ENGINE TEAM

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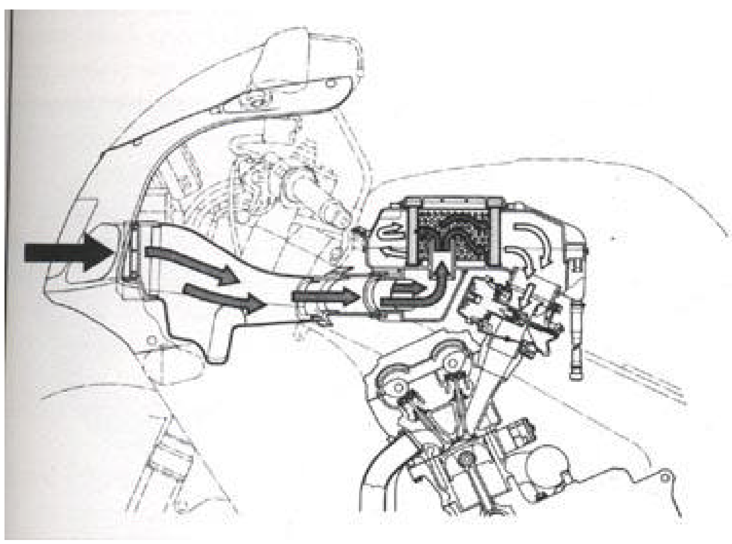
Air Intake System

written by Brian J. Birch

Introduction

The air intake system of a motorcycle is responsible for delivering air to the throttle bodies to mix with the fuel for proper combustion. The current intake system supplied with the Kawasaki ZX-6R is a ram-air induction type connected directly to the carburetors. The ram air system provided an increase in power on the stock motorcycle by forcing air into the carburetors with a small pressure rise at high speeds. This system was eliminated as it occupied a large area required for the propane tank. A schematic of the stock ram air system is shown in the figure below. An air intake system needed to be developed that allowed ample space for the propane tank while maintaining the performance of the motorcycle.



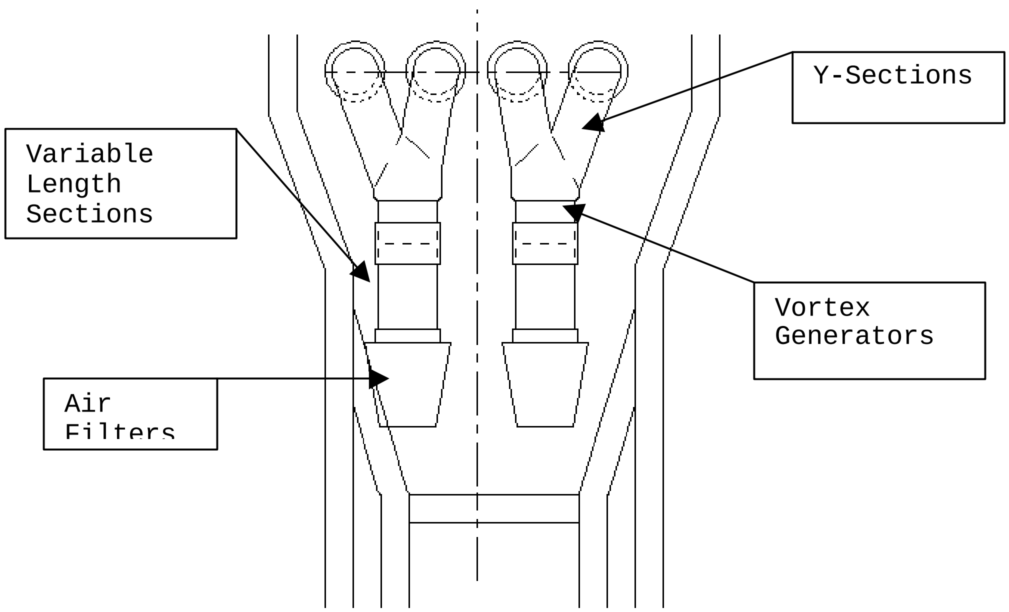
Schematic of stock ram air system on the ZX-6R

Preliminary Designs

Several systems were investigated through research, drawings, and design before the final system was chosen. The first system researched was a vortex airbox that would occupy the area behind the cylinder head and provide high velocity, turbulent air to the throttle bodies. This idea was rejected due to space limitations on the ZX-6R.

The second system designed for possible use was a turbo powered, forced air induction system. This system would use a small, centrifugal compressor powered by exhaust gases. This would provide high power increases due to pressurized air that would be introduced to the throttle bodies. This high pressure air would allow a higher density charge to be combusted and result in high power output. This idea was rejected due to high cost, high complexity, difficulty in tuning, and consumer acceptability.

Final Design
The final and optimum air intake system utilizes two tuned length intake tubes with vortex induction, connected directly to the throttle bodies. This system will provide high velocity, turbulent, cool air to the throttle bodies for maximum efficiency. The system is also designed to introduce power pulse resonance to the throttle bodies which will force air into the cylinders and increase the output power. The vortex system will spin the air leading into the combustion chamber to provide an improved mixture for better emissions and higher power. This system achieves all the design goals by maintaining the motorcycle's performance while allowing enough space for the required propane tank. A top view representation of the new intake system is shown in the figure below.



New Intake System, Top View Representation

The new intake system installs and removes easily for maintenance and is designed to use corrosion resistant materials to last the life of the motorcycle. The weight of the intake system is lower that the stock ram airbox system, resulting in a weight reduction of approximately 10 pounds. The pipe sections will be made of 6061 aluminum with all tig welding at the joints. The Y-sections connect to the throttle bodies with rubber gaskets and hose clamps. The variable length sections are attached to the assembly with similar gaskets and hose clamps to reduce the number of different parts required. The air filters are varying conical diameter fabric filters from K&N Engineering.

The intake system includes a replaceable pipe length section that will allow varying lengths of pipe to be attached during the engine tuning process to achieve the best performance curve. The overall length of the intake system was designed to induce resonant power pulses in the system. The equation used to calculate this length is a derivation from the Helmholtz resonant formula:

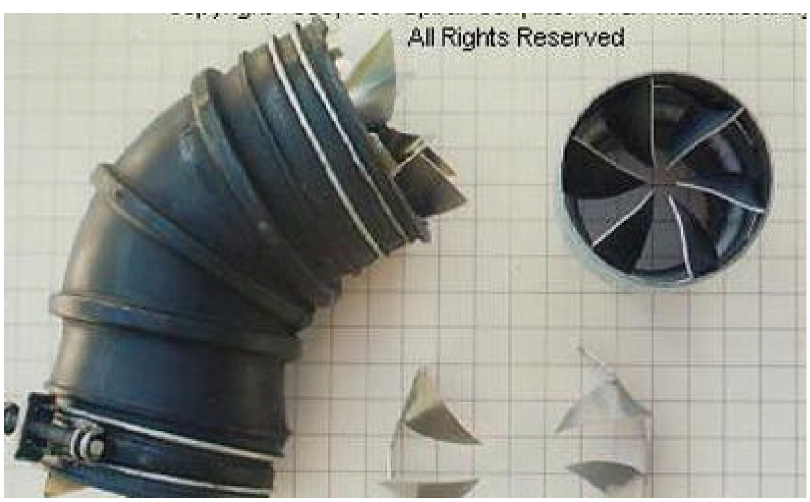
$$F = c / (4*(Lp = 3*D))$$

F = engine speed in Hz
c = speed of sound
Lp = intake pipe length
D = pipe diameter

The frequency that corresponds with the length used is the standard operating range. The frequency used was 5,000 to 8,000 rpms, which results in a length of 8 – 9 inches. The intake length was designed at 8.5 inches in order to provide the maximum torque in this rpm range. This should make the motorcycle perform extremely well during normal operating conditions and day to day use.

Resonance in the engine is a pressure wave caused by the first, second and third, fourth cylinder intakes to be connected together. Since the engines cycle is 1-4-2-3, these cylinders will always be in opposite strokes. When the first cylinder is beginning the intake stroke, the fourth cylinder will be beginning the compression strokes. When resonance is present, the pressure will be high and “drive” more air into the just beginning intake stroke. The same is happening on the other cylinders at the same time, forcing the exhaust out a little faster, cooling the cylinder. The longer the intake length, the lower this torque increase will be in the rev band. With proper tuning, this resonance could increase power in the designed range by 10-15%.

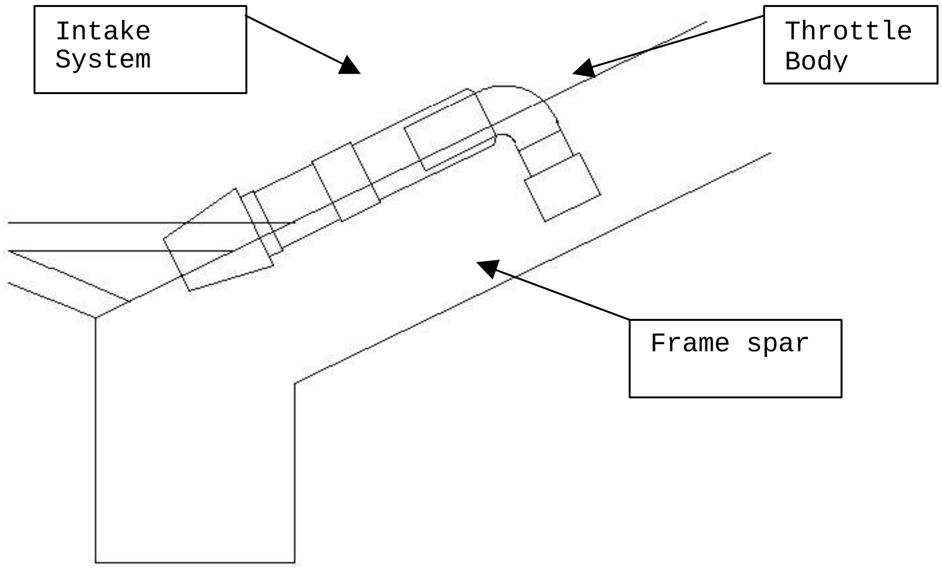
Vortex inducers are installed in the end of the Y-section of the intakes. These inducers have been donated by a sponsor, SpiralMax. The product is a set of stainless steel stator blades which work to spin the air leading to the throttle bodies. Since the densities of air and propane are different, they have a tendency to mix poorly. This could cause a loss in power and an increase in emissions due to an incomplete burn. By spinning the air, the mixing ability of the two gases will be greatly increased. In turn, this will increase power and lower emissions. A picture of the vortex inducers is shown below.



SpiralMax® Vortex Inducer

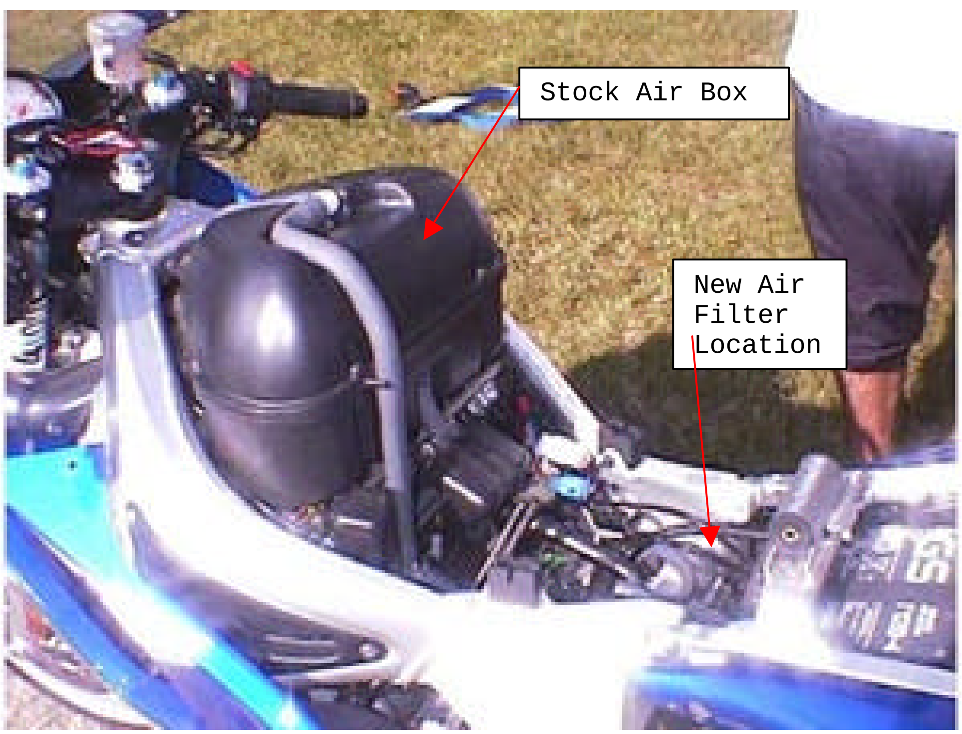
The intakes have also been designed to provide equal air flow to all four cylinders. The airflow will be drawn into the air filters using a scoop on each side of the bike. The stock tail piece of the bike will be replaced with an after market piece that eliminates the rear seat. The scoops will be fabricated into this tail section with fiberglass to direct high velocity air from the sides of the bike into the air filters.

The new design allows ample space for the propane tank. This is accomplished while providing little or no loss in power, a decrease in weight, and easier engine and injector maintenance. The side view representation below shows that the intakes only rise one inch above the frame spars. This will not interfere with the propane tank.



New Air Intakes, Side View Representation

The figure below shows the location of the intake system on our motorcycle.



Detailed drawings of the top and side views can be found in Appendix A for further review. The Bill of Materials for the intake system can be seen below.

Bill of Materials

Quantity	**Part Description**
1	**1-2 Y-Section**
1	**3-4 Y-Section**
4	**1.5" Rubber gaskets, 1.625 ID**
8	**1.625" – 2" Hose Clamps**
2	**51 mm SpiralMax**
2	**2" length, 2.125" diameter pipes**
2	**3" length, 2.125" diameter pipes**
2	**K&N Filters, 51mm ID inlet**
2	**2" Rubber gaskets, 2.125" ID**
4	**2 – 2.5" Hose Clamps**

Conclusion

The purpose of the new intake design was to eliminate the large stock ram air box to provide space for the propane tank. The new intake also needs to maintain current engine performance without adding significant weight. These goals were accomplished using variable length, vortex inducing intakes that utilize resonance. This design provides high, even flow to all 4 cylinders. The resonant power pulses force air into the cylinders, while the vortex system spins the air for better mixture. Together, they combine for higher performance and reduced emissions. The overall design lowers the overall motorcycle weight by 10 pounds by using lightweight materials and removing the bulky stock ram air system.

References:

Sportbike Performance Handbook; Kevin Cameron, 1998

Kawasaki Service Manual, ZX-6R, Kawasaki Motor Co, 1997

ZX-6R Riding Test, Motorcycle Online, 1996

LPG Powered Vehicles, ABC's of AFV's, 1998

All about ATF's, Alternative Transportation Fuels, 1999

Fluid Mechanics and Thermodynamics of TurboMachinery, Dixon, 1998

Introduction to Internal Combustion Engines – Second Edition; Richard Stone, 1992.

Throttle Body Design
written by Chris Dew

Introduction

The design of the throttle must accomplish two main goals. They are to maintain proper airflow while also minimizing the use of space. In order to accomplish these goals it was decided that a throttle body for each cylinder would be the best method. This type of system was chosen for a number of reasons: 1) It is compatible with an intake designed on the model of an organ pipe resonator; 2) The hardware for four separate throttle bodies already exists on the motorcycle in the form of the carburetors; 3) The placement of throttle bodies in the same location as the existing carburetors allows for the use of the existing throttle cables and brackets; 4) It provides an excellent mounting point for the injectors; and 5) it minimizes throttle lag by placing the throttles and injectors very close to the intake valves.

Final Design

Making use of the resonant properties of the air fuel mixture is very important. This resonance arises from the fact that the air fuel mixture is unsteady compressible flow. The flow is drastically changed each time the inlet valve opens and closes. This results in compression waves within the intake system. These waves reflect as opposite waves off an open end (i.e. an expansion wave reflects as a compression wave), and as same waves off a closed end (i.e. an expansion wave reflects as an expansion wave.) Using this idea of resonance it is possible to design a system in which the waves are timed in such a way as to increase flow when the intake valves are open. In general it is desired that an intake system resonates at 3, 4, or 5 times the cycle frequency (one half engine speed due to the 4 stroke nature of our engine; the intake valve opens every other cycle of the crank shaft.)

To make use of these principles, an intake based on an organ pipe resonator is employed. The resonant frequency of such a system is given by:

$$F_p = C \; / \; (4 * (l + 0.3*D))$$

Where C is the speed of sound (350 m/s). Using this equation with the knowledge that on average the diameter of the pipe (d) is approximately 1.5 inches and the system should be designed to resonate at 4 times the cycle frequency it is possible to solve for the length:

$$L = (\tfrac{1}{4} * (C / (4 * (speed \text{ ¸ } 2)))) - (0.3 * D)$$

Where speed is the engine speed in Hz (ref. Stone p 268-269.) For our engine this equals approximately 14 inches. Although this length is long, there is sufficient room to achieve a length close to this. It must also be noted that this length includes the intake runner length within the engine head.

Once the air has been ducted through the intake it then passes through the throttle bodies. The throttle bodies will be constructed by machining new throats. Drawings that illustrate this design can be found in Appendix A. These throats will be constructed of circular aluminum stock. To construct the throats, the stock will be drilled the machined to the proper throat diameter. A second piece of aluminum stock will be mounted perpendicular to the throat through the centerline of the throat. This member will act as the support for the throttle plate and shaft. This will be done by drilling through the throat and welding the support to the throat on both sides. The inside of the throat will then be drilled and machined to remove the excess metal of the support member on the inside of the throat. This procedure will minimize any inaccuracies due to warping of metals during welding. Once the new throats have been machined the throttle bodies will make use of the existing carburetors' moving parts. These include the throttle plates and shafts, return springs, and connecting brackets. Also to be used will be the throttle cable mounting bracket.

Once the air has passes through the new throttle bodies it mixes with the fuel that is supplied by the fuel injectors. The fuel injectors will be mounted to the throttle bodies on the rear portion of the throat. This places the injector and the flow of propane out of the path of the throttle plate because the plate will swing up on the rear side and down on the front side from a closed position to regulate the airflow. By placing the injectors and the fuel lines underneath the air intake it will minimize the amount of space used by those components.

This throttle body and fuel injector arrangement will be mounted to the engine head by standard rubber carburetor mounts. The mounts will be modified in two ways to save space. The first is to slot the mount such that the injector can slide into the mount. This eliminates the need to add material to the throttle bodies to mount injectors, thus shortening the throttle bodies and saving space. The second is to reduce the length of the mounts to also save space. The process of machining the rubber mount will require that the mounts be frozen. This ensures the rubber will be hard enough to machine.

The reduction in the length of the carburetor mounts creates an interference problem. On one side of the engine block an oil line is mounted that interferes with the throttle-actuating cam when the throttles are moved too close to the engine block. By extending the throttle shaft and moving this cam beyond the oil line, it is possible to achieve a total reduction of length in the rubber carburetor mounts equal to ¼ of an inch.

References

Introduction to Internal Combustion Engines – Second Edition; Richard Stone, 1992.

Engine Design

written by Mike R. Munsey

Introduction

The engine of our motorcycle is responsible for powering our final design in the most efficient and emissions friendly manner. The engine used in our Kawasaki ZX-6R motorcycle is a four-cylinder engine that operates on mid-grade gasoline. It was our goal to convert this engine to operate on propane, which has a much higher-octane level than gasoline. This higher-octane level allows for an overall increase in compression levels within our engine. The stock engine is a 599 cubic-centimeter, 16-valve, dual-overhead cam, liquid cooled, in-line four-cylinder. Our overall goal when making changes to the engine was to take advantage of the better emission associated with the use of propane. Our second goal was to maintain the performance of the stock design.

Preliminary Designs

Various diversified setups were initially contemplated through research and design. The initial design entailed machining the head to a specified value. This would sequentially reduce the overall combustion volume by decreasing the distance between the heads and cylinders, which would increase the compression ratio of the engine. This plan was met with many concerns related to piston/valve clearance. The stock clearance of the valves and pistons is very minute; therefore we decided to investigate other means of increasing the compression ratio.

The second initial design was to modify the existing head gasket. Replacing the stock head gasket with a thinner design would also reduce the distance between the heads and cylinders, therefore increasing the compression ratio of the engine. This design was rejected due to the lack of head gaskets with slender dimensions available for our particular model. Also the risks of a collision with the pistons and valves was still a concern.

Other topics associated with the engine were studied. Strengthening of the main components ranging from valves to cams was discussed. We determined that the main component that needed strengthening was the head bolts. These will be incorporated into our final design discussed below. An aftermarket ignition was also researched along with a digital acquisition system. Both of these devices would allow for easy tuning and monitoring of the engine and its components. The digital acquisition system was rejected due to budget constraints. The digital ignition system will be implemented in our final design. The specific details are discussed below.

Final Design

The final design incorporated high compression pistons and related components. A digital ignition system will also be incorporated. We choose to implement the high compression pistons due to the fact that the piston/valve clearance problem is not an issue. This had been the main constraint with regards to raising the compression ratio during the research phase of the project. The kit we choose to use was a Muzzy® high-performance overbore kit. The basic representation of the kit and its contents is shown below.

Muzzy® overbore high-performance piston kit

The pistons are a 1mm overbore that raises the stock displacement of 599cc to 617cc. The compression ratio of the engine is also influenced. The rise in compression is contributed to the head design and size of the pistons. These pistons feature a domed/cutout profile that allows for tighter clearances between the pistons, valves, and spark plugs. This design therefore decreases the compression volume resulting in an increased compression ratio. The pistons are constructed of forged, aluminum alloy. The kit includes not only the four pistons, but also rings, clips, and pins. This design utilizes the stock connecting rods and crankshaft. The compression ratio is increased to 12.5:1 versus the stock value of 11.8:1. This combination was found to be the best choice with respect to both performance and emissions.

The second part of our design was to incorporate an ignition system. The implementation of this system will drastically aid in the fine-tuning of our converted engine. The use of different components throughout the engine will allow us to take advantage of advancing the ignition of the engine. The system of choice is a Dynatek® DYNA 2000 ignition. The ignition controller and its included components are shown below.

Dynatek® DYNA 2000 system

The features associated with this system include independent cylinder timing, various advance curves, and multiple test modes, to name only a few. This system is also fully compatible with the GFI propane controller unit. This will allow the propane controller to make dynamic adjustments to the engine's ignition during operation.

Due to changes made to the engine's operations, the operating range might need to be limited after extensive tests have been run. This system incorporates an adjustable rev limiter for resolving this problem. A digital tachometer output is also standard on this particular system. This will make implementation of a digital, user-friendly instrument cluster a moderate task. Overall, this system will allow us to tune the engine to operate in its most efficient operating range while permitting user friendly adjustments throughout the testing stage.

The internals of the engine are now going to be introduced to excessive stresses associated with the increased compression. To overcome this we will be installing higher-grade hardware throughout the engine. The main changes will be ANSI Grade 8 bolts and hardware for use on attaching the heads to the cylinder.

The power range associated with our motor will now be slightly different due to the overall changes from the stock design. To take into account for this, the gearing will be modified so we can take advantage of the most usable power range. Instead of updating the entire transmission with new gears, we will instead, only vary the front and rear sprocket sizes. This does not require disassembly of the transmission case, which is incorporated into one entire case with the engine, on our motorcycle. This will greatly simplify the labor associated with completing a transmission gearing swap. The sprockets can be easily and economically changed to obtain the optimal gearing required for our designated operating range.

After completing the above alterations on our engine we will then need to determine, through testing, what will need modifying. The testing of the engine is to be completed on two separate dynamometers. The first is a chassis dynamometer located at one of our sponsors. This dynamometer will allow us to obtain a before and after reading of our bike. The chassis dynamometer allows for testing of the engine while still within the motorcycle. The drive-train efficiency of the motorcycle can be found by comparing the chassis and engine dynamometer results to each other. The second dynamometer available to us is an engine dynamometer located on Virginia Tech's campus. This dynamometer will allow for testing of the individual engine while the rest of the bike is being modified to accommodate the propane tanks and associated items. We are in the process of designing a test stand for use with this dynamometer. We have a dedicated test location on the engine dynamometer for the entire spring semester. This will allow for extensive testing of our final product. An emission computer will also be paired with this dynamometer. This will allow us to dynamically test the emission levels of our new engine.

Conclusion

The overall design of the engine and its associated components is now complete. When beginning to decipher the problem at hand, the two main goals were better emission levels along with similar performance levels. We feel that these objectives were meet with the above design. We will determine during the upcoming months as to how it performs under operating conditions. Extensive research and design went into the above design therefore minimizing the concern of failure during testing.

References

Sportbike Performance Handbook; Kevin Cameron, 1998.

Kawasaki Service Manual, ZX-6R; Kawasaki Motor Co, 1997.

Engineering Thermodynamics; Jones and Dugan, 1996.

Introduction to Internal Combustion Engines – Second Edition; Richard Stone, 1992.

Various World Wide Web Sites

Exhaust System

written by Julien Bassett and Eric Kruszewski

Introduction

The team's purpose was to improve the motorcycle's emissions, reduce the exhaust system weight, and increase overall performance. Because of funding restraints, our team had to design a system at the lowest possible cost. Within our budget, we devised several concepts that will improve the emissions of the propane-converted motorcycle. After brainstorming about different ideas, we focused on the most realizable propositions and researched the best method for a solution. The final exhaust system modifications included:

- Implementing a catalytic converter
- Purchasing an Indigo Sports after-market exhaust system
- Removing the exhaust gas recirculation system
- Integrating an air pump

After these alterations have been completed, the pending concepts will be further evaluated and implemented in the new exhaust system design. These potential designs and overview of the exhaust system modifications are discussed in the following paragraphs.

Design

Throughout the semester, we have researched different methods of obtaining the above mentioned goals. We first developed a system using an electrically heated catalytic converter to reduce cold start emissions. This electric heater would raise the temperature of the catalytic converter above 300°C. When operating above this critical temperature, the heated converter functions more efficiently, thus reducing the amount of harmful emissions. In order to determine when the substrate has been heated above its critical temperature, the system would require a control device. The control system would include thermocouples mounted onto the catalytic converter sending a signal to the controller, feeding back a temperature reading. From this reading, the controller can be programmed to determine whether or not to supply the electric heater with power from the battery. Once the catalytic converter has reached its critical operating temperature, the controller would stop supplying the heater with power. This design would ensure that the battery power is not excessively wasted.

The energy required to operate the heater would draw power from the main battery before motorcycle start-up. A schematic of this can be found in Appendix A. Since the electric heater requires a significant amount of energy, we cannot rely solely on the main battery to supply the necessary power. Even though an additional battery could be added to provide energy to the electric heater, this is not a feasible alternative because of space constraints and an inadequate alternator (the alternator does not have the capability to recharge both batteries simultaneously). Since the catalytic converter's heater was not a priority in our design timeline, we decided to postpone any design advances thus far. The essential components must be designed before the performance improvements.

The stock ZX-6R comes equipped with an exhaust gas recirculation (EGR) system. The EGR system returns unburnt fuel out of the exhaust headers back into the intake. This aids in reduction of emissions and increased gas mileage. This system will be removed because it is not compatible with the newly designed air intake. To compensate for the loss of the EGR system, we have decided to utilize a pump to feed air directly into the exhaust headers. The air pumped into the exhaust headers will spontaneously combust with the unburnt fuel, thus improving emissions. A catalytic converter can then be used to reduce the remaining harmful exhaust gases.

To achieve our main objective of reducing emissions, we have added a catalytic converter from Diversified Environmental Catalysts (DEC). The catalytic converter uses a 3-way metallic substrate consisting of platinum, palladium, and rhodium. The catalysts use palladium to oxidize hydrocarbons (HC and CO), while the platinum-rhodium substrates oxidize hydrocarbons and reduce NO_x emissions. The outer casing of the catalytic converter is finished with polished stainless steel and has overall dimensions that can be referenced in Appendix A.

The current stock exhaust system on the Kawasaki ZX-6R is shown in Appendix A. The exhaust gases flow through four headers, converge into a collector, and are expelled through the exhaust pipe and muffler. The catalytic converter will be placed in the exhaust pipe. To insert the catalytic converter, a section of the exhaust pipe will be cut and replaced by the catalytic converter welded at each end of the section as shown in the detailed drawing included in Appendix A. Furthermore, the catalytic converter and stock exhaust diameters are not the same. Therefore, we designed the system using bell reducers to compensate for the diameter difference. After inspecting the motorcycle, we realized that the current stock exhaust system contains a metal plate that would impede airflow through the catalytic converter. Because this plate can not be removed, we will substitute the stock exhaust system with an after-market design.

To obtain an after-market system, we have researched different motorcycle exhaust system manufacturers. The advantages of utilizing the after-market system include:

- Decreasing the weight of the exhaust system by half
- Matching the catalytic converter diameter
- Delivering better airflow
- Increasing the performance

This after-market system will be purchased from Indigo Sports at a discounted price. Using the new after-market exhaust, the catalytic converter can be easily included in the exhaust system assembly. For this design, bell reducers will not be used since the exhaust pipe diameter and catalytic converter's entry and exit diameters are equal.

Conclusion

The final design will include a catalytic converter, an after-market exhaust system and an air pump. Further research will be conducted in the future to possibly incorporate an electric heater to aid in the reduction of cold start emissions. We have achieved our design goals thus far by reducing the overall weight of the exhaust system, reducing harmful emissions, and increasing the motorcycle's performance.

Attached: Appendix A – Engine Subteam