An Inexpensive Flow-Bench for Mechanical Engineering Labs

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Abstract

A flow-bench is a valuable piece of lab equipment useful for various mechanical engineering flow experiments. For example, in an Internal Combustion (IC) engines course students can test modifications to cylinder heads (valve lift, valve size, porting, etc) on such a flow-bench. An experimental device like this could also be used in a general fluid mechanics and instrumentation course.

This paper describes the design, construction and testing of a flow-bench built for less than $1500. Commercial flow-benches can cost from $50,000 to $500,000. The current flow-bench has the capacity for air flow up to 300 CFM (cubic feet per minute) and a pressure drop of 28 inches of water. Experimental data were taken on a standard 5.3 liter aluminum Chevrolet truck engine head and were compared to existing data in the literature. Specific details are provided so that other universities can fabricate such equipment.

Introduction

Various industrial and commercial devices must be flow-checked before being manufactured for the public. For example, in the engine design-phase a flow-bench is used to measure the amount of air that can pass through various components (intake and exhaust ports, intake and exhaust valves, etc.) associated with the combustion process of an engine. The amount of horsepower that an internal combustion engine can produce is limited by the amount of air that can pass in and out of the combustion chamber. Further, a flow-bench can also be used to evaluate any component that is used to flow a gas such as air filters manifolds, carburetors, throttle bodies, exhausts manifolds, pipe fittings, valves, etc.[1] A flow-bench can also be used for the study of many other types of fluid mechanics problems; therefore a flow-bench can be a valuable teaching tool in engineering education.

Engine builders for racing or automobile manufacturers often try to analyze engine parts to optimize engine performance. From the fuel delivery process through the exhaust process, the various engine components can be analyzed through the use of a flow-bench.[2]. For example when a cylinder head is flow-tested in a flow-bench the amount of valve opening, port geometry, valve configuration, etc. can be varied and studied to optimize flow performance. A typical results on a flow-test is shown in Figure 1. The market for a commercial flow-bench offers various designs with prices ranging from a few tens of thousand dollars to several hundreds of thousand dollars.

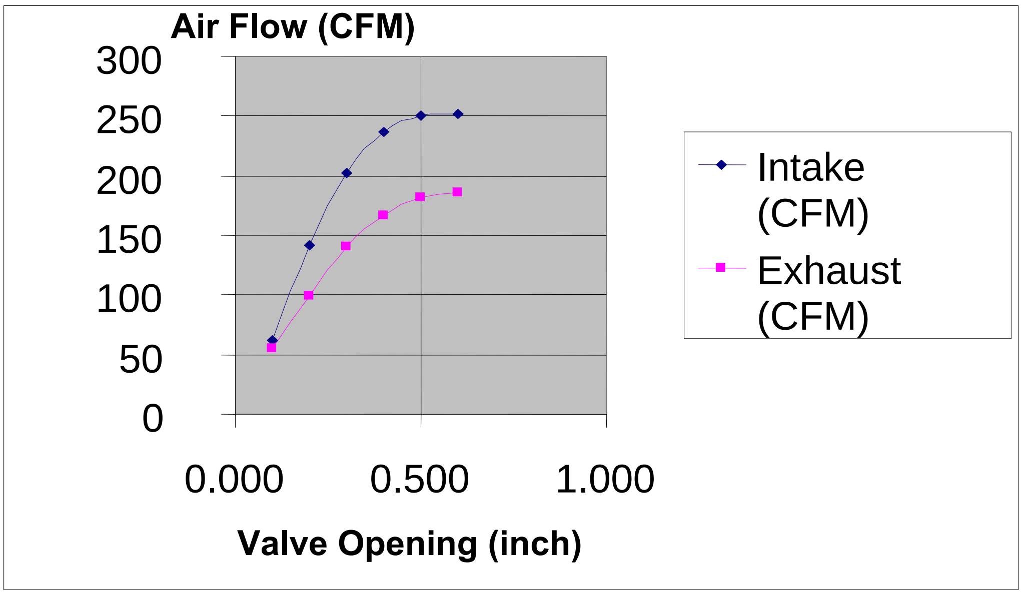

Figure 1. Typical Engine Head Flow Test Data .[2].

The primary focus of this project was to design, build and test a flow-bench for use in a mechanical engineering laboratory while keeping the system within reasonable financial limits without sacrificing experimental performance. Standard components of a flow-bench are: test piece, air-flow measuring device, air temperature measuring device, flow control mechanism and a device to measure the pressure drop across the test piece [3]. The unit should also be safe for the experimenters and the spectators. The apparatus would also have to be able to test automobile equipment at standard test conditions (which is usually 28 inches of water pressure drop). The general layout of such a system is shown in Figure 2.

The sizes of various components in the current design were chosen to provide a reasonable balance between initial cost and operating costs. The pressure drop characteristics of each of the straight sections, elbows, entrances and exits were calculated using the Moody diagram and standard head-loss coefficients. A 4-inch (ID) PVC pipe section was used at the top of the bench plate under the test piece and 3-inch (ID) PVC pipe was used for all of the sections except for the flow measurement section. The resulting apparatus required four-220 volt single-phase vacuum motors were required to produce 28 inches of water pressure drop in the plenum at 300 CFM air flow. (A flow of 300 CFM was selected since this is an upper limit for the flow capability required for typical modern V-8 engines.) A by-pass valve on the plenum is used to control the flow. Air temperature in the flow stream was measured with a thermocouple. Note that the air flow is a “pulling” system rather than a “pushing” system. The reduces the turbulence (and error) at the flow measuring section by having the fans downstream of the flow measuring section.

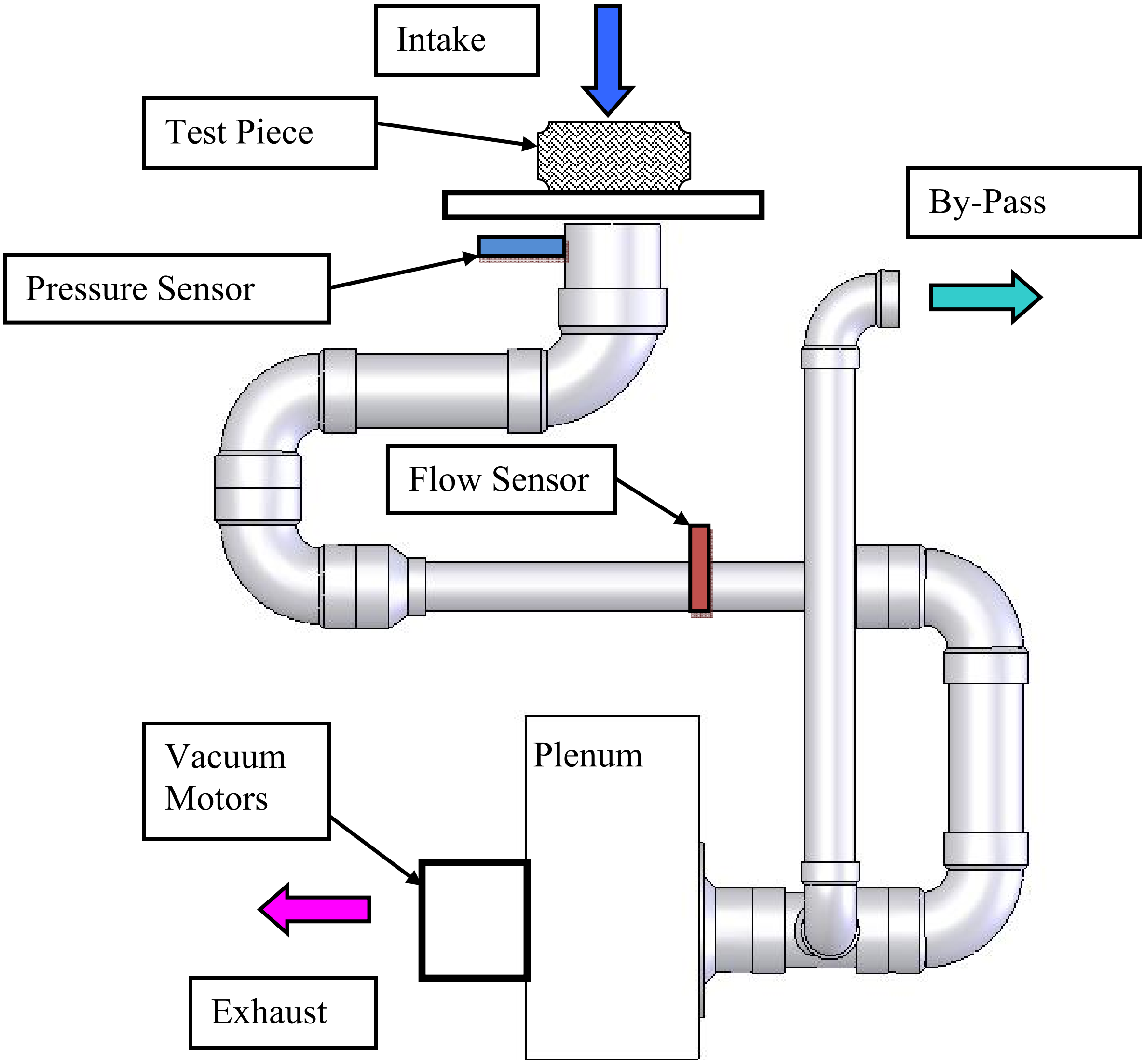

Figure 2. Flow Bench Flow Path

The frame of the machine had to withstand the weight of test item, flow piping, bench top, plenum and vacuum motors. See Figure 3. The frame was built from 1½-inch square steel tubing providing substantial support for the system weight, yet light enough to keep the apparatus portable (using four swivel-base casters). The vacuum motor box/plenum, constructed from 1/8-inch steel plate, was designed to withstand the forces that could be created from the maximum pressure differential. The total cost of the system was slightly below $1500.

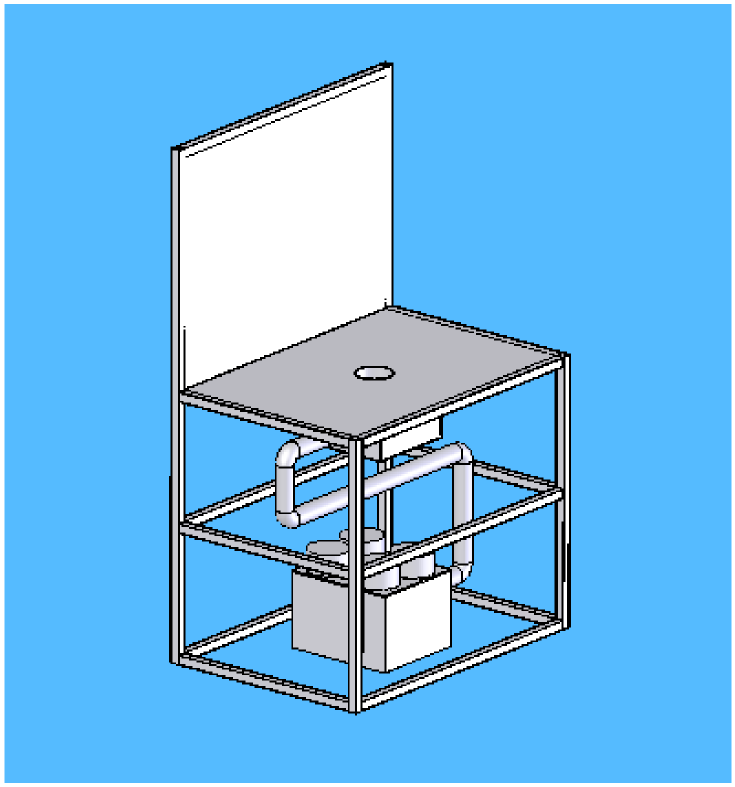

Figure 3. Flow Bench Frame - schematic

Figure 4. Flow Bench Frame – Actual

For cylinder head flow testing a special valve-opening device was also required on a cylinder heads where the flow is a function of the amount of valve opening. See Figure 5.   Here a valve opening plate was fabricated to bolt on the top or the heads so that a dial micrometer could measure the amount of valve opening during each flow test. Note that some flexible material such a putty is used on the entrance to the port to smooth the air flow.   The final flow bench is shown in Figure 6.   Other details for each item can be obtained from Table 1 and the authors' report.[3]   In an actual experiment all personnel used safety glasses and ear plugs.

Part Number	Description	Qty.	Cost	Cost	Company
6MT69	2" PVC Schedule 40 Pipe	10'	$10.18	$10.18	Grainger
6MZ31	2" PVC 90° Bend	5	$1.33	$6.65	Grainger
2M424	4amp 240V 102cfm 87.8" sealed	4	$84.20	$336.80	Grainger
3T404	36" U-tube Manometer	2	$61.75	$123.50	McMaster

Table 1. Major Equipment Parts List

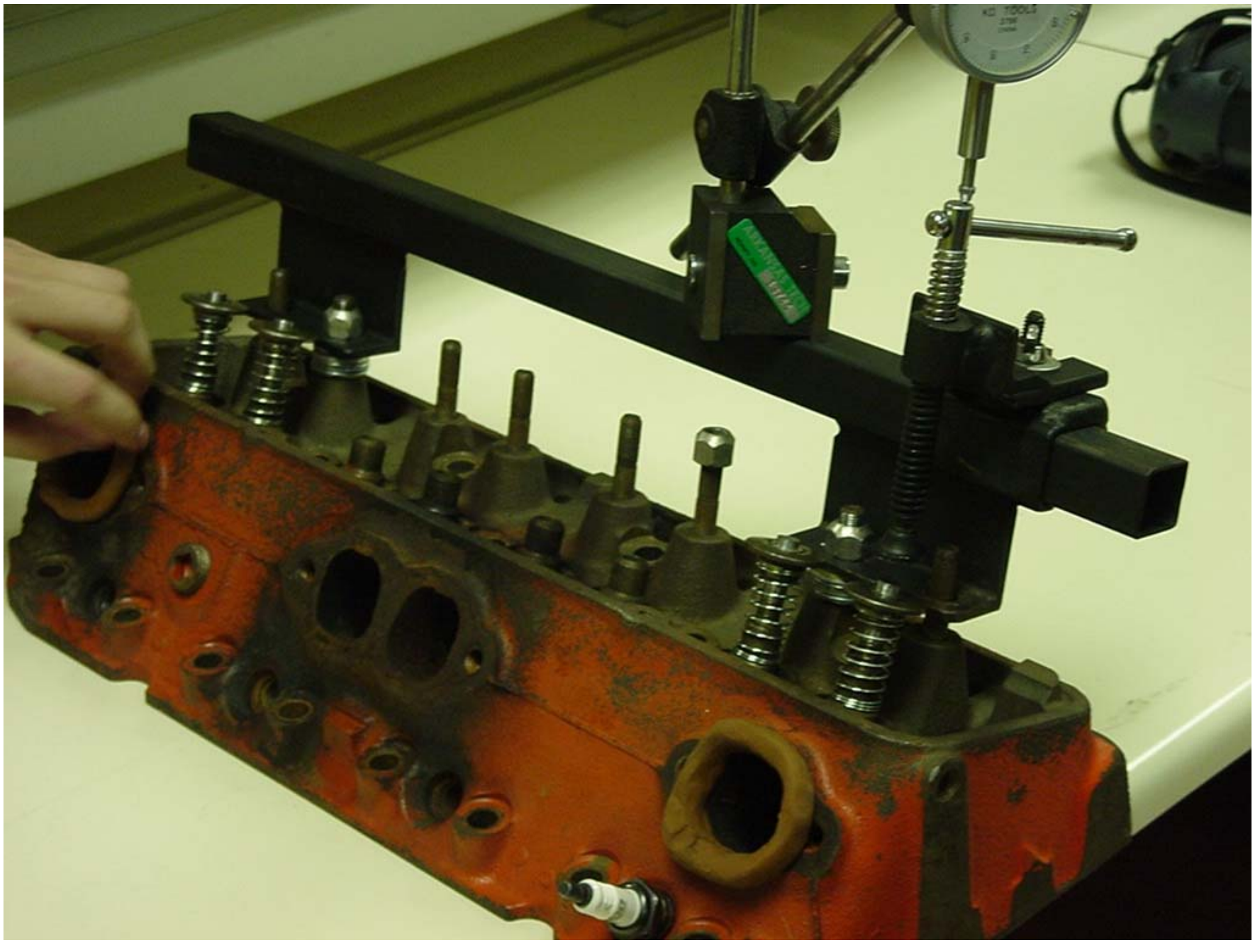

Figure 5 Valve Opening/measuring device

Figure 6. Completed Flow Bench

Theory and Analysis

Engine head flow data from a flow-bench is usually presented as volumetric flow verses amount of valve opening at standard pressure drop (28 in-water). Several devices could have been used to measure the air flow rate such an orifice-plate style or venturi style flow meter. However an averaging pitot tube[4] was used in the present apparatus. An averaging pitot-tube uses the standard pitot-tube velocity equation based on Bernoulli's equation (equation 1) applied between the stagnation point and the static pressure point in order to compute a velocity (equation 2) .

$$p + \frac{1}{2}\rho V^2 + \gamma z = \text{constant along streamline} \qquad (1)$$

$$V = \sqrt{2\Delta P / \rho} \qquad \text{(for no change in elevation)} \qquad (2)$$

Where V is the average velocity, ΔP is the measured pressure drop, and ρ is the fluid density.

With appropriate units and constants the dimensional equation is equation 3 [4]

$$V = 1096.2\sqrt{\frac{\Delta PT}{1.325P_a}} \quad (3)$$

Where ΔP is the pressure drop measured between the pitot-tube and the stagnation pressure point in inches of water. T is the temperature in Rankine. P_a is the atmospheric pressure measured in inches of mercury and velocity is in feet per minute.

The volumetric flowrate Q (cubic feet per minute) is then determined from

$$Q = VA \quad (4)$$

where A is the cross-sectional flow area (feet^2),

The averaging pitot tube has a series of holes at the stagnation side of the tube. See Figure 7.

Figure 7. Averaging pitot tube [4]

The averaging pitot tube measures the average velocity through the cross-section of the test section only if the flow is uniform. However the flow in a duct is usually never uniform. As fluid flows through a pipe it moves slower at the edges of the pipe and faster at the center. Averaging the pressure drop across the test section does not yield an average velocity since velocity is not linearly related to pressure drop[6]. Therefore the averaging pitot tube meter was calibrated with a velocity traverse across the duct cross-section using a hot wire anemometer. The results are given below in Table 2. The results reveal that the calibration reduced the velocity error by about 10%.

Δ P (Inclined Manometer) (in-H20)	Volumetric Flow Rates		% Difference
	Indicated (CFM)	Actual (CFM)	
7.20	387.50	338.90	13.38
6.00	365.40	309.40	16.60
5.00	316.10	282.40	11.26
4.00	278.40	252.60	9.72
3.00	240.70	218.80	9.53
2.40	211.70	195.70	7.85
2.00	197.20	178.60	9.90
1.00	145.00	126.30	13.79
		Average	11.50

Table 2. Flow Rate Calibration Data

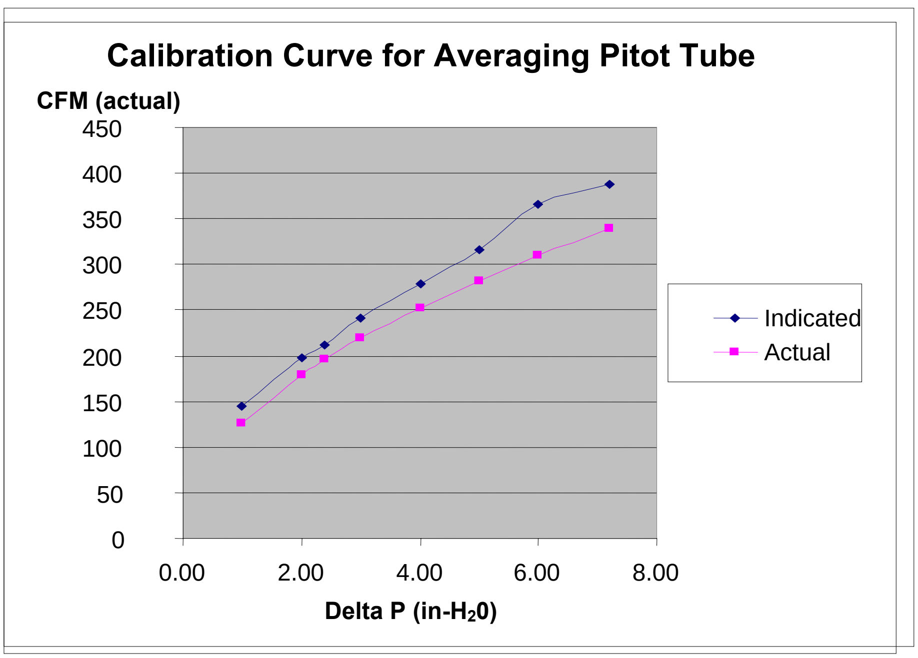

Figure 8. Flow Rate Calibration Curve

Based on basic uncertainties in the basic parameters of:

ΔP = 5%
Diameter = 0.5%
Calibration curve = 2%

The volumetric flow rate (CFM) had an uncertainty of about 6% and the valve opening has an uncertainty of 1%.

Results

The group performed flow testing on a Chevrolet 12559862 casting aluminum cylinder head used 5.3 liter engines (see Figure 9). The measurements for a given valve lift were recorded twice for each port on the cylinder head (A total of twelve tests on the head), and the average value of the flowrate was calculated using each measurement for the intake and each measurement for the exhaust. The standard deviation was calculated by comparing the two different measurements made on the same port at the same lift. The actual valve springs were replaced with lower spring-rate units so that compression of the valves would be easier to accomplish during the tests (see Figure 5).

The flow data for this head is shown in Table 3 and Figure 10. The intake flow numbers are rather close to the expected values within a few percent while the exhaust flow numbers are higher than expected[6]. The head was obtained from a local GM dealer so there is no real reason why the exhaust value should test higher. However there are slight variations between head castings and the inlet flow transition section will differ between one experimental unit to another. The standard deviation between the measurements made on the same port at the same lift was calculated to be 1.170.

Figure 9. Typical GM 12559862 LS1- Head

These results indicated that the flow-bench provides reasonable flow data. This indicates that the flow data to be accurate with some data is the literature to be ~ 5% on the intact and less than 20% on the exhaust.

	Average of Test		Published Value [7]		Percent Difference	
Lift (inch)	Intake (CFM)	Exhaust (CFM)	Intake (CFM)	Exhaust (CFM)	Intake (%)	Exhaust (%)
0.100	55.9	49.9	N/A	N/A	N/A	N/A
0.200	127.8	89.3	123	108	3.76	20.94
0.300	181.9	125.8	180	147	1.04	16.85
0.400	213.0	149.7	219	172	2.82	14.90
0.500	225.3	163.0	231	193	2.53	18.40
0.600	226.5	167.7	N/A	N/A	N/A	N/A
Std. Dev.	1.170					

Table 3. Chevy Aluminum [LS1 casting number -12559862] 5.3 Liter Flow Data.

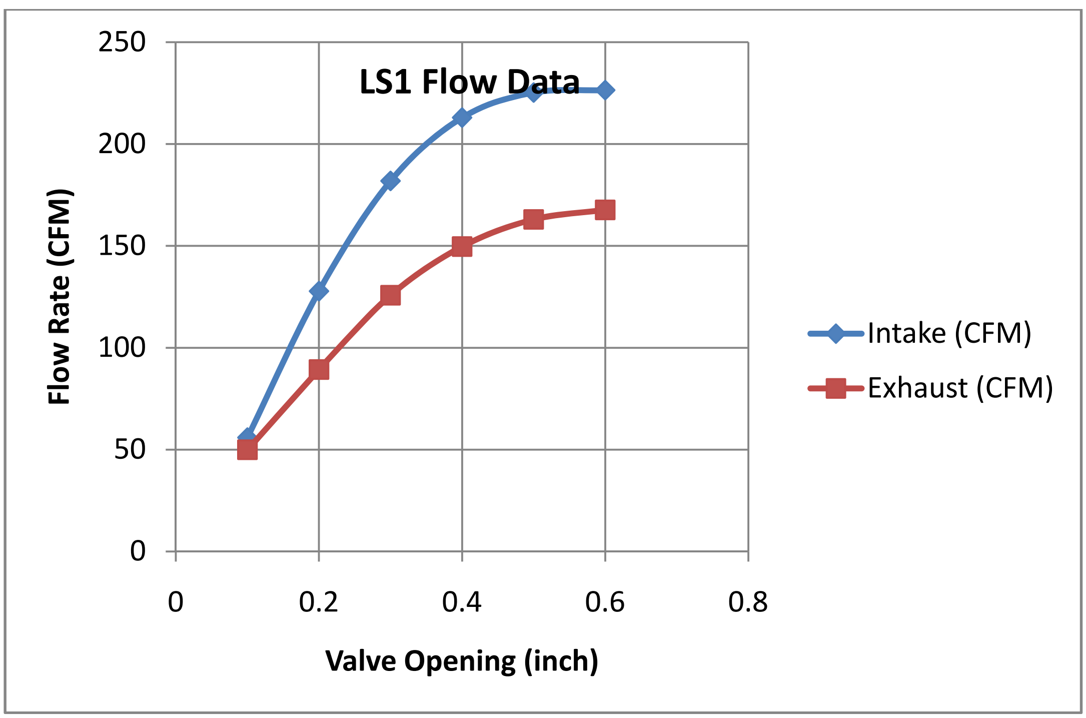

Figure 10. Chevy Aluminum [LS1 casting number -12559862] 5.3 Liter Flow Graph.

Conclusions

A flow-bench was designed, fabricated and verified with experimental data on a typical automobile engine head. The apparatus cost less than $1500 to complete. This apparatus could also be used in a general fluid mechanics and instrumentation course as well as in an Internal Combustion (IC) engines course. Specific details are provided so that other universities can fabricate such equipment.

References

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