PERFORMANCE ANALYSIS OF SUPERCHARGING PROCESS IN SI ENGINE & CI ENGINE AND APPLICATION OF SUPERCHARGER

Prakash Kumar Sen[1], Rohit Jaiswal[2], Shailendra Kumar Bohidar[3]

[1]*Student of M.Tech Manufacturing Management, BITS Pilani*

[2]*Student of Mechanical Engineering, Kirodamal Institute of Technology, Raigarh, (India)*

[3]*Ph.D. Research Scholar, Kalinga University, Raipur (India)*

ABSTRACT

In this paper study on performance of supercharging process on SI & CI engine and application of supercharger. In this paper made to determine whether the mechanical action of a high speed supercharger improves engine performance. Most passenger automobiles are overpowered and probably 80 per cent of such vehicles operate at less than 55 kmph for 90 per cent of the time. Passenger car requires from 12 to 15 hp, but the engine carried is capable of developing from 50 to 55 hp. The result is that the car is operated for the greater part of the time at one-third to one-quarter throttle opening. Full power is needed only for accelerating and hill-climbing during the remainder of the time the excess weight of the engine and other parts must be carried at a loss of efficiency. That smaller engine can be used advantageously when equipped with supercharger, the supercharger being used only when excess power is required.

***Keywords*: SI & CI Engines, Performance, Supercharger, Supercharged Engine**

I. INTRODUCTION

The power output of an engine depends upon the amount of air indicated per unit time, the degree of utilization of the air and the thermal efficiency of the engine. The amount of air inducted per unit time can be increased by increasing the engine speed or by increasing the density of air at intake. The increasing the engine speed calls for rigid and robust engine as the inertia loads increase. The engine friction and bearing loads also increase and the volumetric efficiency decreases when the speed is increased. The method of increasing the inlet air density, called **supercharging**, is usually employed to increase the power output of the engine. This is done by supplying air at a pressure higher than the pressure at which the engine naturally aspirates air from the atmosphere by using a pressure boosting device called a **supercharger.**

The power output can also be increased by increasing the thermal efficiency of the engine, say, by increasing the compression ratio. However, this increases the maximum cylinder pressure. The rate of increase of maximum cylinder pressure is less than rate of increase of break mean effective pressure in case of supercharged engine. This means that for a given maximum cylinder pressure more power can be obtained by increasing the compression ratio. The rate of increase of maximum temperature is also low in case of supercharging. This results in lower thermal loads. [1]

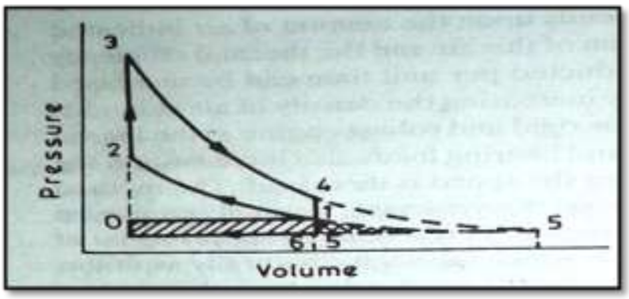
II. OBJECTS OF SUPERCHARGING

The increase in the amount of air inducted per unit time by supercharging is obtained mainly to burn a greater amount of fuel in a given engine and thus increase its power output. The objects of supercharging include one or more of the following:-[1]

1. To increase the power output for a given weight and bulk of the engine. This is important for aircraft, marine and automotive engines where weight and space are important.
2. To compensate for the loss of power due to altitude. This mainly related to aircraft engine which lose power at an approximate rate of one per cent 100 meters altitude. This is also relevant for other engines which are used at high altitude.

III. EEMODYNAMIC CYCLE WITH SUPERCHARGING

Fig (1) shows p-v diagram for an ideal Otto-cycle supercharged engine. The pressure p_1 represents the supercharging pressure and p_5 is the exhaust pressure. Area 8-6-7-0-1-8 represents the work done by the supercharger **(**mechanically driven) in supplying air at a pressure p_1 while the area 1-2-3-4-1 is the output of the engine.



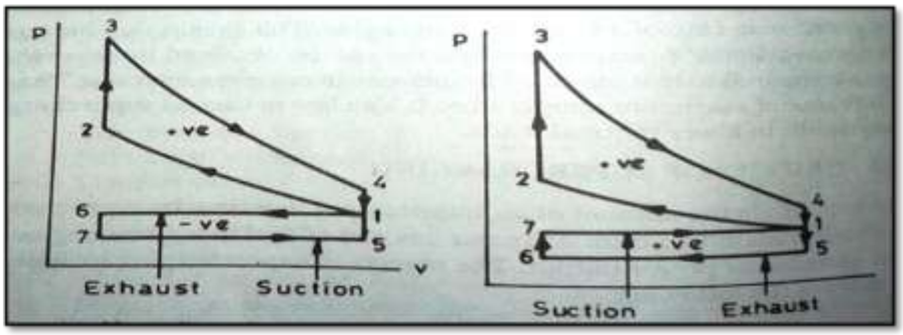
Fig(1) P-V Diagram for an Ideal Otto Cycle Supercharged Engine

Area 0-1-6-7-0 represents the gain in work during the gas exchange process due to supercharging. Thus a part of the supercharger work is recovered. However the area 1-6-8-1 cannot be recovered and represents a loss of work. This loss of work causes the ideal thermal efficiency to the supercharged engine to decrease with an increase in supercharging pressure.[2]

Fig(2) shows the different between the p-v diagram of an unsupercharged and supercharged engine. Two important differences are:-

(i) Increase in pressure over the unsupercharged cycle.

(ii) The pumping loop of a supercharged engine is positive instead of negative. Hence to get the net ip the power represents by pumping loop is to be added instead of being subtracted.



(a) Naturally aspirated engine **(b) Supercharged engine**

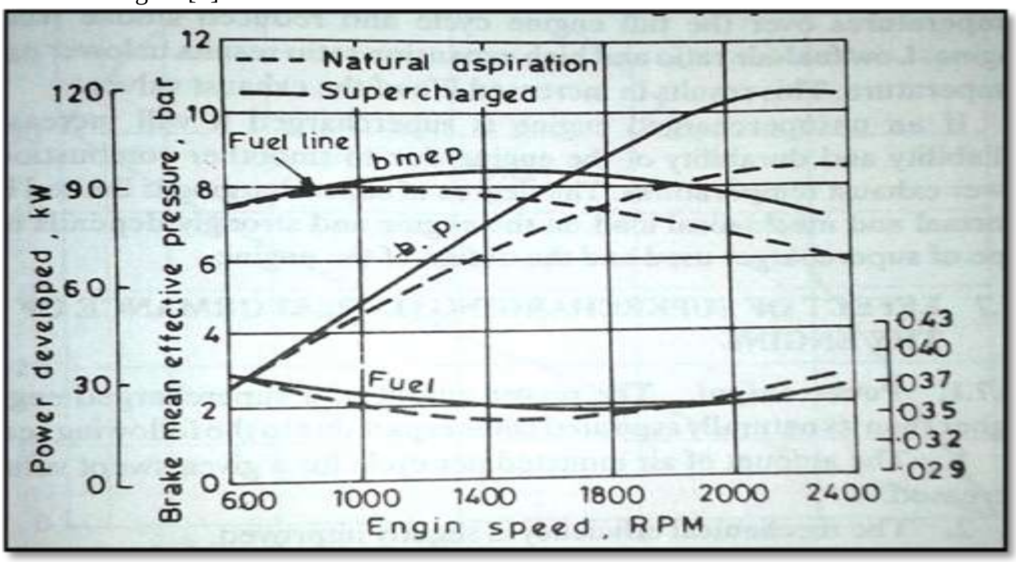
Fig(2) Difference between the p-v diagram of naturally aspirated and supercharged engine

The gain in the output of a supercharged engine is mainly due to increase in the amount of air inducted for the same swept volume. An additional amount of air is also inducted due to compression of residual volume to a higher pressure. Supercharging also results in an increase in mechanical efficiency, and in better gas-exchange process. An engine should be designed from the start as a supercharged engine to obtain optimum performance with the desired life.[2]

IV. SUPERCHARGIN OF SPARK-IGNITION ENGINE

As far as spark-ignition engines are concerned, supercharging is employed only for aircraft and racing car engine. This is because the increase in supercharging pressure increases the tendency to detonate and pre-ignite. Apart from increasing the volumetric efficiency of the engine supercharging results in increase in the intake. temperature of the engine. Increased intake pressure and temperature reduces ignition delay and increase flame speed. Both these effect result in a greater tendency to detonate or pre-ignite. For this reason, the supercharged petrol engines employ lower compression ratio. The use of lower compression ratio and increase heat losses due to higher value of specific heats and dissociation losses at higher temperature results in lower thermal efficiency for such engines. Thus supercharged petrol engine have a greater fuel consumption than naturally aspirated engines.

Fig(3) shows that performance of a supercharged petrol engine for different speeds. Knocking can be controlled in highly supercharged engine by injection of water in the combustion chamber. However, large amount of liquid needed for this purpose becomes prohibitive. Another alternative is to use intercooling of the charge before it is fed to the engine.[3]



Fig(3) Effect of supercharging on a petrol engine

V. SUPERCHARGING OF CI ENGINES

Unlike SI engine supercharging does not results in any combustion problem, rather it improve combustion, in a diesel engine. Increase in pressure and temperature of the intake air reduces ignition delay and hence the rate of pressure rise resulting in a better, quieter and smoother combustion. This improvement in combustion allows a poor quality fuel to be used in a diesel engine and it is also not sensitive to the type of fuel used. The increase in intake air temperature reduces volumetric and thermal efficiency but the increase in the density due to pressure compensates for this and intercooling is not necessary except for highly supercharged engine.

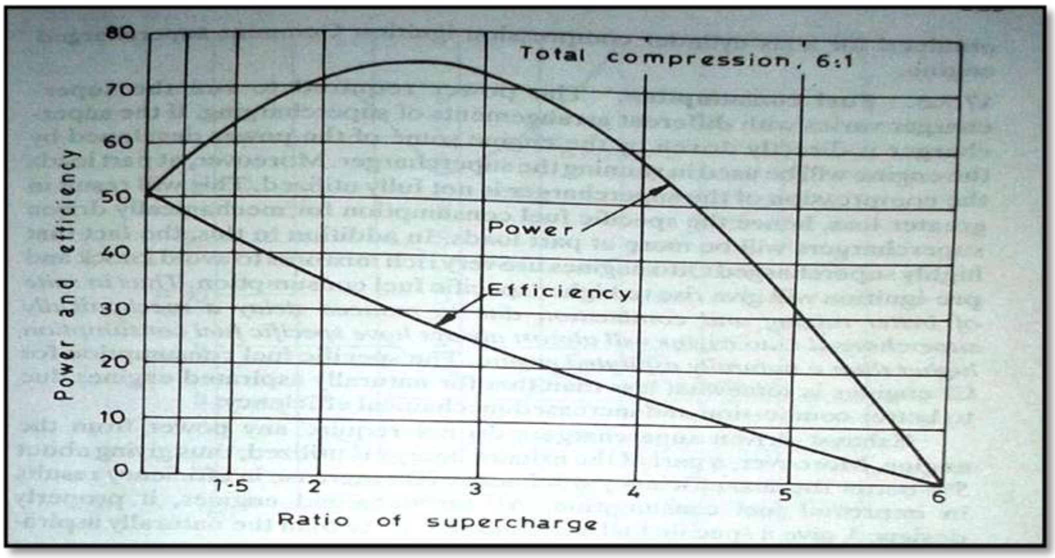
However, mechanical and thermal loading increases with an increases in supercharging. But this increase in mechanical and thermal loading is only moderate because of the use of lower compression ratios and the effect of cooling due to increased valve overlap of the supercharged engine. It is possible to use lower fuel-air ratios in a supercharged engine as the increase in fuel flow is less than the increase in air flow. This results in lower temperature over the full engine cycle and reduced smoke from the engine. Low fuel-air ratio and high expansion ratio results in lower exhaust temperature. This results in increased life of the exhaust valve.

If an unsupercharged engine is supercharged it will increase the reliability and durability of the engine due to smoother combustion and lower exhaust temperature. The degree of supercharging is limited by the thermal and mechanical load on the engine and strongly depends on the type of supercharged used and the design of the engine.[3]

VI. EFFECT OF SUPERCHARGING ON PERFORMANCE OF THE ENGINE

Power output – The power output of a supercharged engine is higher than its naturally aspirate counterpart due to the following reasons:-

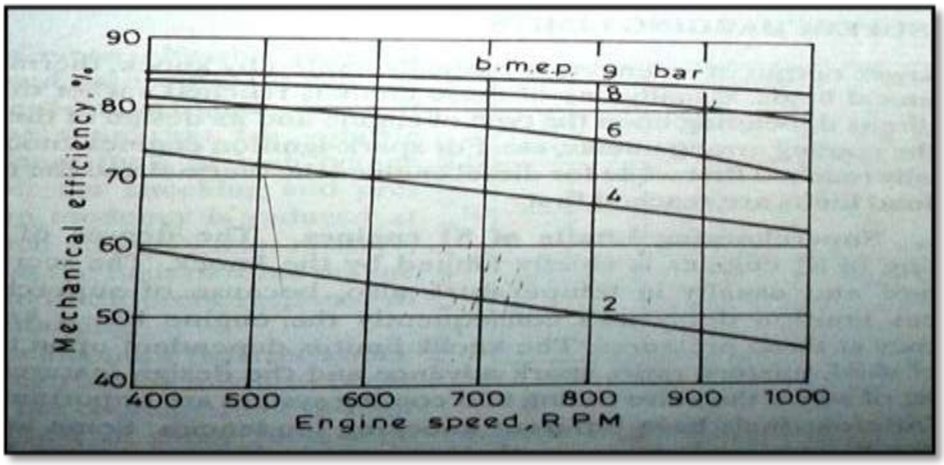
1. The amount of air inducted per cycle for a given swept volume is increased.
2. The mechanical efficiency is slightly improved.
3. During the gas exchange process some of the work done on the supercharger is recovered.
4. Supercharging results in better scavenging and reduced exhaust gas temperature in the engine. The reduced residual gas fraction helps in better combustion and reduced temperature improve volumetric efficiency.[4] **Fig(4)** shows the effect of supercharging ratio on power output and overall efficiency of an engine.



Fig(4) Effect of supercharging ratio on power and efficiency

Mechanical efficiency:- An increase in the supercharging pressure increases the gas load and hence large bearing areas and heavier components are needed. This increase the frictional forces. However, the increase in temperature is much more than increase in frictional forces. Typical values are 11% and 7.5% increase in frictional forces for petrol and diesel engines as compared to 40% increase in temperature for 60%

supercharging. Thus the mechanical efficiency of supercharged engine are slightly better than the naturally aspirated engine. **Fig(5)** shows the mechanical efficiencies obtained for a six cylinder compression-ignition Cummins supercharged engines.[4]



Fig(5) Mechanical efficiency of a supercharged Cummins CI engine

Fuel consumption:- The power required to run the supercharger varies with different arrangements of supercharging. If the supercharger is directly by the engine some of the power developed by the engine will be used in running the supercharger. Moreover, at part loads the compression of the supercharger is not fully utilized. This will result in greater loss, hence the specific fuel consumption for mechanically driven superchargers will be more at part loads. In addition to this, the fact that highly supercharged Otto engines use very rich mixtures to avoid knock and pre-ignition will give rise to higher specific fuel consumption. Thus in spite of better mixing and combustion due to reduced delay a mechanically supercharged Otto engine will almost always have specific fuel consumption higher than a naturally aspirate engine. The specific fuel consumption for CI engine is somewhat less than for naturally aspirated engines due to better combustion and increased mechanical efficiency. [4]

VIII. SUPERCHARGING LIMITS

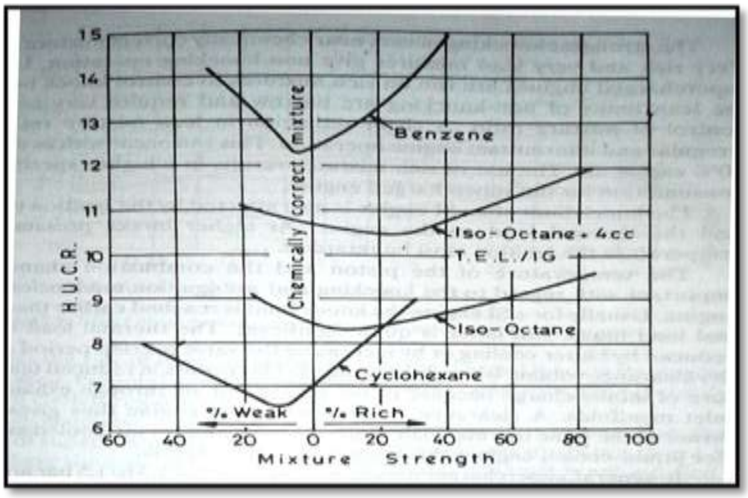
The power output of an engines is basically limited by knock, thermal and mechanical loads. Usually one of these limits is reached earlier than the other limits depending upon the type of engine and its design of the structure, the cooling arrangements, etc. For spark-ignition engines knock limit is usually reached first while for diesel engines the thermal and the mechanical load limits are reached first.

Supercharging Limits of SI engines:- The degree of supercharging in SI engines is chiefly limited by the knock. This increase in pressure and usually in temperature also, because of supercharging reduces ignition delay and consequently the engine has a knocking tendency at these pressure. The knock limit is dependent upon the type of fuel used, mixture ratio, spark advance and the design features of the engine, of which the valve the valve timing and cooling system are important.

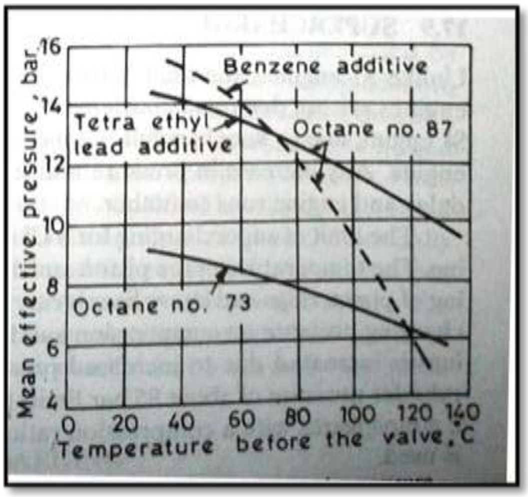
Different fuels have different knocking tendencies. Some are more sensitive to increased pressure, others to increase in temperature. **Fig(6)** shows higher useful compression ratio for different fuels used and **fig(7)** shows mean effective pressure obtained with different fuels at different intake temperatures. It can be seen that for volatile petroleum fuel of high octane number the knocking and pre-ignition tendency is reduced at very rich and very lean mixture, and that fuels of same octane value have different response to supercharging.

The strongest knocking occurs near chemically correct mixtures ratios. Very rich and very lean mixtures give non-knocking operation. Usually supercharged engines are run on rich mixtures to control knock because the lean limits of non-knocking are narrow and required very accurate control of mixture ratio. A slight reduction in lean mixture results in irregular and intermittent engine operation. This can occurs with as early as 20% excess air. The use of rich mixtures results in a higher specific fuel consumptions for the supercharged engines.

The knock limits of an SI engine is also affected by the ignition timings and the thermal load on the engine. At higher intake pressure and temperature the ignition must be retarded. In general, supercharger pressure of the order of 1.3 to 1.5 bar are used. The corresponds to about 30 to 50% supercharging. [5]



Fig(6) H.U.C.R .v/s mixture strength curves for different



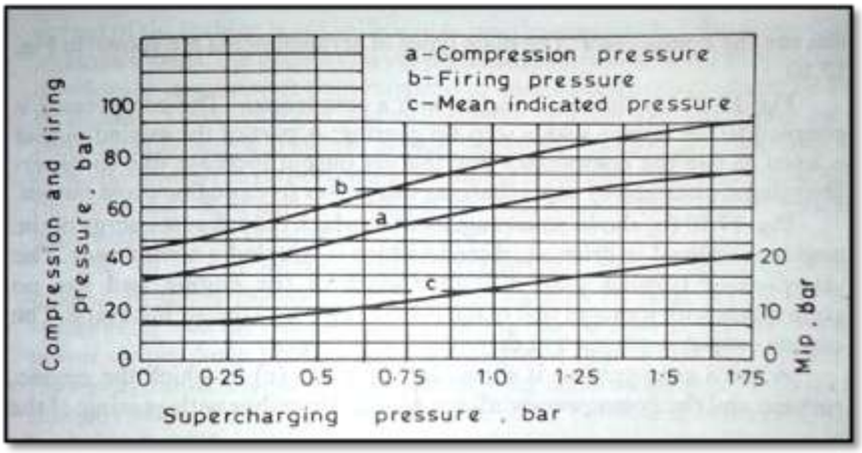
Fig(7) Highest mean effective pressure near the knock limit v/s temperature of the charge for different fuels.

Supercharging Limits of CI engine:- unlike SI engines, the limits of supercharging for compression-ignition engines are not due to combustion. The factor which limit the output of a SI engine due to knock, result in quieter and smoother operation of a CI engine. An increase in pressure and temperature decreases the ignition delay and engine runs smoother.

The limit of supercharging for CI engine is reached by thermal loading. The temperature of the piston and cylinder if very high results in scuffing of piston rings and heavy linear wear. **Fig(8)** shows the effect of supercharging pressure on compression and firing pressure. The load on bearing is increased due to increased pressure in the cylinder. A maximum cylinder pressure of about 85 bar limits the supercharger pressure to about 2 atmospheres with a compression ratio of 15:1 if a copper-lead bearing is used.

Durability, reliability and fuel economy are the main considerations in limiting the degree of supercharging of a CI engine. Increase in maximum pressure in cylinder decreases the reliability of the engine. This also increases the rate of heat release and hence the thermal load and on the engine is increased. For intake pressure greater than 2.5 atmospheres very sturdy and well cooled engines are needed.

Fuel economy is also an important consideration in deciding the degree of supercharging for a CI engine. For intake pressure less than 1.5 atmospheres the cost complication of the supercharger is not justified.[5]



Fig(8) Effect of Supercharging Pressure on Compression and Firing Pressure

VIII. MODIFICATION OF AN ENGINE FOR SUPERCHARGING

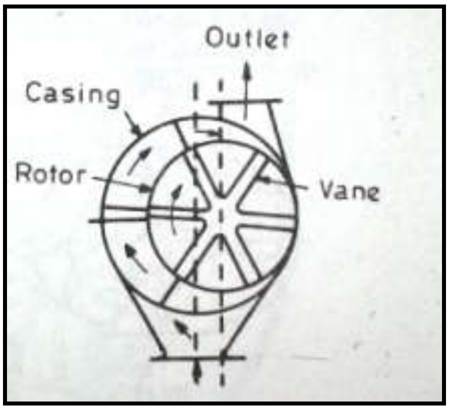
The power output of a naturally-aspirated engine can be increased by supercharging. However, certain modifications will make the engine more suitable to supercharging. These modification include increase in the valve overlap period to allow complete scavenging of the clearance volume and increase in clearance volume by decreasing the compression ratio. For a diesel engine, injection system must be modified to supply increased amount of fuel, this will require greater nozzle area than the normally aspirated engine. In case of turbocharged engine the exhaust valve opens a bit earlier to supply more energy to the turbocharger. Moreover, the exhaust manifold of such an engine is insulated to reduce heat losses in contrast to the water-cooled exhaust manifold of a normally aspirated engine.

IX. APPLICATION OF SUPERCHARGER

Reciprocating compressors, positive displacement type rotary blowers, toots type blower, centrifugal compressor, turbocharger all are used to supercharge engine for various application. The following is a brief discussion of each type and its main field of application.[6]

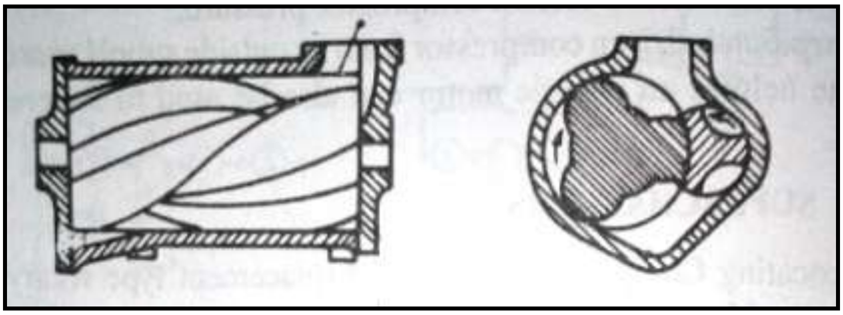
(i) Reciprocating compressor:- Reciprocating piston compressor are very rarely used now a days except for some stationary installation. The size of the compressor is decided by the volume of the air to be supplied to the engine. This make it quite bulky and heavy. Through reciprocating compressor allows a high compression ratio to be obtained and its isentropic efficiency is about 75-85%, the speed is limited. This increase the weight of the compressor.

(ii) Vane Blower:- fig(9) shows a vane type supercharger. It is positive displacement rotary type. This consists of a rotor rotating in a large cylinder casing. The rotor, which has four slots, remains in contact with the casing at least at one point all the time. The axis of the rotor is mounted eccentrically. The blade slide radially in and out of the slots of the rotor as it moves. When the blade move out air is induced between the space between the blade which is increasing. The air is discharged when these space decreases near the exhaust side of the supercharger. Due to vane the flow is pulsating and noisy, and the speed is limited because of the radial motion of vanes. Nowadays vane type supercharger are almost obsolete.



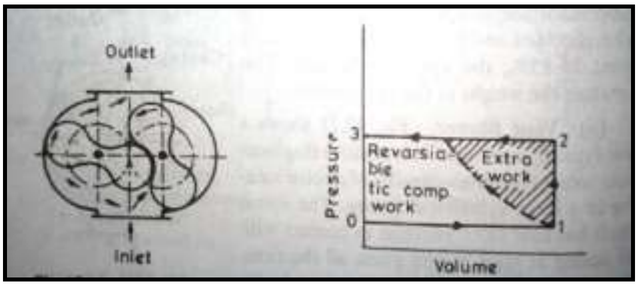
Fig(9) Vane Type Supercharger

(iii) Lysholm compressor:- fig(10) shows another type of positive displacement rotary supercharger called Lysholm compressor. The air is admitted at one end of the compressor and trapped between helical rotors and the casing. The screw action of the rotors displaces the air axially. The lysholm compressor produce a constant compression. The compression is produced internally unlike roots blower, where compression occur only at the opening of the exhaust port. The main disadvantage of this type of compressor is its mechanical complexity which has limited its extensive use.



(iv) Fig(10) Lysholm Supercharger

(v) **Roots Blower:-** Roots blower **fig(11)a** consists of two cylindrically shaped lobes rotating in opposite direction in a common housing. Air enters the space between the rotor lobes at inlet and is carried around the rotor to discharge port. It should be noted that no compression occur in this process which is shown by **fig(11)b.** Compression takes place only when this discharge port is opened and the pressure rise almost instantaneously. When the exhaust port opens back-flow of air occurs and more work is required to compress the air. The extra work is required to compress the air. This extra work is represented by the shaded area of fig.



Fig(11) (a) Roots blower (b) p-v diagram of roots blower

X. CONCLUSION

From the analysis of experimental results in papers reviewed, the effects of supercharging on the engine performance can be summarized. Experimentation and competition results have proven that the performance of downsized engines can match that of their larger counterparts, with the aid of intake boosting. However, the extent to which swept volume can be reduced in any downsized application is combustion limited. If the combustion in high speed, small bore engines could be better understood or even enhanced to promote faster burning, the severity of end-gas knock could be minimized. This would allow further increases in compression ratio and/or manifold absolute pressure, resulting in increased performance and efficiency.

1. These results indicate that the supercharged engine performance was mainly dependent on the mechanical loss to drive the supercharger at low speed. In addition, at high speed, the supercharged engine performance was more influenced by the compression ratio than mechanical loss.
2. Engine performance investigations using the supercharger indicate that the output and torque performance can be improved in comparison with the naturally aspirated engine at speed range from 1,500 rpm to 3,000 rpm in most of the cases.
3. Limit of supercharging is imposed due to maximum permissible pressure and temperature and thermal stress in the cylinder.

REFERENCES

[1]. Chang Sik Lee, Ki Hyung Lee, Dong Hyun Whang, Seo Won Choi and Haeng Muk Cho "Supercharging performance of a gasoline engine with a supercharger" International Journal, vol II, No. 5, 556~564, 1997.

[2]. Guzzella, L., Wenger, U., and Martin, R., "IC-Engine Downsizing and Pressure-Wave Supercharging for Fuel Economy", SAE Technical Paper 2000-01-1019, 2000, doi:10.4271/2000-01-1019.

[3]. Milburn, S., "Introducing a High Efficiency Variable Positive Displacement Automotive Supercharger", SAE Technical Paper 940845, 1994, doi:10.4271/940845.

[4]. Attard W., Watsom H.C., Konidaris S., and Mohammad A.K. Comparing the performance and limitations of a downsized sae engine in normally aspirated,supercharged and turbocharged modes SAE Technical Paper Series, 2006

[5]. M. Muhamad Zin, R. Atan "Boosting Performance Enhancement For SI Engine - Experimental Study", International Conference on Automotive, Mechanical and Materials Engineering (ICAMME'2012) Penang (Malaysia) May 19-20, 2012.

[6]. Christensen, M., Johansson, B., Amnéus, P., and Mauss, F., "Supercharged Homogeneous Charge Compression Ignition", SAE Technical Paper 980787, 1998, doi:10.4271/980787.