

University of Wales Trinity Saint David

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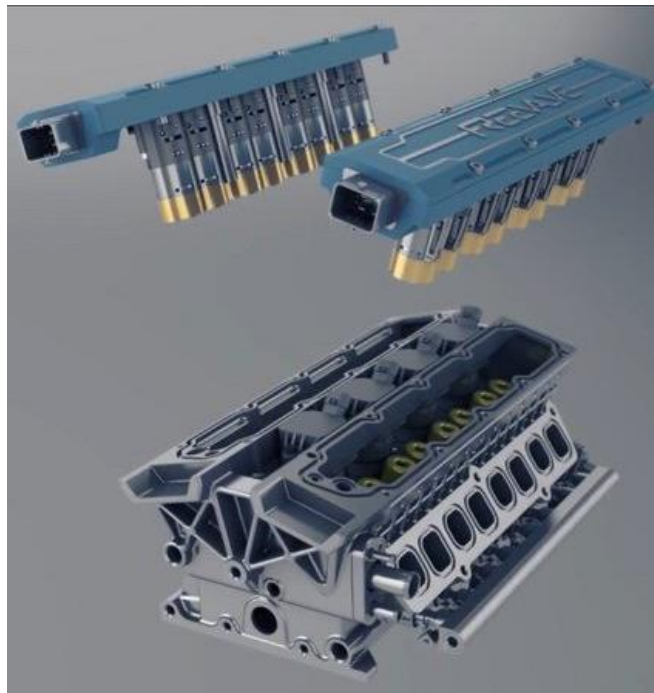
Improving volumetric flow and efficiency by using fully variable
valve actuation (FVVA)

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Abstract:

This project is looking at improving volumetric flow and efficiency by using an actuation system known as FVVA (fully variable valve actuation) this system is a replacement for the conventional camshaft engine. As part of the testing it looked at the flow of a normal camshaft engine cylinder head and see how much the exhaust and intake valve flow at different increments of opening, by doing this can then see in a graph what happens as the valve is fully open and when it reaches peak point. The camshaft lobe was also measured to produced camshaft lift, the measurements from this was then put into excel to be converted from camshaft lift to valve lift. This was done by using an excel spread sheet and using some calculations. Once the excel spread sheet was completed could then see the profile of the camshaft compared to the actuation system and where gains could be made. A basic 3D model was made in cad after being made then used basic motion to represent the actuation system and a small graph was produced just to show the actuation working. The overall project concludes that the FVVA is a big improvement for volumetric flow and efficiency and with this system there are many other advantages that outweigh the expensive of the camshaft less engine, some examples of the advantages of this engine include improved fuel consumption and lower emission more will be discussed in the report.

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1. Introduction:

This project is looking at improving the flow of air that passes the intake valve and into the chamber, one way to achieve this is by replacing the conventional camshaft with FVVA (fully variable valve actuation). Why it is important to improve the air flow, there are many reason for this reduction in emission more power if wanted, fuel economy and engine efficiency. By using FVVA there are many advantages such as, opening the valve earlier which will allow max air flow for longer, less overlap, cylinder deactivation, less friction, no throttles, can adjust valve lift per rpm, engine weight is less and variable valve lift and timing all of these advantages will be discuss further on in this project within more detail. As part of this project the camshaft profile was produced in excel, also the flow of the valve at different increments of the valve opening can also be seen. There is a comparison from camshaft to FVVA which is displayed, due to facility's the FVVA produced was done theoretically in CAD and excel. The flow test was done using a flow bench and the camshaft lobe profile was measured using an optical dividing head. The cylinder head used to retrieve flow test data was a Yamaha R6 cylinder head and a DTI (dial test indicator), the camshaft used in the optical dividing head was also of a Yamaha R6. The equipment used to compete the test will be explained later on in this project. The aim of this project is to look at camshaft less engine by using actuators instead of camshaft and to see if this will improve volumetric flow and efficiency and what are the advantages of this.

2. Literature review:

Volumetric efficiency is how much air and fuel is in the cylinder, in prospective with regular atmospheric air, for an engine to be one hundred percent efficient it would need fuel and air at atmospheric pressure. If an engine is fitted with a turbocharger or a supercharger it is said that the volumetric efficiency can be more than one hundred percent efficient this is caused by the increase in pressure from either turbo charger or supercharger. If an engine cylinder has vacuum pulling then the engine efficiency will reduce and be less than one hundred percent efficient. Most engine that are naturally aspirated run at about eighty percent volumetric efficiency, there many things that can cause reductions in the efficiency such as casting irregularities, not having a smooth intake pipes and having bends in the intake system all these have impact on getting the air in as best as possible. This is why company's port and polish cylinder head to improve the air flow as much as possible the more air can get into the engine the better fuel efficiency and more power if desired (Victor aviation.com, 2019).

There are couple of things that can be done to improve volumetric flow and efficiency, one of them is trying to keep the intake mixture as cool as possible this can be done by getting air from outside the engine compartment, by getting colder air in this means the mixture is at a lower temperature which can improve volumetric efficiency. By having cooler air the mixture is then denser which improves engine efficiency.

By modifying the ports this can increase the volumetric efficiency by making any changes so that the mixture can flow much easier this can be done by reshaping ports, smoothing out any bends, polishing the ports and reshaping the back of the valve heads.

The volumetric efficiency can be improved being able to control how the valves for longer or further this can cause many improvement not volumetric efficiency but how the air enter the cylinder and how it leaves (Publishing, 2019).

The project is looking at how to improve volumetric flow and efficiency, one way to achieve this is by using FVVA (fully variable valve actuation). Using the FVVA instead of the conventional camshafts. FVVA replaces the camshaft by using an electromagnetic actuator and a return spring some other systems use a hydraulic actuator instead. With this system setup the valve moves horizontally as opposed to vertically which open and closes the valve, to connect the cylinder head to the intake and exhaust ports there are slots in the valve which are aligned to the cylinder head slots and this connects the ports to cylinder.

With a normal camshaft driven valve train the valves closing and opening is a steady process of the time taken to open and close and it last the entire valve procedure. The valve speed is related to crankshaft speed so means that they can only go faster or slower if the crankshaft is going faster or slower as the valves are connect via camshaft which has a timing belt on the camshaft which is attach to crankshaft. By having actuators instead of camshaft means that the speed of the valves open and

closing are only restricted by the hydraulic forces. These actuations are not connected to the crank shaft speed so these can operate independently to the crankshaft, even if at low or high speeds the profile of the valve open is very close at high speeds hydraulic pressure is used to have to best volumetric efficiency at high speeds as well as low speeds (Schechter et al., 1996).

The system consist of springs and actuator which has to opposing electromagnetic coils there are many advantages to using actuation instead of camshafts. The advantage of this is by having less moving parts unlike the conventional camshaft means that the engine weight overall is lighter and the height of engine being shorter this helps by being able to fit it in a smaller space if desired, less moving components also means less friction and less friction also means less heat and wear to the components.

A big advantage being is that it can be adjusted to what is desired, by being able to control how much lift and duration is wanted. By being able to control the lift and not having a set amount of lift like on a camshaft means can control the valves independently, by being able to do this means can control how much fuel and air enter each cylinder. Both intake and exhaust need to operate to be able to get the fuel and air in and out. By being able to control the valves independently means can open the valves more and for longer.

By increasing the lift and the duration of the valve opened means can produce higher power at a higher rpm. By increasing the duration of the valve means an increase in valve overlap which would in result in changing the camshaft to have a better suited lobe angle on the camshaft but by having actuators this can compensate for the overlap and can decrease or increase valve overlap as desired by being able to control the overlap with the actuators this eliminates the problem of piston and valve contact (Lunatipower.com, 2019). The valve lift is where the valve is open and how much it has opened by there is always a maximum valve lift which gets to point where there's no more air able to get in which is at its peak point.

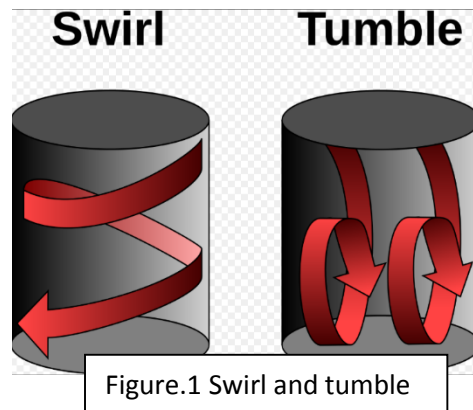
Valve overlap is where both intake and exhaust valves are open at the same point this done by the timing of the engine, this occurs just before the end of the exhaust stroke, when the exhaust gases released just before the intake valve is open which allow more time for the clean air to come through the intake valve and start to fill the cylinder chamber. The valve overlap is needed because as the engine speeds increase the time that used on the intake stroke reduces due to the decreased time spent on the intake stroke means that the intake valve opens sooner to allow for the air to flow and fill the cylinders, if there was no camshaft the overlap could be changed to whatever was desired rather than having a fixed camshaft lobe and set amount of overlap to decrease or increase actuation would be a better solution, the camshaft profile are only perfect at certain times in the engine cycle (Reference, 2019). By being able to have less overlap this would mean clean air is not lost through the exhaust and that would be a better mixture of clean air and fuel in the chamber, by not having both valves open same time and mixing old burned and dirty air with clean fuel and clean air.

Camshaft duration is the time measured from when the valve opens and until it finished closing, the duration is measured in crankshaft degrees and not the camshaft degrees (Jegs.com, 2019).

By being able to control the valves independently means can close the valves completely and not have them operating which in turn means have a useful advantage of being able to shut of cylinders as desired by being able to shut of cylinders this can improve fuel consumption. When cruising around the city to save fuel can shut of cylinders and drive on less cylinders, then when speed up for the motorways the other cylinder operate by being able to do this improves fuel consumption. If stopped at set of lights the cylinder can shut off to save fuel can either turn the engine off or just reduce the number of cylinders operating just to keep the vehicle engine idling. Also by being to shut of cylinder for cruising around city driving the emissions are reduce from the cylinder that are deactivated (Martinez-Botas, 2015). Some cylinder deactivation system will only shut of some cylinder not all of them, Dynamic skip fire (DSF) by being able to deactivate any cylinders to meet the drives demand of torque and at same time saving fuel. To maximize the efficiency the cylinder fuelling can be changed depending on the drive style and engine requirement (Van Ess et al., 2018). By being able to shut of cylinders there is a twenty five percent improvement in fuel consumption at low speed, emission also reduced by forty percent in hydrocarbons and forty seven in carbon monoxide at idle according to Dresner et al 1989.

With the setup of FVVA there is no need to have a throttle, as the actuators can act as the throttle by being able to let the fuel and air in. The fuel and air can be controlled by using actuators by not having throttles. Using FVVA combined with no throttles there is a seven percent improvement of fuel consumption (Cleary and Silvas, 2007). The fuel consumption improvement is done by the eliminations of the throttle and for load control over a wide speed, load range and including idle.

By using the actuators instead of camshaft this will help improve volumetric flow and efficiency, one way to improve this is by being able to have an effect on the tumble and swirl by using actuators. Making the adjustments to the valves opening and closing this can change the in cylinder motion from tumble to swirl not only does it have an influence on this but can also effect the turbulence. Swirl and tumble are different ways of mixing the fuel and air together, by having a better fuel and air mixture this will result in a better burn which will help lower the emissions by being able to burn more of the mixture. Any unburnt fuel is wasted and will result in an emission increase (Laramée et al., 2019). Using this non-camshaft setup does have an impact of having large tumble. By angling the slots in the intake valves, substantial swirl can be also generated with only modest reductions in the tumble and the volumetric efficiency as stated by Babbitt et al., 2017.



With using actuations there are many less components, by having less moving parts means the valves can be changed without removing the cylinder head as there no camshaft or overhead components, to remove the valve just remove the actuator as it is one complete assembly then that can be taken apart due to less time taken to change the valves if ever needed to the labour cost would be less as won't take as long to replace.

There is a more variety of choice to locate the spark plug and injector, the new degrees of freedom means that have a greater performance opportunities for the engine one being and increase in brake mean effective pressure (BMEP) across the engine rpm range. Whilst the piston is on the combustion stroke it is the pressure produce on this stroke which gives a value for the bmep, by be able to work this out to some extend can see how effective is to get power from the fuel used, can also see the pressure and stress on the components on the engine internally (Tuner University, 2019).

By not having camshaft it enables to have variable firing order by using the FVVA system which means unlike the conventional firing order for example 1-3-4-1 can use the actuation to alter or change the firing sequence to whatever best suits that engine, the firing order on a conventional engine is that every 720 degrees of the crankshaft moves the camshaft in turn, turns 360 degrees which then fires each cylinder once, which means camshaft rotates once to every second time of the crankshaft which then for every 180 degrees a cylinder is being fired. Where the cylinder make the power this in a sequence this is the firing order (Autoshackghana.com, 2019).

By using the camshaft less engine an external egr (exhaust gas recirculation) is not required, it's not requires because it has the ability to vary the timing of the exhaust valve closing. Egr affects the residual gas fraction that is in the cylinder. By having a larger amount of residual gas this reduces the peak combustion temperature which in return decreases the amount of nitrogen oxides produced during the combustion process. By having a twenty nine percent residual fraction there was a ninety percent decrease in NOx this is according to both Dresner et al 1989 and Gould et al 1991.

Both of these were done by being able to tune the closing of the exhaust valve and using actuation in camshaft less engine to achieve ninety percent reduction in NOx.

Stein et al 1995 used intake and exhaust camshaft with a simultaneous retard to delay overlap at part loads to increase the gas fraction residue, by closing the valve late for pumping reduction and opening the exhaust late for an expansion increase. That project showed reductions in NOx and HC by twelve and fifteen percent.

Increasing the inlet air velocity by reducing the intake valve lift, which leads to faster burn rate and improves idle stability this done at low engine speeds, this happens because of the increase in air velocity speed due to reduced valve lift.

Reduction in fuel consumption by being able to tune valve overlap as well as valve lift this has the potential to lower the idle speed and by doing this it has a result in a reduction in fuel consumption. Both Lee et al 1995 and Hatano et al 1993 said that thirty percent fuel economy improvement.

By using cylinder deactivation the other cylinder have to work harder to maintain the engine output the increase on load reduces fuel consumption. The camshaft less engine can selectively deactivate any pair of valves this is controlled by a control system, when interrupting the electric signals which controls the solenoids which are hydraulically controlled. A small amount of residue of gas gets trapped but this contributes to low in cylinder pressure which helps keep the friction to a minimum, this also leads to improved fuel economy and hydrocarbon emission here are some figure below stated by Dresner 1989.

“(Dresner et al 1989) quote one researcher who reported 25% improvement in fuel consumption at low-speed cruise and 40% at idle. In another case significant reductions in emissions were achieved: 40% in HC and 47% in CO at idle (Schechter et al.,1996)”.

This system has the ability to be able to open and close the valves differently at different engine speeds which will result in better emissions and fuel consumption by being able to control the valve independently of each other at different engine cycles. By being able to control varies of things with fully variable valve actuation compared to a camshaft this improves the torque and low and high engine speeds. One other advantage is that it can have an influence on the compression and expansion ratios.

This system consists of:

- Engine valve: To cool the piston and lubricate, the hydraulic fluid circulates in a chamber above and below the valve piston, the valve sleeves opens and closes allowing the hydraulic fluid to enter and exit.
- Solenoid valve: The both low and high pressure solenoids have the same design, when the high or low pressure solenoid closes that's when the

hydraulic energy is at the greatest loss, this happens when the piston is at the highest velocity, the faster the closure better the recovery of energy.

- Low pressure pump: The oil gets delivered to the main pump by pumping oil from the sump and into the inlet of main pump using a small electric driven pump.
- High pressure pump: the ability to deliver fluid to the high pressure pump of the same quantity the system requires at different engine speeds and loads, is critical to achieve low energy consumption.
- Cool down accumulator: any oil that is trying form pockets of oil vapour, the accumulator releases oil into the system to compensate for shrinkage or the oil forming into small oil pockets.
- Lift modifier: the pressure in control gallery is adjusted by the single pulse - width modulated solenoid-valve.

As discussed there are many advantages to the FVVA over the camshaft but what are the limitations of this system. The main issue for this system is the cost to manufacture and to produce it. The cheaper option is to have a hydraulic actuation instead of the electromagnetic actuator. With the electromagnetic actuator it requires more electric power which could result in a bigger battery, at this moment in time this system is only fitted to petrol engine which have short stroke and lower in cylinder pressure according to Babbitt et al., 2017.

3. Methodology:

To be able to achieve the relevant data needed the first thing that was done is to calculate the valve lift to be able to calculate valve lift, the camshaft lobe needed to be measured. To measure the camshaft lobe two bits of equipment was used which included an optical dividing head as can see below in figure.2 and a DTI (dial test indicator) as can see below figure.3. The optical dividing head is a tool which allows the camshaft to be rotated and know what degrees of angle the camshaft is at, whilst the camshaft is in this tool, can then use a DTI which then placed on the lobe of the camshaft which will measure the lobe in millimetres as the camshaft is rotated the lobe of camshaft will push on the needle of the DTI gauge which will give the lift of the lobe at each degree of angle of the camshaft.

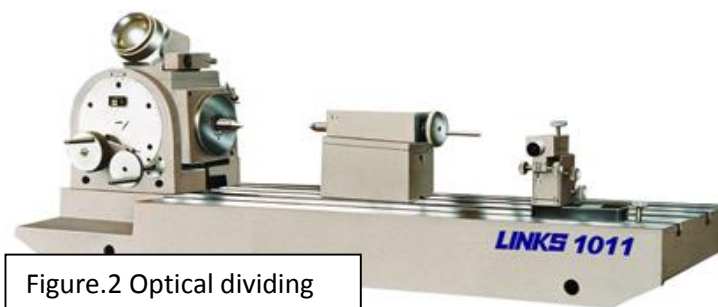
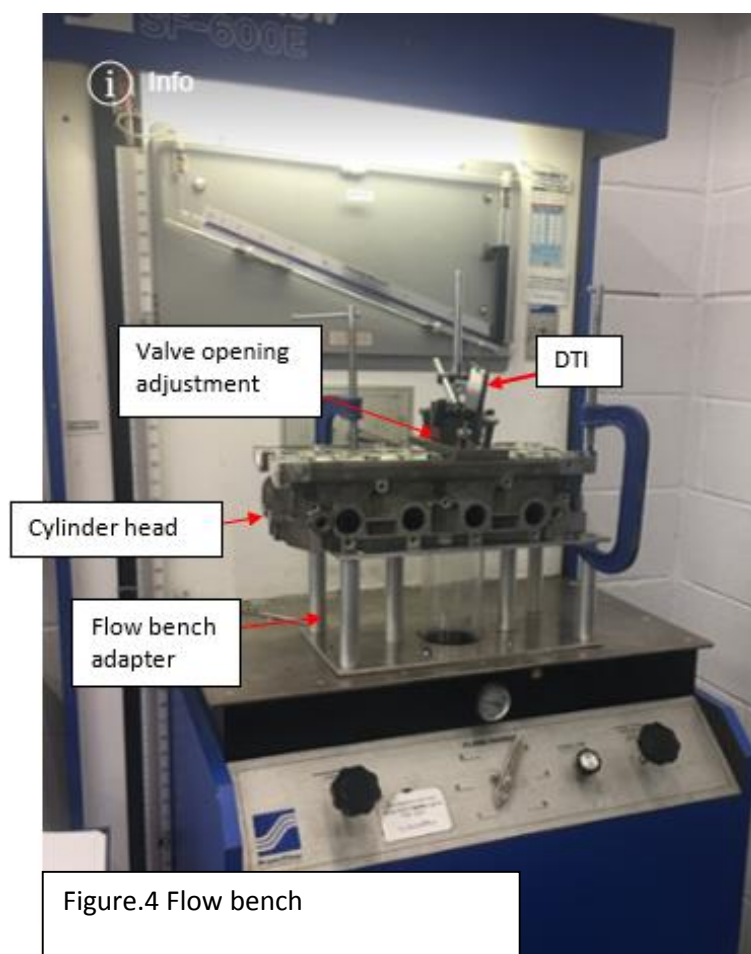


Figure.2 Optical dividing head



Figure.3 DTI (dial test indicator)

Once this process was completed, then took the cylinder head and fitted it to the flow bench to see how much air will pass the intake valve. For the cylinder head to be fitted to the flow bench it required using adapter which fits in between the flow bench and cylinder head when fitting the adapter both ends of the adapter need an air tight seal. Once this is all mounted, then use another adapter which consist of metal plate which bolts across the top of the cylinder head which is directly above the valve bucket, when this adapter is secure there are two bolts which are fitted to the plate which is directly above the valves which allows to push the valves open in the increments desired. To be able to open the valve at the measurement wanted a dti was mounted over the top of the bolts that are on the plate, which push the valve open so then as the bolt is turned the valve will open and can see on the dti how much the valve has opened by.



Once the flow bench was all setup and ready to go the first procedure was check that there is no air leaks which will lead to a false reading, once the flow bench and the cylinder head has an air tight seal can then proceed with the test. The test procedure consisted of opening the valve in 0.1mm (millimetres) increments, each increment was tested and the flow bench then give a percentage flow value. Depending what range the flow bench was in depends on how calculate the litters per second. The range of flow bench is one to six, when the percentage on the flow scale reaches its maximum

of hundred percent would then move to the next range until same thing happed and repeat process until reach the point that the valve is all way open. To retrieve a value for litres per second an equation is used which is.

Range value x flow percentage = flow (litres per second).

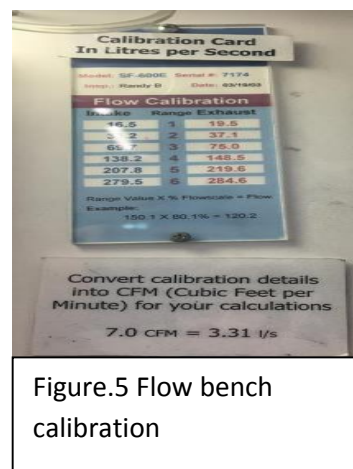


Figure.5 Flow bench calibration

To then convert the litres per second (l/s) to CFM (cubic feet per minute) use 7.0cfm = 3.31l/s, once this procedure is all completed will then have achieved the flow at each increment.

Once all the data is collected from the flow bench this is then entered into a excel document with valve increments opening and the flow, by doing this can then produce a graph of valve lift over flow and can see as valve opening the flow increasing the graph will be shown in results. After getting all the data and plotting the flow graph. What was needed to work out was the valve lift, the valve lift is different to the camshaft lift as previous said. The camshaft data that was collected from the optical dividing head can be used to calculate the valve lift using excel.

To calculate the valve lift first step is to have an excel spread sheet which has 360 degrees across and 360 degrees down which go up in one degree increments. From collecting the data of the optical dividing head which has measured the camshaft lobe, this data was entered into a column next to the 360 degrees going down. The 360 degrees going down is known as theta. The next step is to calculate s which is the measured data of the camshaft lobe, plus the radius of the base circle of the camshaft lobe. S is the distance from the surface to centre of the camshaft, s is then used as the hypotenuse of a right angle triangle to calculate the length from centre of camshaft

to the point vertically below this is repeated for every degree of theta and every degree of camshaft rotation know as Phi. The longest length for every degree of phi is then the valve lift plus the radius of the base circle of the camshaft lobe. The camshaft lobe profile produce in excel was done by using the xy graph, s times sin of the angle of camshaft lobe theta (measured camshaft lobe angle optical dividing head). $Y =$ the same except use cos instead of sin.

Once the excel was completed then used CAD (computer aided design) to make a basic cylinder head and an inlet valve and use it in a motion study to produce a graph, the graph will then represent actuators instead of camshafts.

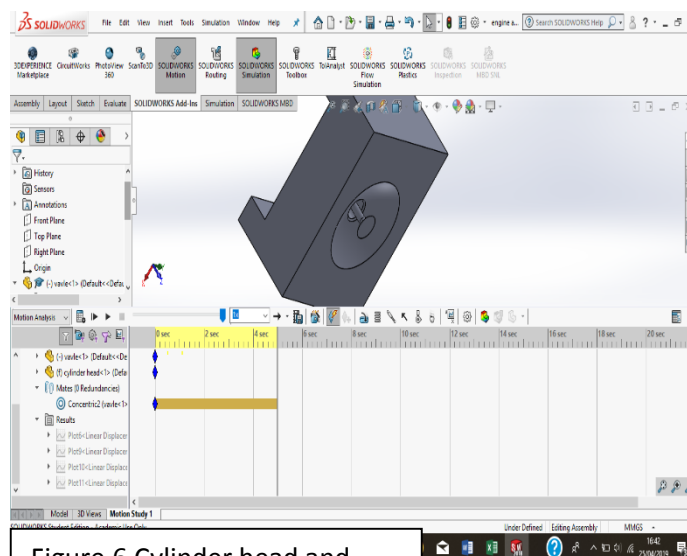


Figure.6 Cylinder head and valve motion

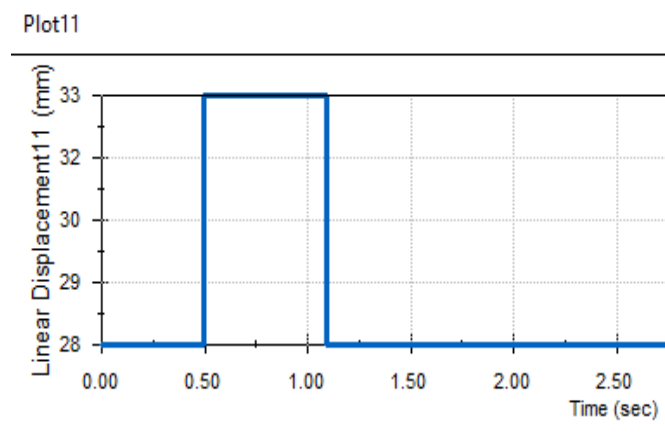


Figure.7 Fvva opening closing

4. Results and Analysis:

From doing the testing on the cylinder head which was fitted to the flow bench, when opening the valve and seeing the flow of air the data collected was put into excel and a graph was produced and the results of that will be below in figure.8.

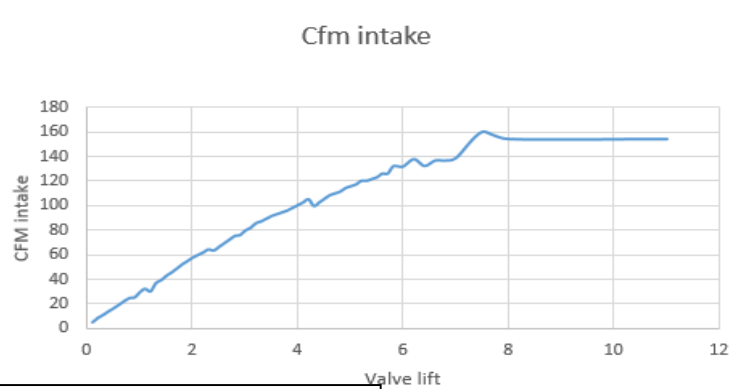


Figure.8 CFM intake over valve lift

As can see in the figure.8 as the intake valve is opening the air flow is increasing but notice that once the valve is open by about 8mm of lift its reached the maximum flow the valve diameter is 27mm. When the Yamaha r6 engine is in operation it is using 9.6mm of lift now what is indicated on the graph is it does not need to be open any more than 8mm of lift as its reached the peak point and not able to achieve anymore air. The small little drops and spikes in the graph are from human area as trying to read of from a bar with measurements while the fluid in that bar is moving when the fluid stops that's the measurement to be taken but to each individual the reading could be slight different which explain the small spikes in data. This can also be from the machine getting hot and due to the heat giving a slight different reading also.

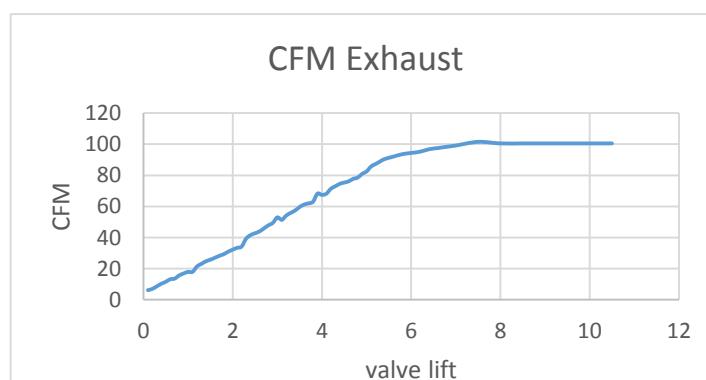


Figure.9 CFM exhaust over valve lift

By looking at both figure.8 and figure.9 can see that the intake flow is much higher than compared to the exhaust, so that would show can get more air in and not as much air out for it to be really efficient and make an improvement, to get same flow in and out by being able to get all the old air and burnt fuel out and have clean fuel and air in this would increase engine efficiency and lower emission as more of the fuel is burnt which would will also result in less residue.

The graph figure.10 below shows the camshaft lift which was measured using the optical dividing head, the grey line is the measurements taken. The blue line is the actual valve lift which is produced using excel after camshaft lift is converted into the valve lift.

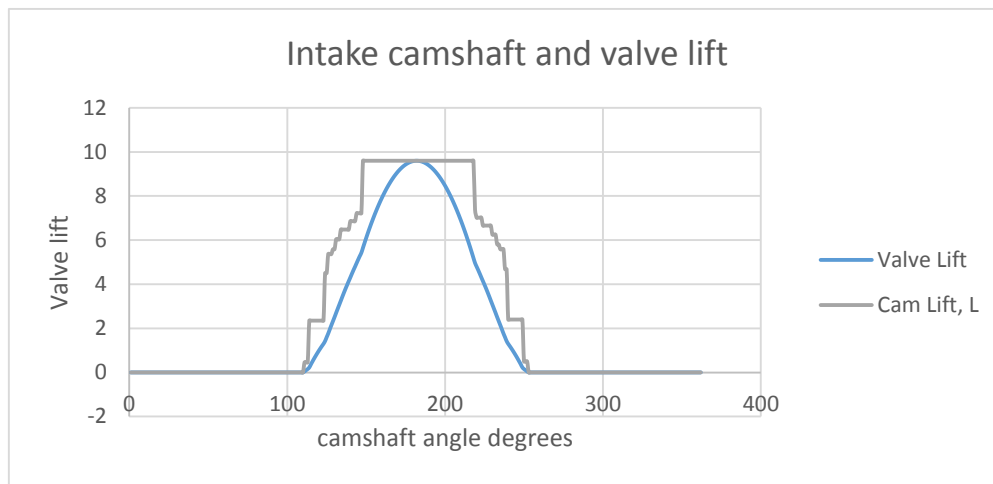


Figure.10 Intake camshaft and valve lift

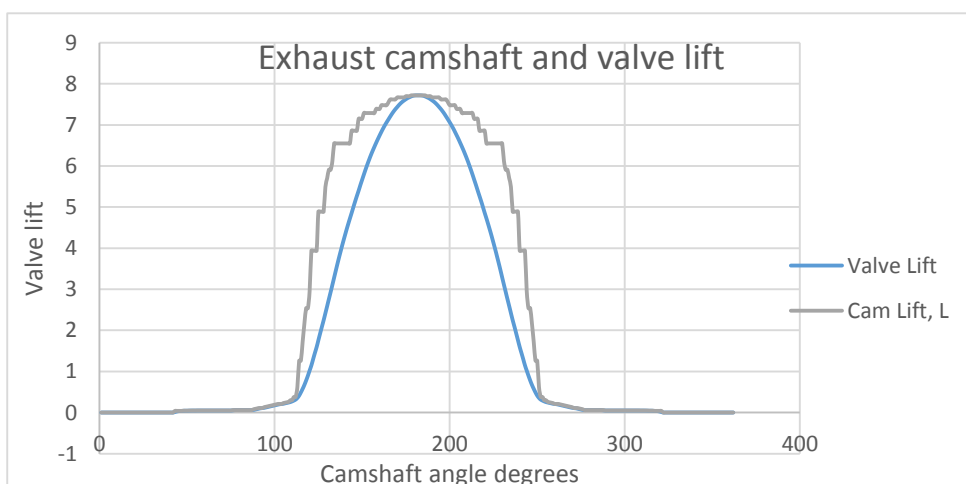


Figure.11 Exhaust camshaft and valve lift

Looking at both figures 10 and 11 it is visible that the difference between the two, first being the exhaust valve diameter is smaller and not opening as much as the intake, the profile of the exhaust is much stepper which would indicate it opens the exhaust valve in less time as it don't open as far. The exhaust diameter is 23mm and the intake valve is 27mm and opens further, the intake has the ability to open to 9.6mm and the exhaust can reach 7.72 of lift but both of these valves reach their peak point of flow before the maximum lift. If actuators were to be fitted with intake and exhaust valve being same size both would achieve a much better flow of air in and out and in return would result in better fuel consumption, lower emission and improved engine efficiency.

From the excel sheet by using the x y the camshaft lobe shape of intake and exhaust can be seen in the graph below in figure.12 and figure.13.

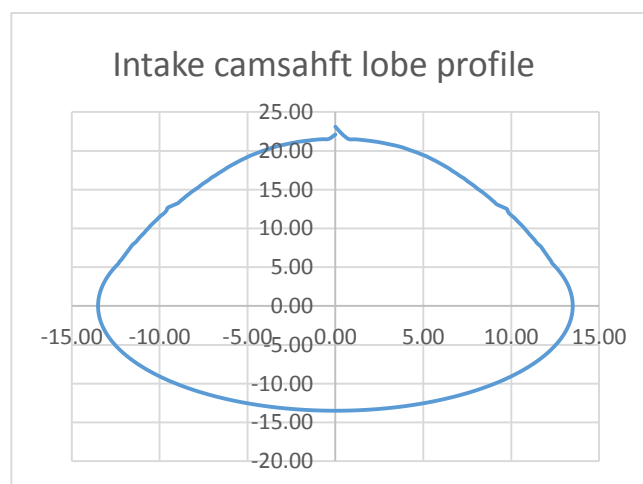


Figure.12 Intake camshaft lobe profile

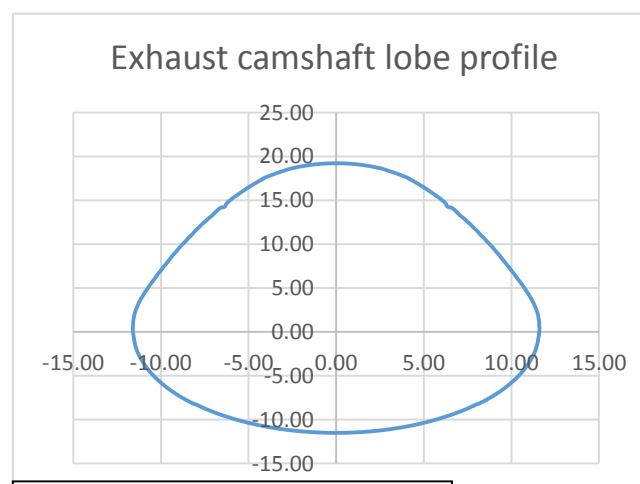


Figure. 13 Exhaust camshaft lobe profile

Figure.14 below shows the difference in the profile of fully variable valve actuation and camshaft as can see the actuation can open a lot earlier and shut a lot later.

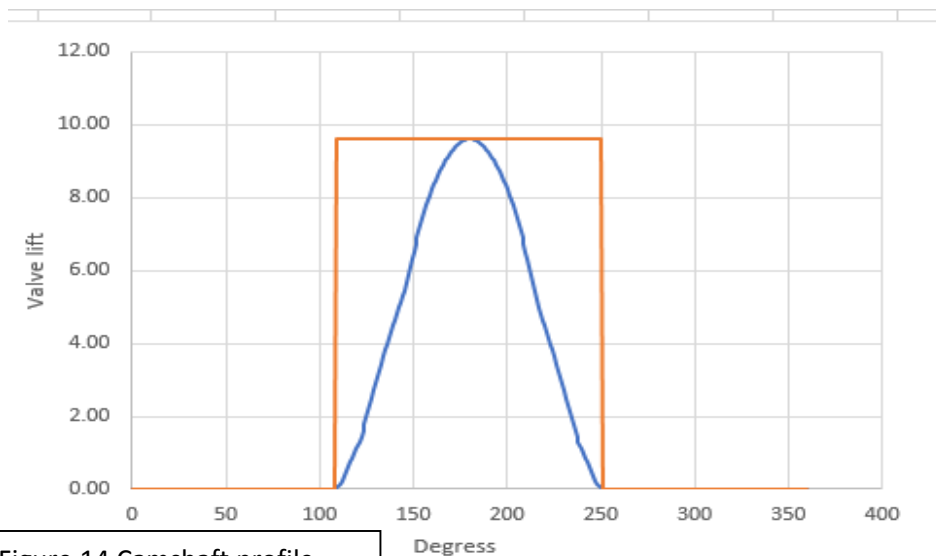


Figure.14 Camshaft profile and Actuation

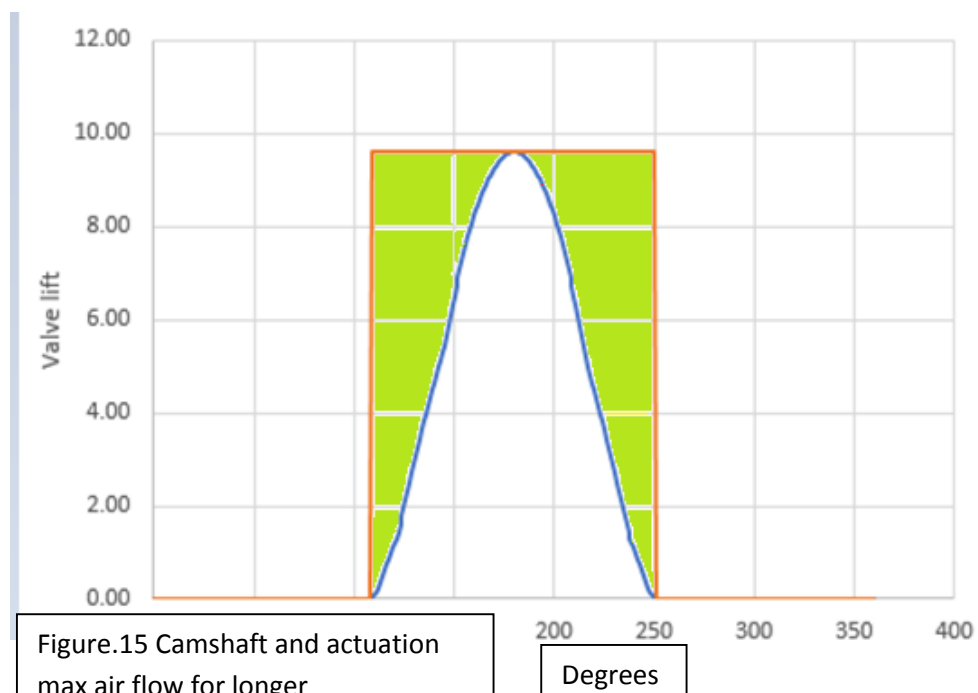


Figure.15 Camshaft and actuation max air flow for longer

Degrees

The graph above in figure 15 displays the actuator which is the orange line and the camshaft which is the blue line by using the actuations, will then be able to get more air in where the green area is highlighted all that area is potential extra air which can be achieved by using actuation. By being able to open earlier means can get the maximum air flow which means can also get the maximum air flow for longer and shut it later or can open it more than once in the sequence. By being able to open the valve earlier and possible for longer if desired this means can keep valve open for longer, if use the actuation on both intake and exhaust valve. Then would be able to get the air in and out much faster which would also be cleaner air. If can get more in and out quicker this can improve performance emission even fuel economy.

From the results that have been obtained and compared figure 14 and 15 to the results of Schechter et al., 1996 can see that the way valve actuation opens and closes has similar traces as to figure 14 and 15 in this project.

5. Conclusion:

From what was collected from the testing and the extensive research done it shows that by having a fvva engine opposed to the camshaft engine there are many benefits to this such as lower emission, better fuel consumption, engine efficiency and the volumetric flow and efficiency is enhanced creating a better burn in the cylinder. The packaging of the engine is much smaller and the height of the engine is low so can be used in wide variety of vehicle body shapes. By not having camshafts and actuators instead there much more control of the engine and can have influence on certain thing for example the flow of air into the chamber and just generally how the engine runs overall. The flow bench testing should that the intake had a much better flow if could increase the flow of exhaust and use actuators there be even more improvements. Measuring the camshaft profile shows that they are different with the fvva system won't need any camshaft and have more freedom on how to control the valves. A lot of the data taken and produced was done using excel spreadsheet. This system is expensive to produce and is only been operated on certain engines. The overall project shows that the FVVA would be more beneficial and the advantages would outweigh the cost of production as there's many beneficial factors to be gained.

6. Evaluation:

With this project would have been good to show how accurate the flow bench is by calculate the theoretical flow of the intake and exhaust valve and doing a comparison of the results taken from that compared to the results with the flow bench to see how accurate it is. Using a fluid bar to read the measurements of the flow bench could be a more accurate way by using a digital flow bench and a digital dti for much more accurate reading. To make it more accurate opening the valves using a digital dti to help with the increments would be a big improvement. The flow bench would get warm/hot quite quick which would lead to an inaccurate readings. When measuring valve lift, tried to put the cylinder head and camshaft in the optical dividing head as one piece, to get a more accurate reading but was not possible to fit the cylinder head in the machine. That's why an excel spreadsheet was used to convert camshaft lift to valve lift. For further testing be more accurate to have a machine that could fit the camshaft and cylinder head to see the valve lift which then could be used as comparison for the excel sheet and see how accurate that is. Could also repeat the test more than once to be able to see if any human error and for a better accuracy.

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