DESIGNING EXHAUST MANIFOLD OF THE FORMULA STUDENT VEHICLE

INTRODUCTION

Product development is an important aspect of any organization and it is important that all these development follows the right engineering path and uses the correct engineering techniques. The current exhaust manifold design of the OBR car is reasonably good as it does meet the performance criteria, but the team struggled to pass the noise test in FS Austria. Formula Student is perhaps the greatest platform for students across the world to showcase their talent in the field of engineering. This means that there is heavy scrutineering of every car and there are stringent rules to account to before the team can go on the track. One such rules is the noise test. The rules state that the exhaust system must meet 110 dB at maximum engine speed and 100 dB at idle speed.

The team failed to pass the noise test with the aerodynamic package and to clear the test had to resort to removing the rear wings. The current team is looking in to the issue and is working on a complete redesigning of the exhaust system. The new system will have the same design philosophy followed the previous year but with heavy improvements in the area of performance characteristics and noise dampening. The current team is designing and building a new exhaust system that will not exceed 110 dB at a maximum of 10000 rpm and 100 dB at idle speed, validated by use of a decibel reader oriented 45° from the horizontal and located 19.685 in. from the exhaust outlet.

HELMHOLT RESONANCE THEORY

Hermann Von Helmholtz a German scientist was, arguably perhaps the greatest physicist in the field of acoustics. He is not just known for his work in the acoustics, but infact is known more for his work in laying out the foundation of thermodynamics, electrodynamics and conservation of energy.

Helmholtz resonators have been in use since a long time and has been implemented in different environments. Fromm movie theatres to designing of the television room in offices, Helmholtz resonance theory is used. But, for us and for the sake of this project we will be using Helmholtz resonant theory in our design for the exhaust manifold. A Helmholtz chamber consists of a single cavity and one or multiple necks at the exit of the cavity. The principle of Helmholtz resonator is using the impedance caused by the inertia effect of the air in the neck portion and the spring effect by compression and expansion of the air in the cavity and is most effective in its resonant frequencies to counteract the sound waves of the noise in the chambers.

This theory is widely used in designing of RAM air intakes and it has been proven on numerous occasions that the theory works brilliantly if tuned to perfection.

EXHAUST

In order to determine the tuned exhaust header and acoustic tuning, it is necessary to understand the combustion process of a 4S-IC engine. The four processes (in sequence) in working of a 4S-SI engine are: (1) expansion for intake of air and fuel. (2) compression of air and fuel mixture. (3) expansion due to combustion of air and fuel mixture. (4) compression to expel the exhaust gasses out of the exhaust port. The noise generated during these processes can be uncomfortably high and can peak more than 100s of dB.

The other main purpose of the exhaust is to help in increasing the performance characteristics by helping in the suction process. The intake process is improved if the pressure in exhaust manifold is less than that of the pressure in the chamber and this primarily helps during the valve overlap period. This phenomenon is known as scavenging. Therefore, it is important for the performance characteristics and for keeping the noise level under check to design the exhaust with utmost care.

HEADERS

Headers is the basic pipe length, diameter and shape of the exhaust manifold. In most cases the shape depends on the available space and even though a straight pipe with no bends is desired, it is barely the case. If the theory of conservation of mass is considered, then a small pipe would result in evacuation off exhaust gasses at low speeds faster. But at high speeds the pipe would not have enough mass flow to account for. Hence, we reach a conclusion that it is a trade-off, as is the case with most of the design of the vehicle. Next to consider is the header length. For proper ‘backpressure’ or ‘scavenging’, an ideal length is required to allow for reflected pressure waves to arrive back at the exhaust port in time for the valve overlap period. In the book ‘the scientific design of exhaust and intake manifold’, the table and graph for gas velocities help us determine the ideal manifold diameter for our case. Because of the complex nature of the scavenging effect. It is usually assumed that the manifold is straight with no bends. The two equations which determine the length of the exhaust manifold is given below.

$$P = \frac{ASD^2}{1400d^2}$$

$$P = \frac{850(180+B)}{R} - 3$$

Where P determines the length of manifold in feet, A is the exhaust valve open duration in degrees, S is the stroke length in inches, D is cylinder bore in inches, d is exhaust port diameter in inches, B is 180 plus the degree of exhaust valve opening before BDC, R is target RPM.

QUARTER WAVELENGTH TUBES

The geometry of exhaust manifold is basically dependent on the space available. Ideally, a straight pipe with no bends is desired but that is highly unlikely as there is barely any space available. With that in mind, and after the geometry is decided, the natural frequency at which the exhaust manifold is tuned, is determined.

Quarter wavelength tubes are acoustic devices which help in producing counter wave to the noise and odd harmonic frequencies. The tubes are attached to the main flow path and at low speeds it is found that the acoustic performance is better but not as good as it is when the flow speeds increase. This Adaptive Quarter Wave Tube (AQWT) can perform differently based on different types of configuration. The two most common ways of installing the quarter tube are 90deg branch with sharp edges, 45 deg branch inclination. The 90 deg branch can be made without the sharp edges more like a bell mouth structure. All these designs influence the performance of the quarter wavelength tube.

One of the advantages of the AQWTs is that it is a passive device and does not inject acoustic power in to the system to provide noise reduction.

For a four-stroke reciprocating engine, the piston firing frequency occurs at half the crankshaft speed times the number of pistons in the engine, hence

$$f_{\text{engine}} = \frac{RPM}{60} \times \frac{\text{pistons}}{2} \quad \text{Hertz}$$

Meanwhile the quarter wavelength tube frequency is given by

$$f_{QWT} = c/(4L) \quad \text{Hz}$$

Quarter wave tube provide attenuation at only the odd multiples of their fundamental resonance frequency. Since the length of the quarter wave tube depends on the speed of sound and if we look at the formula to define speed of sound, we know that the speed of sound is sensitive to temperature. Common sense tells us that the temperature is different at different engine speeds. This means that the quarter tube can be tuned only for certain rpm limit and will function at that engine speed. Therefore, a fixed quarter wave tube will provide attenuation at a fixed engine speed and exhaust gas temperature. This led to a problem as in the competition Formula Student, noise test is carried on two different conditions, at idle rpm and at maximum rpm.

It was decided that the quarter wave tuning will be done at the rpm where the piston speed is 15.25m/s. This was chosen because of the rule book stating that the maximum piston speed at which the measurement will take place will be 15.25m/s.

ENGINE SPECIFICATIONS

The engine in which the design will be carried out is the KTM 450. It is a 449.3 cc engine with a bore value of 95mm and stroke value of 63.4mm. It is an over square engine. There are two more types of engine based on bore and stroke dimensions. If the bore is equal to the stroke, then the engine is called square engine. The third case is where the stroke is greater than the bore then the engine is defined to be under squared.

The engine port diameter is measured to be 40mm (appx). The port diameter is important in determining the dimensions of exhaust header. The header length and diameter depend on the engine speed it is tuned for and harmonic length is determined based on space available.

CONCLUSION

In conclusion, it is safe to say that quarter wavelength tube if tuned to perfection can aid in noise reduction and provide an added advantage of helping in the scavenging process. The scavenging process is directly related to the valve overlap period. This short period of time would not have such a huge effect in a single cylinder engine. In multi-cylinder engines however, there should be a pressure drop generated, big enough to affect the performance of engine by affecting the scavenging process in a positive way.

Quarter wavelength tube is a good solution to the problem of the noise and will be tuned according to the specifications mentioned above. The fact that Formula 1 teams like Ferrari employing this type of feature in the 2012 car is more than enough of a proof. The passive system brings in advantages of itself and prevents the system from creating its own reflective sound waves in a bid to cancel out the noise.

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