Analysis Of Change In Intake Manifold Length And Development Of Variable Intake System

Shrinath Potul, Rohan Nachnolkar, Sagar Bhave

Abstract: Gas dynamics of intake system plays a key role in deciding the performance of an engine. This dynamics are different for fuel injected and carbureted engine and vary according to type of engine, number of cylinders, temperature at inlet, valve timing, valve angle and other factors. Careful design of the manifolds enables the engineer (designer) to manipulate the characteristics to the desired level. This paper investigates the effects of intake runner length on the performance characteristics of a four-stroke, single-cylinder spark-ignited engine with electronically controlled fuel injector. In this paper basic intake tuning mechanisms were described. Engine performance characteristics such as brake torque, brake power, brake mean effective pressure and specific fuel consumption were taken into consideration and virtual simulation software LOTUS ENGINE SIMULATION was used to evaluate the effects of the variation in the length of intake plenum on these parameters. It was found that change in runner length had a considerable effect on the rpm atwhich peak value of torque was obtained (occurred). Accordingly a system to adjust the manifold length (tuned adjustable intake pipe) was designed and developed. According to the simulation graphs, in order to increase the torque performance, plenum length must be extended for low engine speeds and shortened as the engine speed increases.

Key Words: intake tuning, intake manifold, gas dynamics, engine performance, toque characteristics, simulation, system development.

1 INTRODUCTION

EFFECTIVELYadjusting the operating parameters such as the relative air–fuel ratio, ignition timing, spark advance fuel injection timing, valve timing, compression ratio in SI engines at different load conditions improves significantly the engine characteristics. The effects of these parameters have been exploited to a great extent using TDCI, Quadrajet, DTS-Si, twinspark, triple-spark technologies.The acoustic and inertial ram effects have not been used to a great extent to increase engine performance. These phenomena contrary to other methods of increasing engine torque allows engine performance to increase without use of extra additional fuel or regulating device. The pulsating nature of the airflow produced through the intake manifold and runner due to valve opening and closing results in resonances in the airflow at certain speeds. [7] Conventional intake manifolds for vehicles have fixed air flow geometry and static intake manifold. The static intake manifold can only be optimized for only a specific rpm and this rpm corresponds to maximum torque rpm of a given engine. So it is beneficial to develop a method to vary the intake length, to broaden the torque curve since the engine operates over a large speed range. Various designs for variable intake geometry have met with varying degrees of success. One such new innovative design using reciprocating mechanism is presented in this paper.

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2 INTAKE TUNING THEORY

There are two parts of a waves basically a compression wave and a rare faction wave. Both these waves can be made useful to increase the volumetric efficiency of the engine thus increasing its breathability. At certain instances (i.e. rpm) the volumetric efficiencies of more than 100 % is obtained. Thus increasing the torque output and performance of the engine. The compression wave is generated when the momentum of the airflow is halted suddenly by the closing of intake valve. This compression travels back and forth along the closed intake runner length. Tuning corresponds to adjusting the length of intake runner so that this pressure wave arrives exactly at the time when the inlet valve opens. This effect is also called as inertial ram effect and length is decided by Chryslers Ram Theory. [5]Another wave is the rarefaction or suction wave, This low pressure wave is generated at the time of the suction stroke of the engine, travels upstream to airflow, gets reflected from the inlet boundary(open intake end) as a high pressure wave, travels downstream towards the combustion space. This compression wave if made to arrive at proper time, by proper designing of intake manifold length increases local density of inlet flow. This effect is sometimes referred to as natural supercharging or acoustic supercharging. Here the length is decided by Acoustic Theory of Piping/Resonance theory. [2] For multi cylinder engines having common intake manifold the compression wave can be tuned using the Chrysler method deciding the length of the individual intake runner .The suction waves produced at the time of suction stroke can be tuned using acoustic theory.

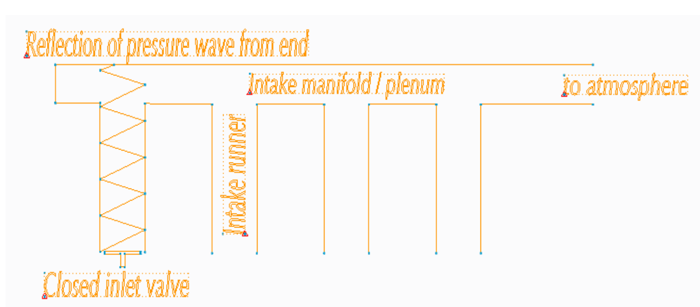

Fig. 1. Chrysler's Ram Theory

For single cylinder engines as the inlet runner and the intake manifold are the same and there is no plenum end,the suction wave when reaches the inlet end open to the atmosphere it gets reflected back as a compression wave and the arrival time of this wave is to be matched with the maximum piston velocity time in order to get a torque increase. The arrival time can be altered by altering the inlet pipe length or changing the cross sectional area of pipe. In order to tune for a compression wave Helmholtz resonators are used.

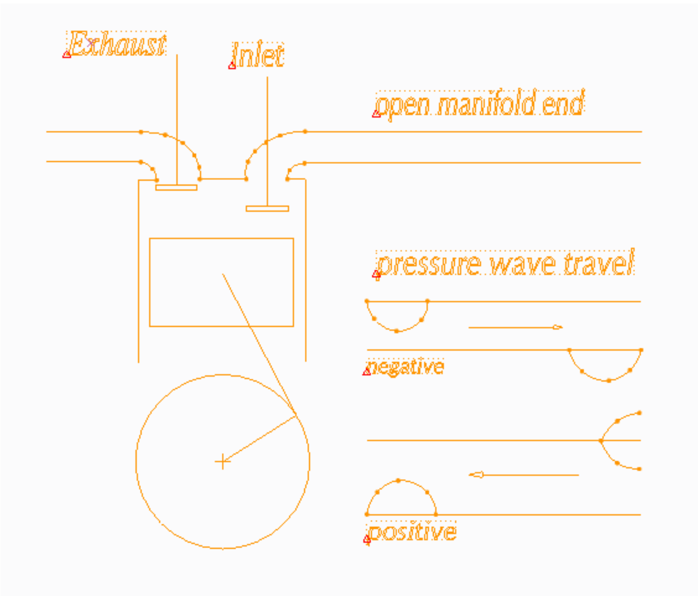

Fig. 2. Acoustic Tuning Theory

Unfortunately, tuned intake manifold works only across a narrow rev band. If the engine revs beyond that band, the pressure wave will arrive too late in the intake stroke, contributing little to charging. If the engine runs below that rev band, the pressure wave will arrive the inlet valve before it opens. In both cases torque output is reduced. With variable intake manifold system torque can be increased for 2 or more different engine speeds. Thus peak torque can be obtained for 2 or more stages. It is generally cheaper to produce because it involves only some cast or plastic manifolds and a few electric-operated valves.

- 2-stage Variable Intake manifold (VIM) in Honda K20engine
- 2-stage Toyota Variable Intake System (T-VIS)
- 3-stage Variable Length Intake Manifold (VLIM)in Audi, 4.2-liter 40-valve, V8 engine
- BMW's DIVA, Differential Variable Intake System,N52 V8 engine

The problem with two stage system is that it occupies very large space as we have to accommodate two intake runners for every cylinder. The lack of space leads to the use of narrower pipes, which in turn limit the mass flow rate of air to the cylinder. Thus it is not very suitable to high-performance engines. Also both runners do not work simultaneously. Atany stage only one of the two runners is in action while theother runner is idle thus accounting for nothing. Also the problems with the 3 stage VLIM and continuous VLIM is that the entire length of the runner is used only for a short range of rpm, as the rpm increases the idle length goes on increasing.Thus both these systems cannot be used in two wheeler vehicles where we have space constraints.

3 Literature Review:

M A ceviz conducted experiments to study effects of intake plenum volume variation on engine performance and emission. Brake and indicated engine performance characteristics, coefficient of variation in indicated mean effective pressure (COVimep) were taken into account. He concluded that the engine performance can be increased by using intake plenum volume that is continuously variable.[3] M.A. Ceviz and M. Akın investigated the effects of intake plenum volume on the performance of a spark-ignited engine with electronic fuel injector. SI engines with multipoint fuel injection system showed better characteristics than carbureted one. The results showed that the variation in the plenum length causes an improvement in fuel consumption at high load and low engine speeds.[2] Dr. Julio Militzer, Jeff Coffey and Adrian Dunlap designed a 2 stage variable intake system using Flap control system for Formula type FSAE car. Flaps were used to switch between two different runners.[1] O. Obodeh, and A.D. Ogbor described the dynamics of exhaust systems, Tuned adjustable exhaust pipe for use on two-stroke motorcycle was designed and tested. The tuned exhaust system was found to improve fuel economy of the engine by 12%. The major engine-out emissions, HC and CO were reduced by a minimum of 27.8% and 10.7% respectively.[4]

4 Calculations:

Helmholtz Resonator:

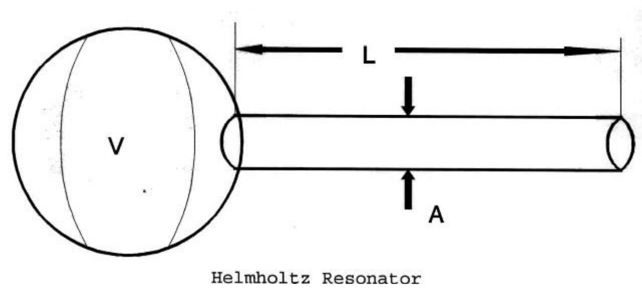

Fig. 3. Helmholtz Resonator

$$f = \frac{C}{2\pi}\sqrt{\frac{A}{L \times V_{eff}}} \quad \ldots\ldots\ldots\ldots\ldots 1$$

The whole arrangement can be modelled as a Helmholtz resonator. The effective volume is considered to be the Cylinder Volume with the Piston at mid-stroke (effective volume).The midstroke is considered because piston velocity is maximum at this position.

$$V_{eff} = \frac{V_D}{2} + V_{CL}$$

Where V_D is the swept volume and V_{CL} is clearance volume. Now Writing Clearance Volume in Terms of Compression Ratio

$$CR = \frac{V_S + V_{CL}}{V_{CL}}$$

$$V_{CL} = \frac{V_S}{CR - 1}$$

Solving for V_{eff} we get;

$$V_{eff} = \frac{V_D}{2} + \frac{V_D}{CR - 1}$$

$$V_{eff} = \frac{V_D(CR - 1) + 2V_D}{2(CR - 1)}$$

$$V_{eff} = \frac{V_D(CR + 1)}{2(CR - 1)}$$

Substituting in 1;

We have

$$f = \frac{C}{2\pi}\sqrt{\frac{A \times 2 \times (CR - 1)}{L \times V_D \times (CR + 1)}}$$

Where

$$L = l + 0.3d$$

$d \equiv diameter\ of\ the\ pipe$
$l = length\ of\ the\ pipe$
$C = speed\ of\ sound$
$f = frequency$

The tuning peak will occur when the natural Helmholtz resonance of the cylinder and runner is about twice the piston frequency.

TABLE 1
ENGINE PARAMETERS FOR KTM 200 DUKE[6]

Engine Type	Single-cylinder,4-stroke, spark-ignition, liquid-cooled
Displacement	$200cm^3$
Bore	72mm
Stroke	49mm
Max. power	25bhp
Max. torque	19.2Nm

C (Velocity of sound in air at 20°C) $=340 m/s$
A (Cross section air of pipe) $=9.621 \times 10^{-4} m^2$
V_D (swept volume) $=2 \times 10^{-4} m^3$

TABLE 2
CALCULATED PEAK RPM VALUES FOR INTAKE RUNNER LENGTHS

Length (mm)	Tuned rpm
300	8282
250	9042
200	10058

5 SIMULATION AND RESULTS:

Engine simulations were carried out on LOTUS SIMULATION TOOLS. KTM 200 Duke engine was considered for this purpose and following are the results obtained.

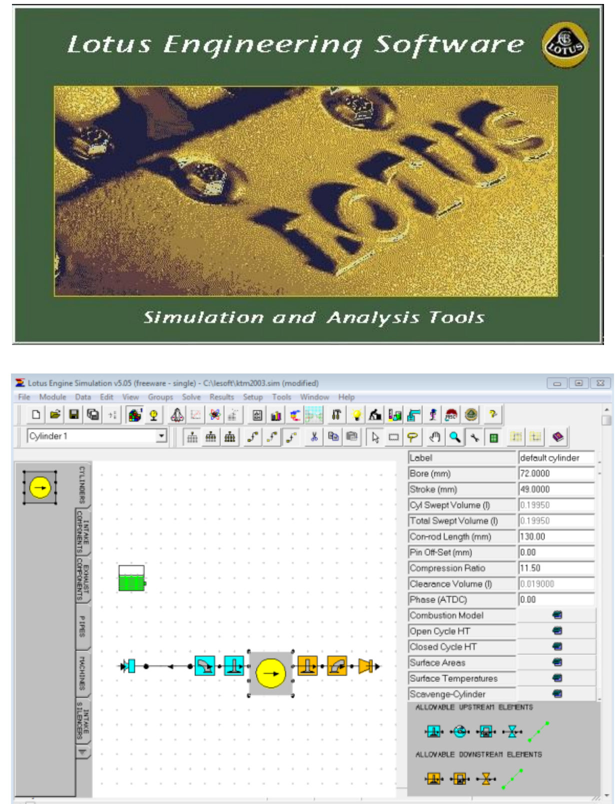

Fig. 4. Engine Simulation

The graphs shown represent the characteristics as specified below for different plenum lengths:
The blue line: torque output
The brown line: power output
The red line: brake specific fuel consumption (bsfc)
The green line: brake mean effective pressure (bmep)

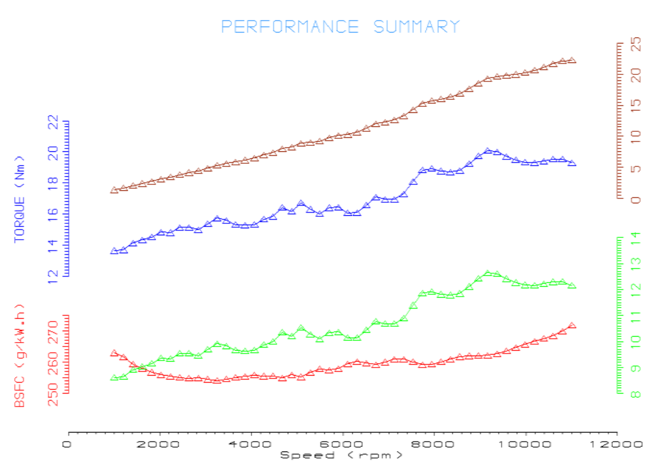

Fig 5. Graph for Plenum Length 200mm

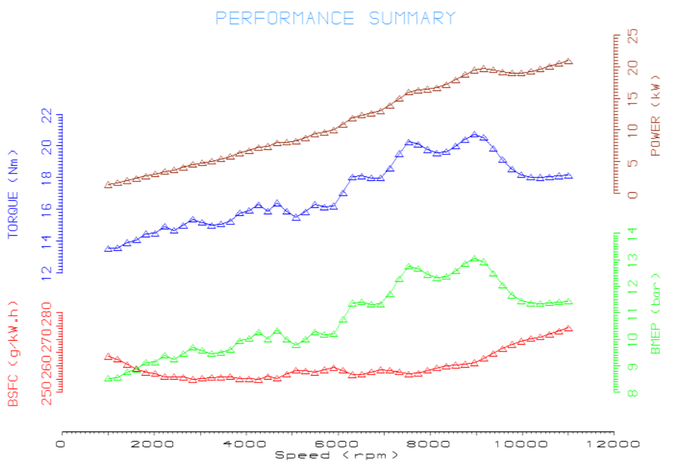

Fig.6. Graph for Plenum Length 250mm

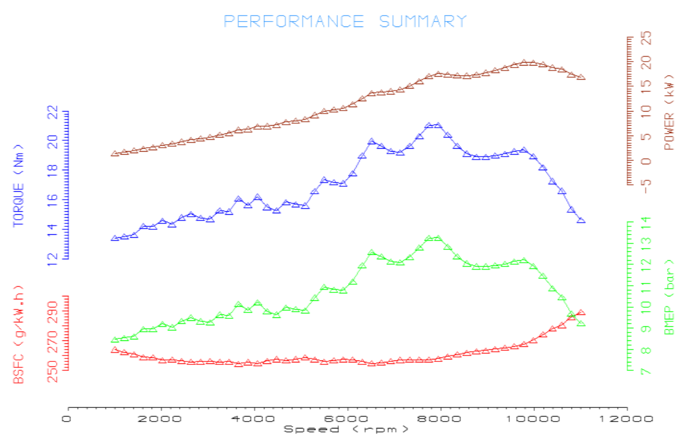

Fig. 7. Graph for Plenum Length 300mm

The blue line is the line of interest and it was observed that torque peak and torque output characteristics varied significantly with change in length of intake. Also the bmep curve was similar to the respective torque curve. The other variables such as power output and bsfc didn't vary much. The working points were inported in a graph plotter and the torque curve for all three lengths were compared.

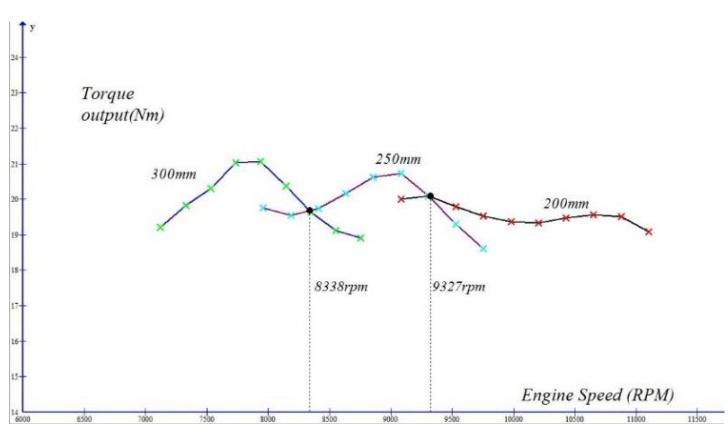

Fig.8. Comparison of torque output for different lengths 200mm, 250mm and 300mm

The comparison of torque curve of the three graphs shows the intersection points.These are optimum points at which the length of the manifold should be changed by 50mm length.Now that we have optimum shift point, 8338rpm and 9327rpm we can now proceed to development of a system that could incorporate this idea.

6 System Development:

6.1 Arduino Microcontroller

The Arduino microcontroller is an open source single board computer based on C language.

Table 3
Parameters of Arduino Board

Microcontroller	Atmel ATmega328
Operating conditions	5 V
Memory	2 Kb RAM 32 Kb flash memory 1 Kb EEPROM
Clock speed	16 MHz
Features	14 digital I/O pins and 6 analog input pins USB connector for connection to the host computer DC power jack

We have used arduino as an interface between the various systems to achieve desired results as in case of changing the plenum length where the motor rotates when signal is provided once specific rpm is reached.

6.2 Hall Effect Sensor

a current-carrying conductor is placed into a magnetic field, a voltage will be generated perpendicular to both the current and the field. A typical Hall Effect Sensor has three wires or terminals: 1. Ground, 2. Supply or reference voltage and 3. Output signal. To produce an output signal, a Hall Effect Sensor must be supplied with a reference voltage from the vehicle's onboard computer (which may be 5 to 12 volts depending on the application).The necessary switching effect takes place due to this voltage. The hall effect sensor is already present in some engines which also can be integrated with this system.

6.3 Reciprocating Mechanism

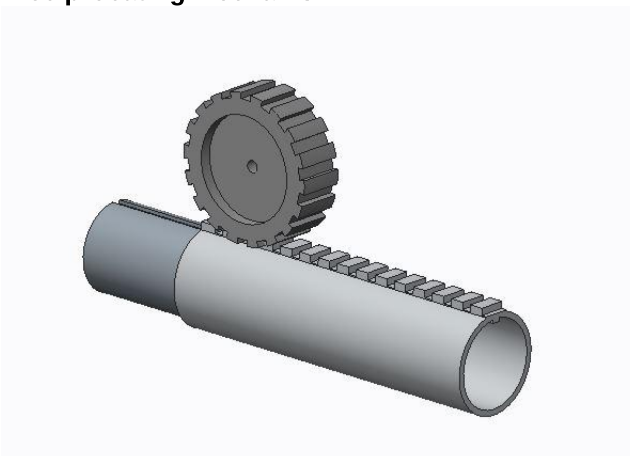

Fig. 9.CAD model of mechanism

The reciprocating system consists of two pipes which which slide int one another as shown in figure. A rack is attached to the pipe and the pinion meshes with the rack. According to the rpm of engine as required the arduino sends signal to motor which rotates pinion and desired length is obtained as discussed earlier.

6.4 Rack and Pinion

A rack and pinion is a type of linear actuator that comprises a pair of gears which convert rotational motion into linear motion. A circular gear called "the pinion" engages teeth on a linear "gear" bar called "the rack"; rotational motion applied to the pinion causes the rack to move, thereby translating the rotational motion of the pinion into the linear motion of the rack. Shaft of DC motor is attached to rack and pinion assembly

Pinion Selection

12 teeth, pitch diameter(D)=0.5"(12.7mm)

Circumference of pinion=πD=39.89mm

To calculate Delay:

5V 150rpm DC Motor

Time for 1 revolution:

$$= \frac{1}{150} min$$

$$= \frac{1 \times 60 \times 1000}{150} ms$$

$$= 400 ms$$

For 50mm travel

No of revolutions

$$= \frac{50}{39.89} = 1.25$$

Time required$=1.25 \times 400 = 500 ms$

From this calculation we can make a program in Arduino for our requirement.

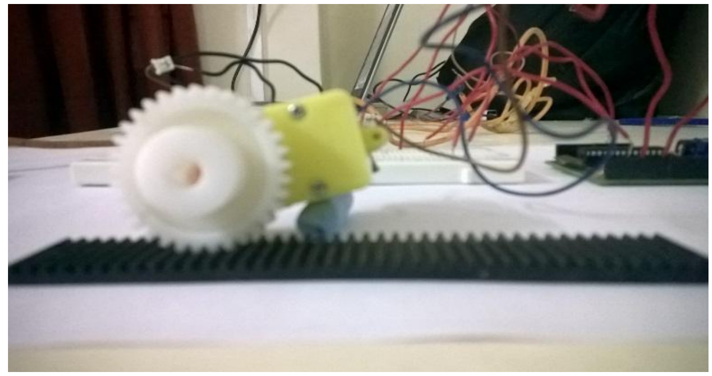

Fig. 10. Rack and Pinion Setup

6.5 System Integration

Hall effect sensor is used to measure rpm of engine it gives output in the form of pulses hall effect sensor having three connections

1. +Vcc
2. GND
3. Output

+Vcc is connected to +Vcc of Arduino, GND is connected to GND of Arduino, Output is connected to Pin 2 of Arduino. Output of Arduino is connected to Actuator which is 12V DC motor of 150 rpm 1 pin of DC motor is connected to pin 4 of Arduino and another pin is connected to pin 7. The connection are shown in the representative diagram below. The prototyped model of mechatronic system is also shown in fig 12. The hall effect sensor gives input of rpm in form of signal, which gets processed in arduino and the required rotations to change length of reciprocating system then comes into picture. The motor rotates the number of revolutions needed to obtain required length.

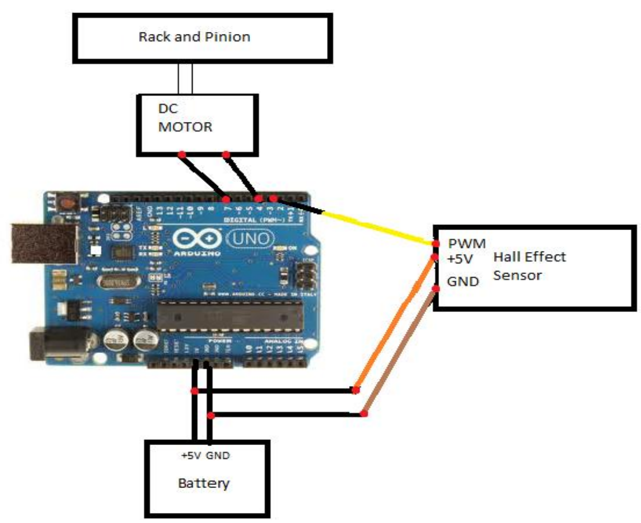

Fig. 11. Development of system according to above connections

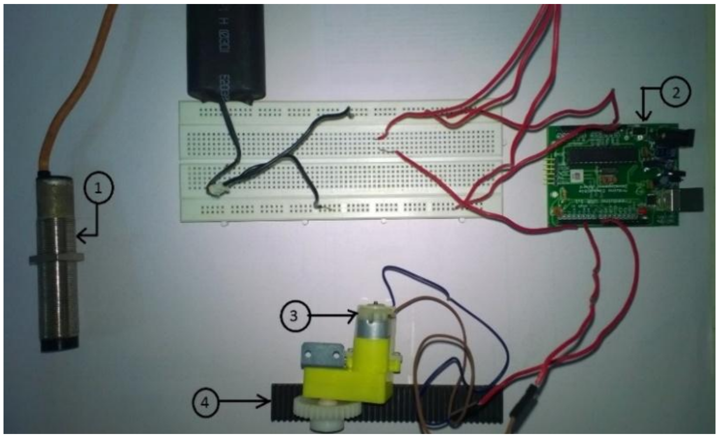

Fig. 12. System integration of components

1-Hall Effect Sensor, 2-Arduino Board, 3-Dc Motor, 4-Rack and Pinion Arrangement.

7 Conclusion

[1]. In this paper detailed study on generation of suction and compression waves was carried out and methods to obtain the maximum use of these waves to improve engine performance were discussed.

[2]. The effect of resonance of these waves and change in manifold length on engine performance was analyzed mathematically and also using simulations.

[3]. The engine performance can be increased by using intake plenum length that can be varied continuously.

[4]. It was found that the rpm at which peak torque occurred changed greatly with intake pipe length. As discussed above in order to increase the torque performance, plenum length must be extended for low engine speeds and shortened as the engine speed increases.

[5]. It was also concluded that for shorter plenum lengths the torque curve was more flatter while as the length was increased the torque output curve peaked more and more.

[6]. A proposed mechatronic system was prototyped. Future work includes implementing this system on a engine and verifying results of practical, simulated experimental system.

8 References

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