers and the valves which is greater than the normal or **Running** clearance. This is called a **Checking** clearance and is normally **1.00mm** (40 thousandths of an inch). Timing at checking clearances means that you will have to temporarily change the shim or adjuster on each valve prior to measuring the timing but more on this later.

Some factory timing figures are given at Running clearance even though there is no appreciable gas flow below 0.5mm lift. This is done to provide enhanced figures which make Duration and Overlay appear much longer which is an advertising advantage when buyers think that longer must be better! If no checking clearance figures are given with the factory timing specification then you have to assume that timing is at running clearance. ie normal operating clearances are used.

The number of degrees from when the valve start to open to when it finally closes is called the **Duration** of the valve timing. Typical factory figures for the bevel drive 900SS are around 320° for both exhaust and inlet valves although these are running clearance figures and so are optimistic!

Another term mentioned above is **Valve Overlap**. This figure describes the number of degrees where both the inlet and exhaust valves are opened at the same time. The reasons behind this were discussed in the 'Advanced' section.

The duration and overlap can be worked out from the factory figures although as you will see later these do not always match the cam that is fitted to the bike! Lets take the bevel 900SS factory figures and do some calculations. Remember all degree figures are for the crankshaft and must be halved if applied to the camshaft.

Note, factory timing at **running** clearance for this model so figures are enhanced!

The exhaust opens 80° BBDC and closes 58° ATDC. The exhaust valve duration is 80° (To BDC) + 180° (BDC to TDC) + 58° (ATDC) = 318°.

The inlet opens 63° BTDC and closes 83° ABDC. The inlet valve duration is 63° (To TDC) + 180° (TDC to BDC) + 83° (ABDC) = 326°.

The overlap is the period of degrees where both valves are open. For this cam the overlap is 63° (BTDC inlet opens) + 58° (ATDC exhaust closes) = 121°.

The other figures we are interested in is the point of **Maximum Lift** (ML) of each valve. Normally this will be half way between the opening and closing degree figures if the cam is symmetrical. So work out where the point of ML sould be we divide the duration of each valve in half and then add that figure to the opening degree figure.

The exhaust valve duration is 318° divide by 2 = 159°. The exhaust opens 80° BBDC (= 260° BTDC) plus 159° (Half exhaust duration). Therefore Exhaust Maximum Lift should be at (260°-159°) = 101° BTDC.

The inlet valve duration is 326° divide by 2 = 163°. The inlet opens 63° BTDC plus 163° (Half inlet duration). Therefore Inlet Maximum Lift should be at (163°-63°) = 100° ATDC.

It is common to refer to these cams as '101°/100° lobe center cams' and as you have probably seen there is a symmetry between the ML figures either side of TDC. This is called **Lobe Center Symmetry** and most engines have the two ML's at equal distance away from TDC. We will use this symmetry to decide if the cam is advanced or retarded when we calculate the real ML figures.

Figure 2 shows the relationship between the opening, closing and maximum lift of each valve for the factory specifications for the 900SS bevel drive.

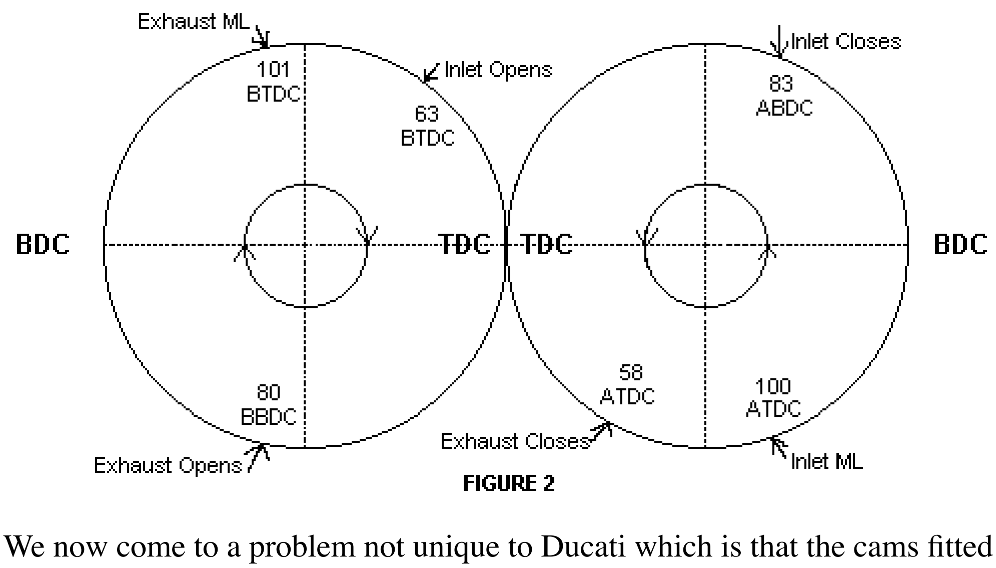

FIGURE 2

We now come to a problem not unique to Ducati which is that the cams fitted to the engines do not necessarily match the ones specified in the manual! For whatever reason most 900SS bevels were actually fitted with cams with a lobe center symmetry of '96°/96°' which are not quite as good a cam as the '101°/100°' items. Don't worry about which cams are fitted to your machine as when we measure the ML it will soon become obvious what you have got! The point is don't assume that the factory figures relate directly to what is acually fitted to your machine!

Figure 3 shows the timing diagram for the 900SS with '96°/96°' cams. Note that the opening and closing figures shown on the diagram assume that these cams have the same duration as the '101°/100°' cams although this may not be the case. As I have no factory figures for the '96°/96°' cams the only known points are the two ML's.

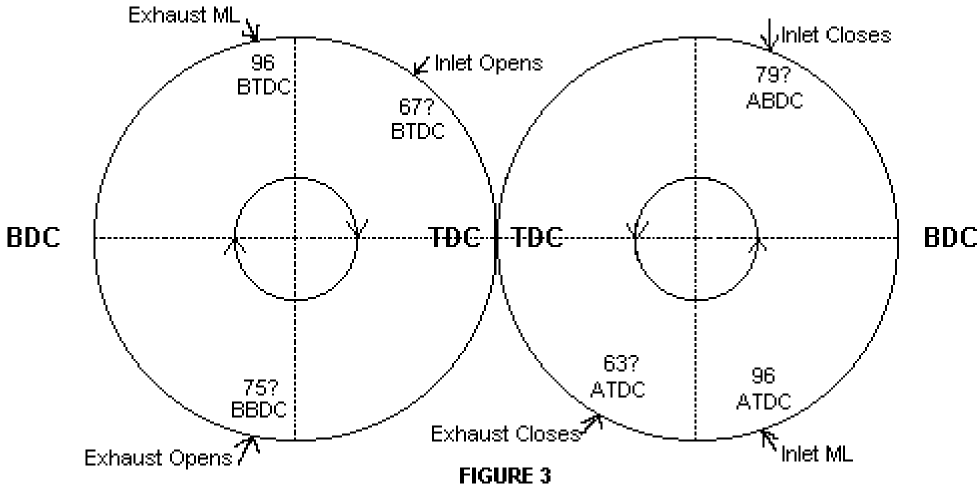

FIGURE 3

The Black Mystic Art of Cam Timing!

Part Two

By Peter Shearman

MEASURING THE TIMING

Continuing on from last month we will now delve into the various ways of describing and measuring the cam timing.

Before we proceed further it is important to note that cam timing figures are affected by worn cam profiles, worn or incorrect rocker follower profiles, rocker to valve seat height and wear, amount of lift, etc. Ensure that all the above items are checked and are within factory specifications to get the best accuracy with your cam timing.

The intention of this article is to guide people through measuring the cam timing of their road going motorcycle(s) with a fair degree of accuracy. If you are doing cam timing on a racing machine then you may need to do a lot more research and work with much more accuracy to achieve the best results from your engine. This would also include dyno testing at various stages as the best 'theory' does not always prove the best in practise!

There are three main methods for specifying and measuring the cam timing and each will give different figures. It is important when specifying any cam timing to state where the timing was checked and why it was done at that point. Good cam timing figures will not only give information on degrees opening and closing but also what clearances were used and/or at what lift this was measured.

Where do we measure the timing and why?

The start and finish of a normal cam's profile consists of the opening and closing **Clearance Ramps.** The opening clearance ramp is very gentle on lift firstly to close up the rocker to valve clearance and past that to accelerate the valve gently off its seat. If you try to accelerate the valve too quickly it leads to dramatically increased wear and tear on all valve train components. This has even more relevance in a valve spring motor where the inertia of the spring is overcome as well as the valve. Similarly when the valve is almost fully closed you want to slow it down gently so that it doesn't hammer hard into the seat that again would cause increased valve and seat wear.

With th valve (relatively) slowly lifting off the seat there is almost no gas flow until the valve has reached around 0.5mm of lift and it is not until past this point that we get onto the 'true' cam profile that results in rapid lift and appreciable gas flow past the valve.

1. Timing at Running Clearance.

Timing at running clearance is when timing figures are given with the rocker to valve clearance set to the standard factory setting for normal engine running. The opening timing measurement is made when the factory clearance closes up and the valve just starts to move and conversely the closing timing measurement is made at the point where the valve has just hit the seat but before any clearance opens up.

Trying to measure the exact moment when the valve starts to move or finishes moving is very difficult with running clearance's, due to the slow rate of lift, and so can give rise to inaccurate figures. Measurements with this method are taken on the clearance ramps and not the 'true' cam profile and the valves are not effectively open till well past this point so the figures arrived at are not a true indication of the engines 'breathability'. This method gives unrealistically long duration and overlap figures and is used by manufacturers to give enhanced figures for advertising advantage where prospective buyers think longer must be better!

2. Timing at Checking Clearance.

A much more realistic place to measure the valve timing is at a lift of 1.00 mm (40 Thousands of an inch). At this point we are well past the clearance ramps and onto the 'working' part of the cam profile. Lift at this point on the cam is rapid making it easier to measure the exact angle when the valve starts to move and it also gives more realistic 'breathing' figures as the valve has opened sufficiently for some 'real' gas flow to occur.

The standard way to measure this timing is at the point where the valve starts to move using a **Checking Clearance** between rocker and valve of 1.00 mm (ie 1.00 mm lift). This figure of 1.00 mm is a cam timing standard and usually if no specific checking clearance figures are mentioned then it is fairly safe to assume they would have been made at this lift but beware 'factory' figures as discussed previously!

If you use methods **1** or **2** you will end up with an opening and a closing degree figure for each valve. These are compared directly with the factory figures (assuming they match your cam) to show if your timing is retarded, advanced or close enough!

If you're not convinced that the figures and the cam match then some simple calculation, as discussed earlier, will give you the duration of the valve opening and the theoretical point of ML. To check this figure or if you don't have or trust the factory timing figures for your cam then you should use method 3 where you will end up directly with the point of Maximum Lift.

3. Timing by Lobe Center Angle.

If you have no factory figures for your cam then a more accurate place to measure cam timing is at the point of Maximum Valve Lift (ML). This point is easier to determine without resorting to changing clearances although like finding TDC for the piston there is a trick to doing it accurately as both the piston and the valve do not move for a few degrees of crankshaft rotation at these points.

This is also the simplest method as you are only dealing with a single figure for each cam and the point of ML can be measured easily and accurately. When you have the figures for maximum lift of both the inlet and exhaust valves it is a simple calculation to work out the **Lobe Center Angle (LCA)** which by definition is the number of degrees between valve ML and TDC (Exhaust).

If the cam lobes are symmetrical then LCA's for both valves should be the same ie The half way point between the ML's of the exhaust valve and the inlet valve should work out to be TDC (Exhaust) for a normal engine if the timing is correct. If the figure you get is before TDC then the valve timing is advanced ie the valves are opening sooner than specified. If the figure you get is after TDC then the valve timing is retarded ie the valves are opening later than specified. (Note that in some specialised engines' cam lobes may not be symmetrical hence LCA's may not be equal. Consult the cam timing figures or manufacturer for more information.).

Before starting any measurement you will need some special equipment to do the job properly.

- A large degree wheel with a length of 8 mm threaded rod or a long 8 mm bolt else the factory tool for turning the engine with a degree wheel attached.
- A rigid pointer that will remain in place once set.
- A positive stop tool for finding piston TDC.
- A dial gauge with mounting system. (The club has a dial gauge & magnetic stand)
- A steel plate to attach the gauge and stand to engine
- A calculator or slide rule for averaging timing readings.

Finding the Exact Top Dead Center.

Before you start you will need to determine the piston TDC accurately so that you can set the degree wheel to reflect piston timing. Whilst the crankshaft is moving a few degrees either side of top dead center the piston is virtually stationary so any measurement at this point will not be accurate enough for the purposes of cam timing. The accurate way to measure TDC is by using some type of 'Positive Stop' device.

The idea behind this is that if you can stop the piston at the same position on its stroke both before and after TDC and mark the degree wheel at both points then TDC must be exactly half way between these two marks on the degree wheel. You can make your own positive stop device with an old spark plug body drilled out and a piece of threaded rod or bolt inserted and fixed in place. See references at the end of part 3 for articles on making and using this type of tool.

Attach the degree wheel to the crankshaft. You will need some way of turning the crankshaft without upsetting the degree wheel either use the factory disc tool, which I found had too much play, remove the side cover so you can get a socket onto the crank nut or select 5th gear and turn the rear wheel. Attach the pointer to an engine cover screw so that it lines up with the degree readings on the edge of the timing disk.

Remove both spark plugs and using a blunt probe locate approximate TDC on the first cylinder you wish to check. Move the timing disk on its bolt so that the pointer lines up with 0° then tighten the disk so that it cannot move on the bolt. Turn the engine forward slightly so that you can screw the positive stop device in without hitting the piston. Then carefully turn the motor back until the piston touches the stop device. Mark the degree wheel next to the pointer then turn the engine forward through almost a full turn until the piston again just touches the stop device. Mark this point on the degree wheel then calculate and make a third mark exactly half way between the first two. This is the real piston TDC point, so remove the stop device and turn the engine until this mark is next to the pointer and now your engine is exactly at TDC.

You will probably find that the mark does not coincide exactly with 0° on the degree wheel due to our first setting being approximate so to make life easier during timing measurements bend the pointer slightly so that it now points to 0° (**Do Not** move the engine!). Rub out all your marks on the wheel and go through the whole process again using the stop device and now you should find that the third mark lines up exactly with 0° on the wheel. Make sure that the engine is at TDC with the degree wheel reading 0° before continuing! Note that if during any part of the measuring procedure you suspect that the degree wheel may have moved in relation to the engine then recheck TDC using the above method before continuing.

If you are using 'running' or 'checking' clearances then you do not need to set up a dial gauge at this time. These degree readings are taken when the 'clearance' just closes up during engine rotation.

Measuring at Running Clearance.

If you are using running clearances then obviously these must be set exactly to the factory specifications before checking the timing. Turn the engine over until the rocker starts to move then continue to turn the engine slowly until the running clearance is reduced to zero. Note down the degree reading at this point that will be your 'valve opening' figure. Continue turning the engine over until the valve has just closed and note down the degree reading at this point that will be your 'valve closing' figure. Compare your figures with those in the manual to find how close your timing is to factory specifications. Remember that these figures are not very accurate or realistic and that measuring the lobe center angle will give you better figures to work with.

Measuring at Checking Clearance.

If you are using checking clearances there are two ways to achieve this. If you have screw adjusters or a selection of shims you can either close the clearance up to zero and measure the timing at 1.00 mm valve lift or open up the clearance to 1.00 mm and measure when the valve starts or stops moving.

If you don't have a selection of shims there is an easy way to achieve the checking clearance. Start by fitting a loose shim in place that leaves a clearance greater than 1.00 mm, then fill the gap with a combination of feeler gauge blades till you get a snug fit. Next subtract the specified checking clearance from the feeler gauge stack (1.00 mm) and this will leave you with the correct checking clearance! With the blades in place turn the engine over until the gauges are a snug fit and take your 'valve opening' reading off the degree wheel. Remove the gauges then continue turning the engine over until the valve closes and keep turning till the feeler stack just slides into the gap again then take your 'valve closing' reading off the degree wheel. Compare your figures with those in the manual to find out if your timing is close to factory specifications.

Measuring at Maximum Lift.

If you are using the 'maximum lift' method then you need to set up the dial gauge. The pointer must rest on the rocker directly over the valve and the instrument be solidly fixed so that it cannot move at all during a full rotation of the engine. A flat piece of steel plate drilled with two holes to match the rocker cover bolt holes will provide a sturdy support for the magnetic stand base. Adjust the gauge so that full movement of the valve does not exceed the limits of the gauge.

Finding the point of maximum valve lift needs an approach similar to finding piston TDC as at this point moving the engine through several degrees will not produce any movement at the valve. Turn the engine over slowly and watch the dial gauge carefully as the valve moves down and note the reading on the gauge when the valve reaches its maximum depression (lift). Pick an arbitrary valve lift figure say 0.05 mm **less** than the maximum lift and rotate the engine forward through almost a full cycle (two rotations) until the dial gauge reads the arbitrary lift figure just before the valve has reached maximum lift. Mark the degree wheel at this point then continue rotating the engine forward past maximum lift until the dial gauge once again reads the arbitrary lift figure. Once again mark the degree wheel at this point and as with finding the piston TDC calculate a third mark exactly half way between the first two that gives you the exact point of maximum valve lift.

Maximum Lift Example.

The following example shows measurements and calculations from my 900SS bevel. Note that I used an arbitrary lift figure of 0.02 mm but this should have no effect on the final timing figures. Take all measurements with the engine moving in its normal forward direction as 'play' in the cam drive system will give different readings in reverse that will not be relevant.

Vertical Inlet

Rough readings; Opens approximately 45° BTDC, ML approximately 107° ATDC
Forward 0.02 mm **before** ML = 85.5° ATDC Forward 0.02 mm **after** ML = 123.5° ATDC
123.5° - 85.5° = 38° divided by 2 = 19°
Therefore the **Vertical Inlet ML** = 85.5° + 19° = **104.5° ATDC**.
Now we need to do the same measurements and calculations for the Vertical Exhaust valve

Vertical Exhaust

Rough readings; Opens approximately 67° BBDC, ML approximately 83° BTDC
Forward 0.02 mm **before** ML = 107.5° BTDC Forward 0.02 mm **after** ML = 65.5°BTDC
107.5° - 65.5° = 42° divided by 2 = 21°
Therefore the **Vertical Exhaust ML** = 65.5° + 21° = **86.5° BTDC**.
From these two figures we can now work out the type of cam that is fitted to the bike.
The Lobe Center Angle for the Vertical cylinder is = Inlet ML + Exhaust ML divided by two.
104.5° ATDC + 86.5° BTDC = 191° divide by two = **95.5°**

The lobe center angle for the vertical cylinder camshaft is **96°**. As discussed earlier the points of maximum lift should be symmetrical about TDC and so we can now calculate whether this cam is advanced or retarded and by how many degrees.

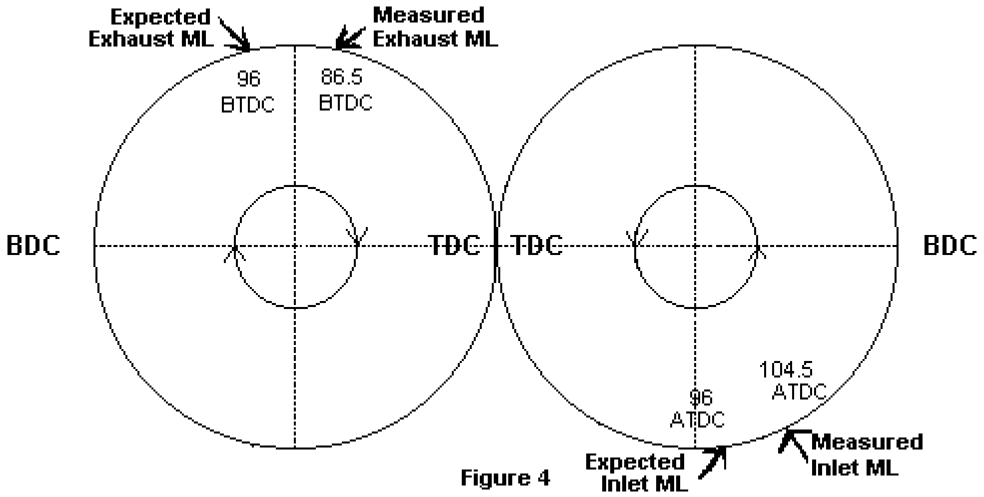

Figure 4

Figure 4 shows the difference between where the cam timing has been measured and where it should be for the standard timing with equal lobe center angles.

Vertical Cylinder Valve Timing is...

86.5° (Measured LCA Exhaust) - 95.5° (Calculated Lobe Center Angle) = **9.0° Retarded**
or 95.5° (Calculated Lobe Center Angle) - 104.5 (Measured LCA Inlet) = **9.0° Retarded**
Retarded valve timing means that the valves are opening later than expected.
Now the whole procedure detailed previously is repeated again for the **Horizontal** Cylinder. I will skip some of the calculations and just work with the figures obtained.

The Horizontal Inlet ML = **93.5° ATDC.**
The Horizontal Exhaust ML = **99.5° BTDC.**
The Lobe Center Angle for the Horizontal cylinder is = Inlet ML + Exhaust ML divided by two.
93.5° + 99.5° = 193° divide by two = **96.5°**

Therefore we have a **96°** lobe center camshaft on the horizontal cylinder so both are the same type of cam as expected! **Never** assume this without measuring both cams as stranger combinations of parts have appeared on Ducati's straight from the factory! If the bike's full history is unknown there is always the possibility that a different replacement cam was fitted at some stage.

Horizontal Valve Timing is...

96.5° (Measured Lobe Center Angle) - 93.5° (Calculated Lobe Center Angle) = **3.0° Advanced**
Advanced valve timing means that the valves are opening earlier than expected.
From these two sets of figures you can see that the difference in cam timing between the vertical and horizontal cylinders on my 900SS bevel was
9.0° Retarded + 3.0° Advanced = **12.0 crankshaft degrees!**

This 12 degree difference is not exceptional as some early bevel twins have been measured up to 28 crankshaft degrees retarded and with similar differences in cam timing between front and rear cylinders!

This is often the hidden reason why two externally identical bikes can have huge differences in top end speed, fuel consumption, and mid range torque. Cam timing variations will also effect compression readings significantly and this can explain why a bike with two fully reconditioned cylinders and heads will still give different compression readings on each cylinder!

Now that you have done all your measurements and calculations you need to make a decision on whether or not to change the valve timing. This decision should take into account the following factors.

How far out is the timing between the two cylinders? Factory specifications give +/- 5° on cam timing. For road use I would leave the timing if there was less than 5° difference between the two cylinders. Obviously for perfect engine balance the closer the two cylinder's valve timings are the smoother the engine will run.

How far out is the timing in relation to where it should be? Once again using factory specifications if the timing was within +/- 5° of TDC exhaust then I would leave it for road use.

Obviously these two figures have to be looked at individually for each cylinder as you could have a worst case where one cylinder was say 5° retarded timing wise and the other cylinder was 5° different from it also retarded which would put the second cylinder 10° out!

You will also have to look at the cost's involved verses the expected improvement. If you have a square case bevel then the cost could be as little as some of your time, but if you have a belt drive and get an expert to do it all for you then the costs could be considerable. If you're still not sure take your figures to someone who knows Ducati engines and get an 'expert' opinion.

Next month we will get into the thick of it by actually changing the cam timing and finding that not only does the engine still run but that it runs much smoother, has better compression and performs better (hopefully without any expensive noises).

Peter Shearman

Part Three

by Peter Shearman

CHANGING THE VALVE TIMING

Last month we had finally found out if our cam timing was out and by how much. Now you need to make a decision on whether or not to change the valve timing. This will be based on how far out the timing is both in relation to between the cylinders and also in relation to where it should be! You may feel that your timing is 'close enough' and you don't want to go any further, but remember any changes that you make can easily be reversed by going back to the original timing marks.

Another point to think about before changing the timing is how easily can it be changed on your machine. If you own a bevel drive then the timing can be changed by 'playing' with the cam drive gears. Square case models are the easiest with an infinite range of adjustment available by moving the double straight cut/bevel gear in the timing chest. Round case models are more fiddly but once again changes can be made without spending any money. Belt drive owners will have to get additional keyways cut in their cam drive sprockets or else get change over sprockets with these keyways already cut. Although this is not too expensive the range of adjustment steps is not as great as the bevel drives but if you know exactly how far you want the timing moved then this information may help the machinist to put the keyway close to the right spot. Offset keys are another option available to move the timing by a small amount on the belt drive models.

For ideal performance tuning you need to be able to change the exhaust timing independent of the inlet timing. This can only be done when you have separate camshafts for inlet and exhaust. If you have this capability then you can change the timing to achieve a desired change in performance. Consult the references for more information if your bike has separate camshafts. Most Dukes have exhaust and inlet cam lobes on the same camshaft so individual changing of one in relation to the other is not possible without removing the camshaft and replacing it with a different specification cam or having it professionally built up and reground to new specifications.

If the engine has not been heavily modified then the main reason for 'dialling in' the cams is to match both cylinders together and maybe give them a little advance if this is known to improve performance. In the case of bevel drive square case machines around 3-4° advance gives the best all round performance based on peoples experiences. Advancing more than 4° can improve mid range grunt but at the expense of top end power. This may still be an advantage if you race your bike on tight circuits like Winton or Broadford but I would not recommend it for normal road use.

CAUTION Before you proceed with changing the timing please note that you can do permanent engine damage if you turn the engine over with the cam timing way off mark. Always double check your figures and turn the engine over slowly by hand to ensure that the valves are not hitting the piston or each other during two full rotations. If all seems OK then start the bike but if you hear any strange noises shut down immediately and ring your bank manager before investigating further!

Square Case Bevel Engines

I will run through the way I changed the cam timing on my 900 SS Bevel drive. Round cases and belts are covered in lesser detail in separate sections.

Last month we found that in my 900 SS bevel the vertical cylinder was 9° retarded and the horizontal cylinder was 3° advanced. As discussed previously the ideal setting for this type of motor is between 3 to 4 degrees advanced based on lobe centre measurements. As the horizontal cylinder was already at 3° advanced I decided not to move this cam as it was close enough to the ideal setting. The next step therefore was to bring the vertical cam into line with the horizontal by advancing it 12° so that it was also at 3° advanced.

Changing the cam timing on square case motors is achieved by 'juggling' the timing gears in the timing chest on the right hand side of the engine. With reference to diagram 1 below the cam drive is as follows. Straight cut double gear 14 sits on the end of the crankshaft. The inner gear drives the oil pump and the outer gear with 24 teeth drives both straight cut gear 9's, one for each camshaft, which have 36 teeth.

Straight cut gear 9 is joined to bevel gear 10 via key 11. ie these two gears turn as one. Bevel gear 10 has 23 teeth and mates to an identical 23 tooth bevel gear (Not shown) which drives the shaft in the cam drive tube. At the cylinder head a 21 tooth bevel gear mates with a 28 tooth bevel gear connected to the camshaft. The reason these seemingly strange combination of gears is used is to spread the load evenly over the gear teeth rather than having the same few teeth always taking the load of opening the valves. This is called the 'hunting tooth' principle and has been used on gear driven camshafts for many years.

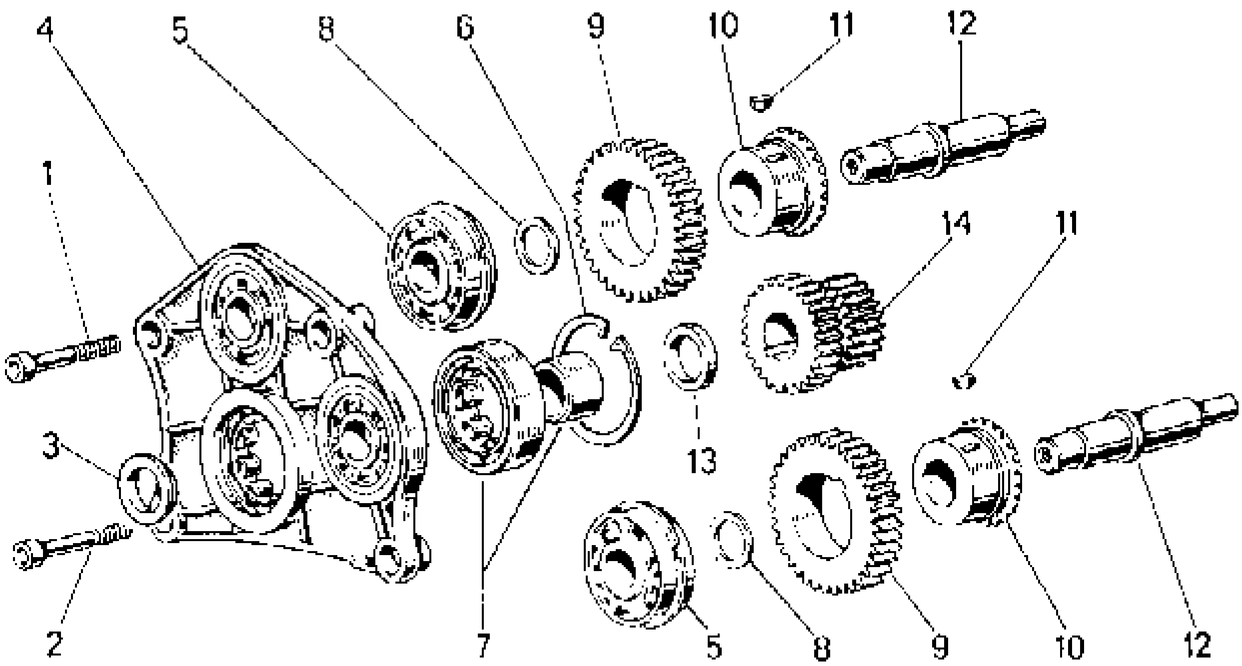

DIAGRAM 1, Square Case Bevel Cam Drive

So our overall cam drive ratio is :-
24/36 = 2/3 . . . 23/23 = 1/1 . . . 21/28 = 3/4 . . . 2/3 * 1/1 *3/4 = 6/12 = 1/2.
The camshaft runs at half crankshaft speed as discussed in the first article in this series.
If we move the 24/36 straight cut combination by one tooth we get a change of
. . . 360°/24 = 15° in relation to the crankshaft.

If we move the 23/23 bevel combination by one tooth we get a change of
. . . 360°/23 = 15.652° **but** as this combination is spinning at 2/3 crankshaft speed then
. . . 15.652° * 3/2 = 23.478° in relation to the crankshaft.

Now on their own these figures are too large to use unless your timing is more than 15° out but because gears 9 and 10 are joined together we can use a combination of moves to give us anything from half a degree up to a 23 degree change.

As an example say we move the 23/23 bevel gear combination by one tooth and the 24/36 straight cut combination by one tooth also. If we move one set back a tooth and the other set forward a tooth the difference is 23.5° minus 15° = 8.5°. Depending on which way we move each gear this can achieve an 8.5° advance or retarding of the cam timing.

Because of the difference in degrees of moving each set by one tooth there are many possible combinations each of which results in a different overall degree change. If we put these figures into a computer program and tell it print out all possible combinations of tooth movement we will get a Printout many pages long. If in this program we limit the number of teeth moved to a workable figure say 15 and limit the maximum number of degrees changed to plus or minus 15° then this gives us one page of possibilities from 0.65° in around 1° steps up to 15°

In my case I needed a 12° change. The program Printout tells me that if I move the 24/36 straight cut gears 7 teeth in one direction and the 23/23 bevel pair 5 teeth the other way I will get...

(5 * 23.487°) - (7 * 15°) = 117.435° - 105° = 12.435°

By undoing the nut on the end of the crankshaft the alternator rotor and distance piece can be removed. Turn the engine over until all the timing dots line up. This will be TDC compression on the vertical cylinder. You then need to remove the timing gear support plate being careful that all shims on the shafts are kept in their place and are not mixed up.

Now comes the tricky part which way do we move the gears? Always keep in mind that we want to advance the camshaft that is we want the valves to open earlier. The camshaft turns clockwise viewed from the timing side of the engine. Remember the crankshaft runs anticlockwise (backwards) when viewed from the same side. The biggest change in degrees is made by moving the 23/23 bevel pair 5 teeth so we must advance the camshaft by 117.435° with this move and then retard it 105° with the 7 tooth move of the straight cut gears.

Start by removing the double straight cut gear 14 from its key and without moving any other components pull the straight/bevel double gear 9&10 out of mesh with the cam drive shaft bevel gear. Rotate gear 9&10 anticlockwise by 5 teeth and then re-engage it. This means that the timing dot on bevel gear 10 is now 5 teeth to the left of it's matching dot on the cam drive shaft bevel.

Now slide the double straight cut gear 14 onto the keyway and almost into mesh and you will find that the timing dot on gear 9 is a number of teeth (not necessarily an exact number) anticlockwise from the dot on gear 14. At this point we have not moved the camshaft and now we will move it the 12.435° required. This time we have to move gear 9 without taking the gear out of mesh. ie we move gear 9 and all components in the drive train to the particular cam shaft. As each tooth on gear 9 is 15° you should find that you only have to move gear 9 a little less than one tooth clockwise so that the timing dot on gear 9 is now 7 teeth anticlockwise away from the timing dot on gear 14.

When you have changed the timing do a quick check to see that you have not miscalculated and put it too far out. With the vertical piston at TDC compression, it should still be there if you haven't moved the crankshaft, check both pairs of head bevels and you should find that the timing dots match up and are relatively close together.

Remember as discussed in an earlier article that the camshaft will only be advanced by 6.217° (12.435° divided by 2) as the camshaft turns at half crankshaft speed. As we haven't touched the bevel gears on the head you will find that the dots still line up although they may not be exactly touching now as the camshaft has been moved by a little over 6 degrees. This means that when head work is required you can still match up the top timing marks and with a little jiggling drop the heads into place the same as before.

If all seems OK at this point repeat the whole measuring procedure to check that the timing is exactly where you want it to be and that you haven't moved the timing in the wrong direction. If you think you have completely stuffed it up never fear as you only need to align all the timing dots again to get back the standard timing!

Of course once you have changed the timing the dots on the lower bevel gear 10 and on the straight cut gear 9 will no longer line up with their mating gears. You should use an engraver or similar to put a new mark on both these gears (9&10) and also make a drawing of how it looks so that if the engine has to come apart you can restore your modified timing without going through the whole measuring procedure again.

Round Case Bevel Engines

With the round case motors there is no straight/bevel double gear and so changes have to be made to the timing case bevel gears as well as the head bevel gears to achieve a change. Diagram 2 below shows the cam gear drive train.

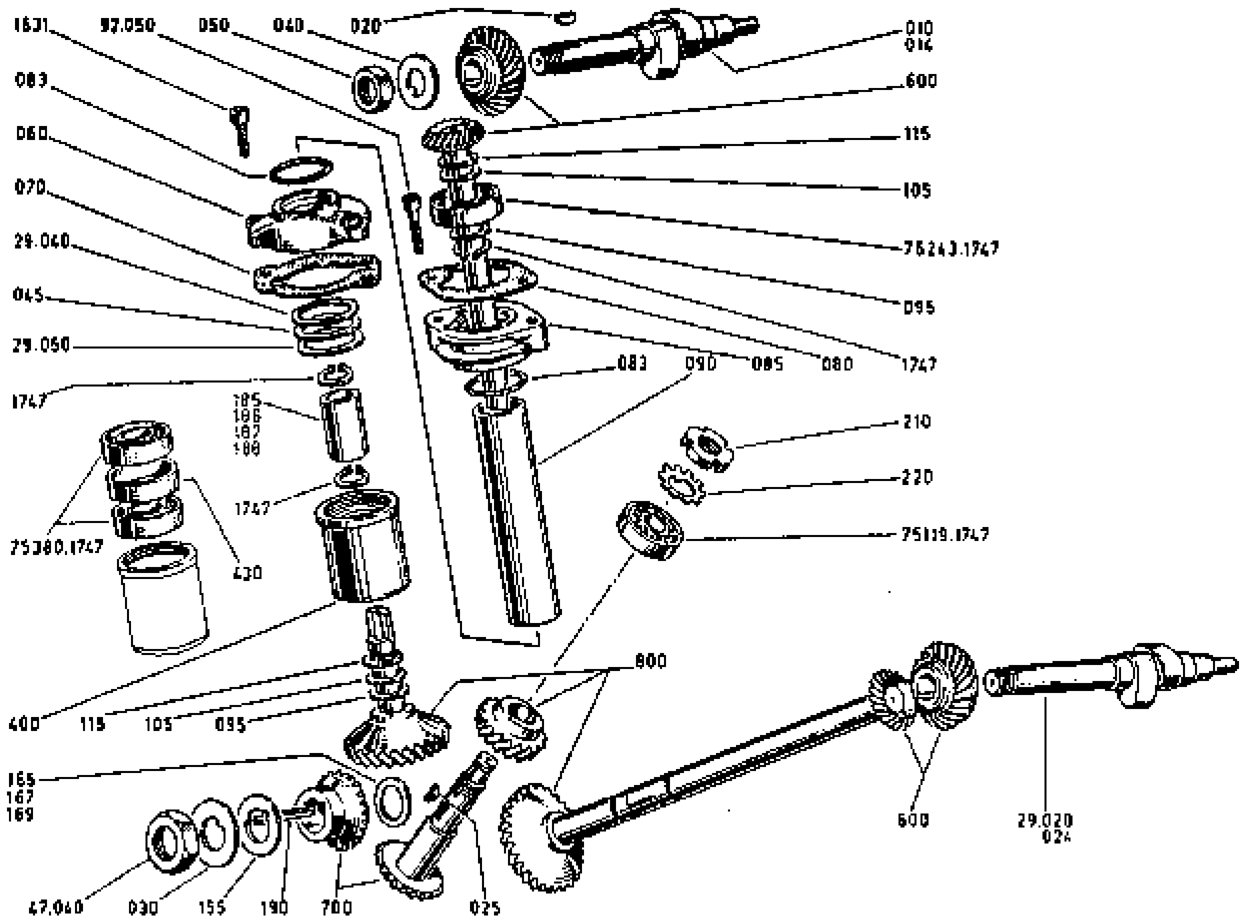

DIAGRAM 2, Round Case Bevel Cam Drive.

In round case motors, with reference to diagram 2, the cam drive is as follows. A bevel gear with 23 teeth sits on the end of the crankshaft and this drives a matching 23 tooth gear (Set 700) on a short shaft. This shaft drives the points cam via a two to one reduction gear set (Not shown) under the points drive base. In the middle of this shaft is a 24 tooth bevel gear which drives two 36 tooth bevel gears, one for each cam drive shaft. (Set 800). At the cylinder head a 21 tooth bevel gear mates with a 28 tooth bevel gear connected to the camshaft. (Set 600).

So our overall cam drive ratio is :-
23/23 = 1/1 . . . 24/36 = 2/3 . . . 21/28 = 3/4 . . . 1/1 * 2/3 *3/4 = 6/12 = 1/2.
If we move the 24/36 bevel gear combination by one tooth we get a change of . . . 360°/24 = 15° in

relation to the crankshaft.
As there is no double gear on this model the only other place we can change the timing is at the head bevels.
If we move the 21/28 bevel combination by one tooth we get a change of . . . 360°/21 = 17.143° **but** as the 21 tooth gear is spinning at 2/3 crankshaft speed then, . . . 17.143° * 3/2 = 25.714° in relation to the crankshaft.

If we move one set back a tooth and the other set forward a tooth the difference is 25.714° minus 15° = 10.714°. Depending on which way we move each gear this can achieve a 10.7° advance or retarding of the cam timing.

Using our computer program again we find there are not quite as many different combinations for this engine but we can still achieve a fairly close result. Using our 12° figure and checking the chart we find that we can achieve 10.7° by moving each set one tooth as detailed above but the next closest is 12.85° by moving the 24/36 gears 6 teeth one way and the 21/28 gears 4 teeth the other way.

The method for achieving a change in cam timing is the same as for the square case motor but in this case the head bevel dots will not line up and additional marking will be required. It is also worth noting that a special tool is required to allow the cam drive shaft bevels to be removed from mesh in the round case motors. (The Club has one of these tools for loan to members.)

NOTE 1. . . If you are lining up the lower timing marks in the timing chest of a round case motor you will notice that the central bevel gear, which drives the two cam drive shaft bevel gears (In set 800), has two timing dots 180° apart which match a single timing dot on each cam drive shaft bevel gear. When the bike left the factory these two dots on the central gear were painted either red or green and matching paint was applied to the single dots on the mating gears. I think green was used for the vertical cylinder and red for the horizontal. It is probable that this paint will be long gone when you come to do the timing so be aware that you can have all the timing marks lined up but still have the point's cam 180° out! The point's cam must be checked and should be just about to open the points for the vertical cylinder (The points closest to the condensers). If this is not the case then rotate the crankshaft three times and all the marks should line up again as well as having the vertical points just about to open. To avoid future problems clean and repaint the dots before reassembly.

NOTE 2. . . The points drive has a set of 2 to 1 reduction gears under the point's body. There is a timing dot on the small drive gear that matches up with a painted mark on the large gear. As mentioned previously this paint may be long gone so if you pull the points drive out be sure to mark the large gear with an engraver, paint or similar to aid correct re-assembly.

As far a round case timing goes the factory figures give a lobe centre angle of 99.5°/98°. When I measured my 750 GT I came up with a lobe centre figure of around 108° so true to form the cam specified in the manual does not match the cam fitted to my machine. Speaking with Brook Henry he believes that there were two different cam grinds for both the GT and the Sport so don't assume without measuring.

According to my measurements on the GT if the lobe centre of 108° is standard then my horizontal cylinder was around 7.5° advanced and the vertical cylinder was 17.5° advanced! So there is a 10° difference and both cams seem over advanced. As stated before more advance gives better mid range power and this is what GT's are famous for. At this time I have not found any information on what would be the best setting for the GT. As changing the round case timing is more involved I probably won't attempt it till the next engine rebuild. If anyone has some detailed information on the standard GT cam timing or the best place to set it then please pass this information on to Club members either via myself or through the pages of Desmoto.

Belt Drive Models

As discussed previously you will need to get your camshaft drive pulleys modified with extra keyways or else get change over pulleys with this work already done. I can't explain the fine detail of this procedure as I have only seen it done at Cafe Racer one service day. The idea is that the extra keyways are set several degrees either side of standard and by trial and error you select the keyway which puts your timing closest to the wanted figure. Set the engine so that the cam is at the point of maximum lift then lock it in place. Remove the belt and camshaft pulley then turn the engine to the wanted figure for maximum lift. By turning the pulley you should be able to find the keyway that allows the closest fit between the belt teeth and the keyway. Also offset keys are another possible way to change your timing by a smaller amount. However you change the timing don't forget to double check your figures by repeating the measurement process.

Summary

The intention of this series of articles was to stir an interest in the black mystic art of cam timing and is really only a starting point for discussion and research for anyone interested in delving further into this complex and fascinating subject. Several of the references mentioned go into much greater detail in specific areas and books such as 'Tuning for Speed' by Phil Irving have whole chapters devoted to this subject.

There are also many Ducati and 'after market' cams available with more radical timing and/or lift to suit racing and other applications. With your new found knowledge of cam timing you should at least be able to understand the conversation when dealing with the suppliers of these cams who should be able to provide you with a cam to suit your specific requirements.

Thanks must go to a couple of cam timing 'experts' who were kind enough to proof read and assist with clarifications and additions to these articles. The fact that these gentlemen did not wish to be credited by name lends credence to the fact that nobody will admit to being a cam timing 'expert'! Still I thank them for their time and effort to bring you a more accurate article!

Peter Shearman

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