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Design of High-Pressure Electric Supercharger

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Abstract:
For several years, CO_2 emission reduction has become a leitmotiv for automotive industry. Engine downsizing is one of the strategies to achieve it. Simply put, it is reducing the cubic capacity of an engine while maintaining its level of performance. Most of the time, this downsizing also provides an efficiency improvement thereby a CO_2 emission reduction. One well-known technology to achieve the downsizing is turbocharging which works best at middle and high speed (engine rotation speed) but not at idle speed. Since turbochargers do not have enough energy coming from the engine exhaust gas to accelerate during idle speed, and hence it is called as turbo-lag. Another prominent method to downsizing is supercharging, in which the power for running the compressor is obtained directly from the engine through a pulley mechanism. Since the supercharger is a work absorbing device, it invariably requires input power.The disadvantage of a supercharger is consumption of engine power and limited pressurization of air up to 2 bar pressure based on engine speed. The prima facie of this project is to develop a new type of reciprocating supercharger which offers air at high pressure to the engine inlet manifold irrespective of engine operating speed with the help of an electric motor as a prime mover.
***Key Word**:Supercharger;Compressor; Electric-Supercharger; Mathematical Model.*

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I. Introduction

In modern automotive industry, one of the potential needs is using alternative technologies to offer low exhaust emissions, good fuel economy and excellent driving performance under all driving conditions. Internal Combustion engines are omnipresent. The goal of a well-designed engine is to deliver power efficiently. Ideally, it should be cheap to manufacture and operate, small, reliable, quiet in operation, output as much power as possible while keeping hazardous emissions and fuel consumption to be minimum. In order to increase the power density of an engine forced induction systems are being used. A forced induction system pushes more air into the engine causing the power to be increased and one of the forced induction systemsis supercharger.

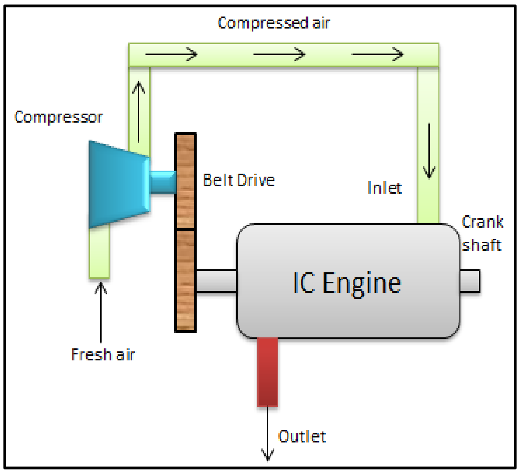

Fig. 1.1 Conventional Supercharger

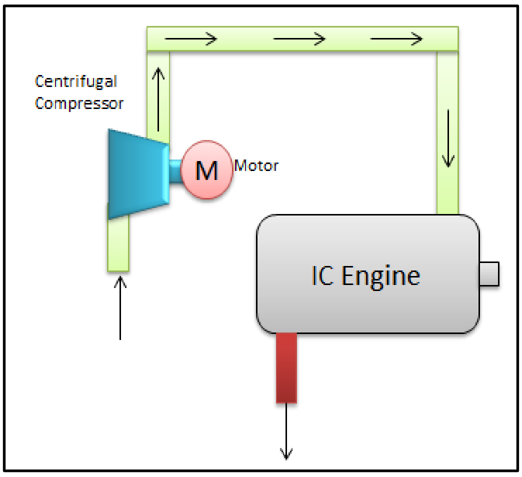

Fig. 1.2 Existing Electric Supercharger

1.1 Conventional Supercharger

A supercharger is typically a centrifugal type air compressordriven by the crankshaft of an engine, usually connected with a belt as shown in Fig. 1.1. Supercharging offers the following advantages: It significantly increases the horsepower; It allows for smaller engine displacements to produce much more power relative to their size; It gives better fuel economy in smaller engines which use less fuel during idle and have less rotational and reciprocating mass.The disadvantages of superchargers are: It is less efficient because they suck engine power simply to produce engine power; It is less reliable as with all forced induction systems, the engine internals will be exposed to higher pressures and temperatures, which will of course affect the longevity of the engine.

1.2 Existing Electric Supercharger

An electric supercharger is a specific type of supercharger that uses an electrically powered forced air system that contains an electric motor to pressurize the intake air. Through pressurizing the air available to the engine intake system, the air becomes denser and is matched for more fuel thereby, producing the increased horsepower to the wheels. Biggest challenge of existing electric supercharger is higher duty cycle of the prime mover viz motor and limited air pressure development with fluctuating flow.

II. Methodology

Overcoming the drawbacks of conventional supercharger and existing electric supercharger, this project develops a new type of supercharger that operate with the help of a motor attempting to offer high pressures independent of engine operating speed with better efficiency in a cost-effective way.

2.1 Proposed Electric Supercharger

Fig. 2.1 shows the schematic diagram of proposed electric supercharger. Atmospheric air is taken as intake for the compressor which is driven by 12V - DC motor. Compressed air from the compressor is stored in a reservoir to avoid fluctuations in supply of pressurized air to the engine inlet. Pressure sensor employed in the reservoir acts as a switch to turn on the motor only when pressure inside reservoir drops below set pressure level which in turn helps to reduce the duty cycle of the motor, heat generated and increases the product life.

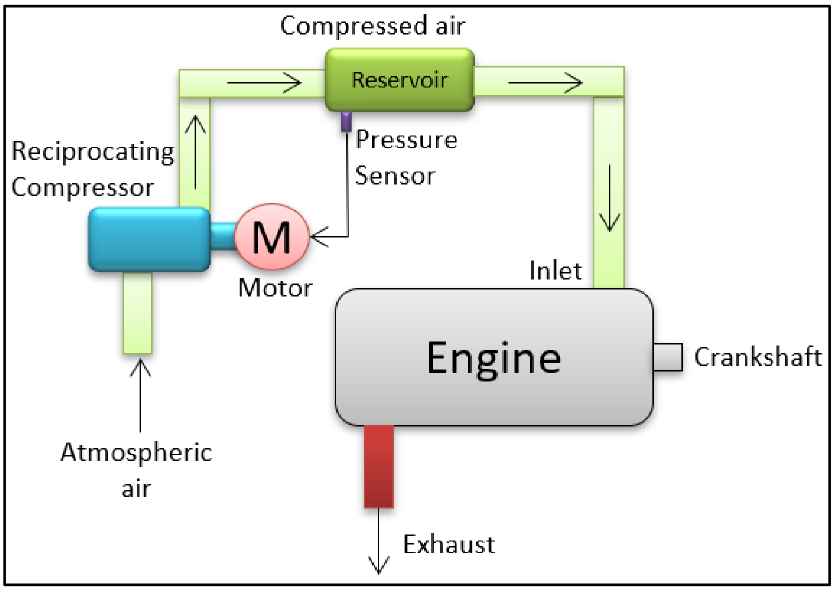

Fig. 2.1 Proposed Electric Supercharger Layout

2.2 Compressor Selection for Supercharger

Compressors are the machines that are used to provide gases at high pressures. Various kinds of compressors are available to compress atmospheric air. The most commonly used compressor in automobile is of reciprocating type. The reciprocating compressor is preferred because of its simplicity, better performance even at lower speeds, good compression ratios and ideal discharge. Reciprocating compressor can be both air cooled as well as water cooled.Compressors are further specified by the following: Number of compression stages; Cooling method (air, water, oil); Drive method(motor, engine, steam or other); Lubrication (oil or oil free). For the proposed electric supercharger, a single stage, air cooled; motor driven; lubricant oil free reciprocating compressor was selected based on its simplicity, performance and cost. Fig 2.2 shows the schematic diagram of single stage single acting reciprocating air compressor.

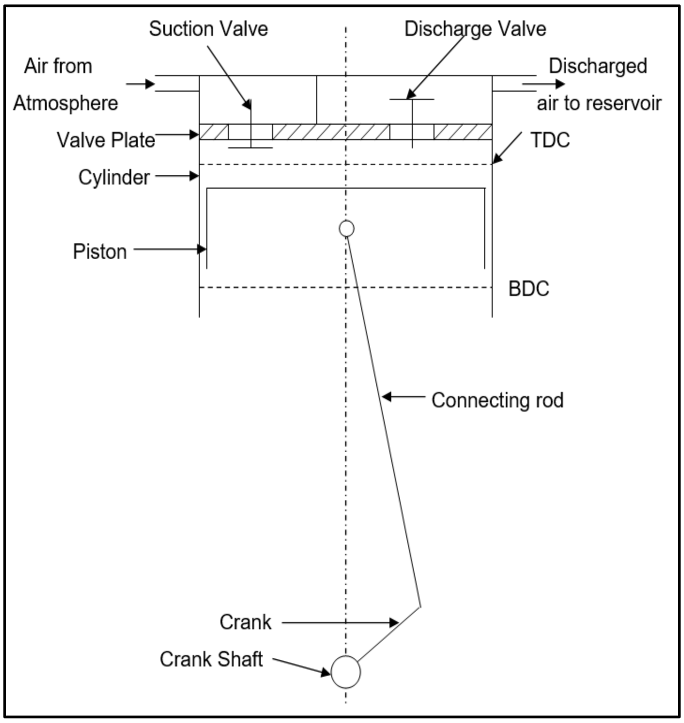

Fig. 2.2Single Stage Single Acting Reciprocating Compressor

2.3Mathematical Model

Mathematical modeling/simulation is the process of designing a model of a real system and conducting experiments with it for the purpose of understanding the behavior of the system. Mathematical simulation is widely used for investigating and designing the compressors. Investigations of the processes of reciprocating compressors using mathematical models is an effective tool by high development of computing technique, which enables complicated problems to be solved with a minimal number of simplifying assumptions. The effective mathematical model for the estimation of reciprocating compressor’s performance was done using multi-domain analysis via SimcenterAmesim software. The effect of various input physical parameters like clearance volume, cylinder diameter, connecting rod length, crank radius, valve lift; various input operating parameters like discharge pressure, compressor speed on the output of thermodynamic behavior of compressor in working condition has been analyzed. The model has been developed for obtaining output parameters like cylinder pressure, cylinder volume, cylinder temperature, valve lift, resultant torque at different crank angles, free air delivered and indicated power of the compressor.

2.4Modeling of Proposed Ideal Compressor

An ideal compressor is one which is working on thermodynamic cycle consisting of all reversible processes and is shown in Fig. 2.3. The input parameters of the mathematical are shown in Table 2.1.The assumptions for the proposed ideal compressors mathematical modeling are as follows:

1. All the processes are ideal.
2. Constant pressure suction and discharge.
3. Expansion and compression follow the law $pV^n = C$ (Polytropic process).
4. Suction temperature is atmospheric temperature.
5. Mass discharged or sucked per cycle is independent of port size and speed.
6. No discharge loss or suction loss due to ‘back flow’.
7. No leakage loss (Blow-by loss).
8. Index of compression and expansion is same and constant during a process.
9. No pressure drops on suction line (between atmosphere and compressor).
10. No pressure drops on delivery line (between reservoir and compressor).
11. Suction head air pressure is atmospheric pressure and is constant during suction.
12. Suction head air temperature is equal to atmospheric temperature and is constant during suction.
13. Delivery head air pressure is equal to discharge pressure and is constant during discharge.
14. Delivery head air temperature is equal to cylinder air temperature during discharge.
15. No effect of heat transfer on index of compression and expansion.
16. Coefficient of discharge is constant.

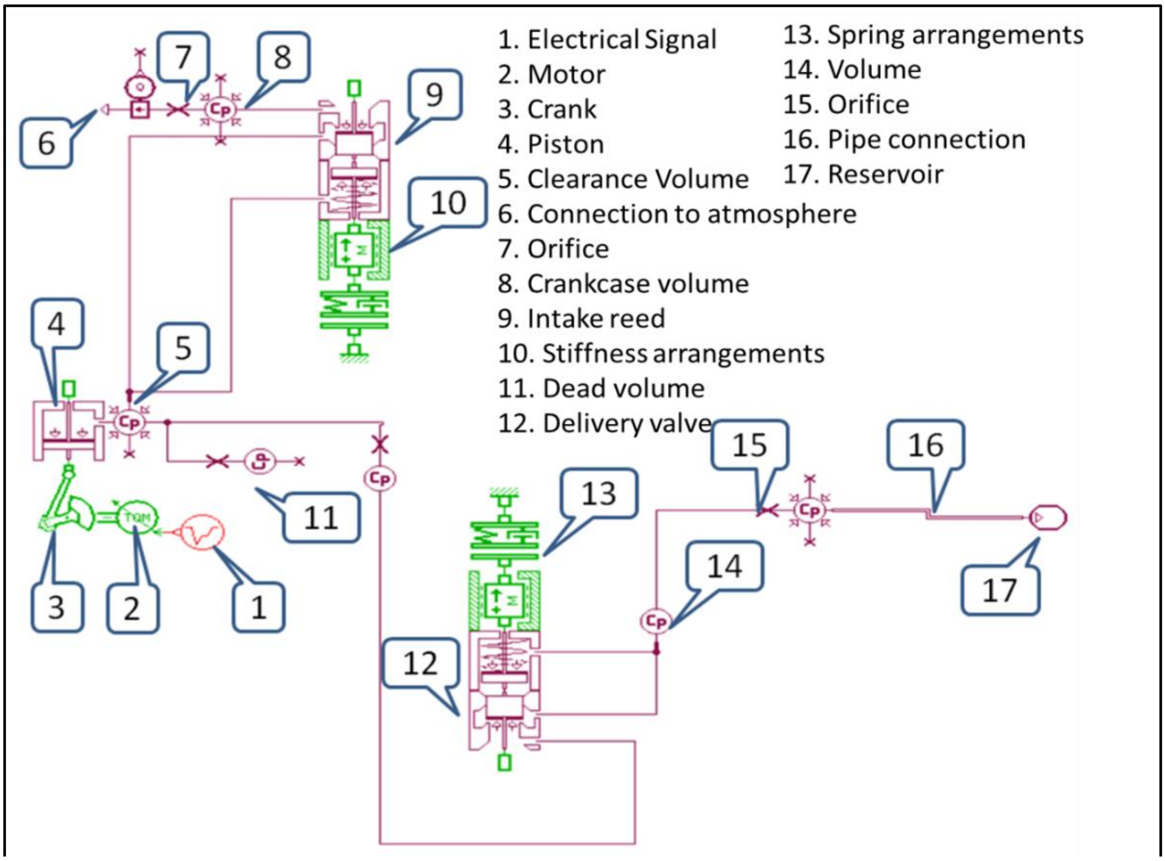

Fig. 2.3Mathematical Model of Proposed Ideal Compressor

Table 2.1: Input Parameters

Bore diameter (D)	34.0 mm
Crank radius (r)	9.2 mm
Connecting rod length (l_c)	70.0 mm
Mass of reciprocating parts (m_{rec})	0.15 kg
Clearance volume (V_c)	1 cc
Ambient temperature (T_a)	308 K
Suction pressure (p_s)	1 bar
Discharge pressure (p_d)	10 bar (abs)
Compressor speed (N)	1500 rpm
Reservoir volume (V_r)	3.7 l
Index of compression (n_c)	1.4
Index of expansion (n_e)	1.4

III. Results& Discussions

The developed mathematical model can predict the values with the deviation of ±2.0% in the flow area and ±7% in the cylinder head temperature, ±3% in the compressor pressure, ±5% in the indicated power and ±3% in the volumetric efficiency. Characteristic curves of pressure, temperature and current obtained at different time are shown in Fig 3.1, Fig 3.2 and Fig 3.3.

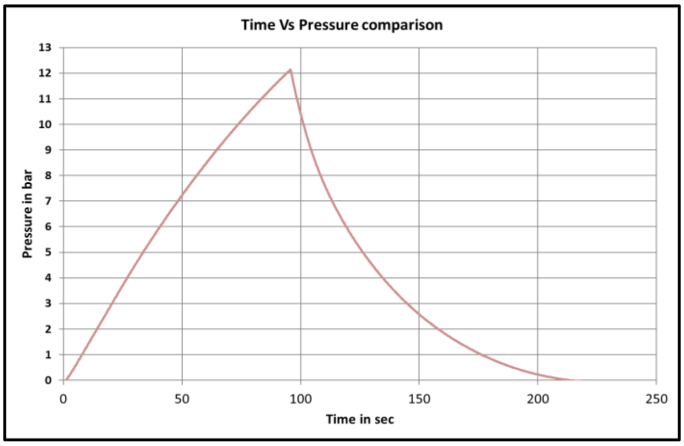

Fig 3.1 Variation of Pressure with Time

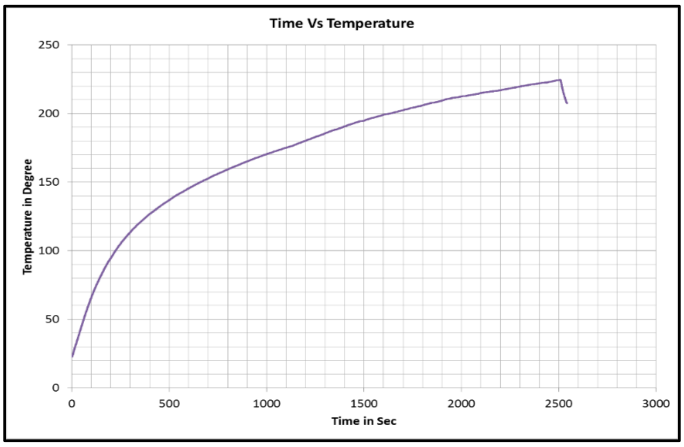

Figure 3.2Variation of Temperature with Time

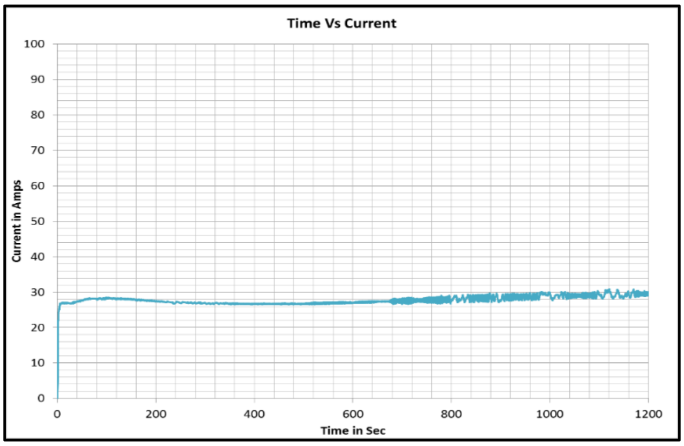

Figure 3.3 Variation of Current with Time

Fig 3.1 shows the proposed reciprocating compressor capable to build 3.7l reservoir with peak pressure of 12.2 bar within 90 seconds. Maximum temperature rise in cylinder head after continuous operation of compressor for 40+ minutes is predicted as 225°C. Increase in temperature with respect to the running time is shown in Fig 3.2. Fig 3.3 shows the current consumption by the 12Volt - DC motor even to build the maximum pressure is less than 34 amps. The normal batteries currently used in the passenger cars can be enough to drive the proposed electric supercharger.

The future investigations can be made on following facets.

- Development of physical samples in line to the theoretical calculations.
- Physical validation of the samples co-relating the real time results with the simulation results.

- Elevated pressure electric supercharger with higher duty cycle can be designed and characterized with reciprocating compressor to cater commercial vehicles.

V. Conclusion

Based upon the demand in market and the research through the literature reviews, design and characterization of high-pressure electric supercharger is necessary to have competitive advantage, increased fuel efficiency, reduced exhaust and reduction of overall weight of the product.

The multi-domain simulation of electric supercharger using SimcenterAmesim shows that the proposed electric supercharger will overcome the drawbacks of conventional superchargers and supplies continuous high-pressure air independent of engine operating speed with good efficiency. Thus, the proposed electric supercharger can replace the conventional superchargers used in internal combustion engine and be used in future hybrid and electric vehicles as well.

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