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ANALYSIS AND OPTIMIZATION of INJECTION TIMING for AN ADVANCED COMPRESSED AIR ENGINE KIT

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Abstract

Increasing air pollution levels and the global oil crisis has become a major hindrance in the growth of our automobile sector. Traditional Internal Combustion engines running on non-renewable fuels are proving to be the major culprit for the harmful effects on environment. With few modifications and also with assistance of few additional components current small SI engines can be modified into a pneumatic engine (commonly known as Compressed Air Engines) without much technical complications where the working fluid is compressed air. The working principle is very basic as adiabatic expansion of the compressed air takes place inside the cylinder pushing the piston downwards creating enough MEP to run the crank shaft at decent RPM. With the assistance of new research and development on pneumatic engines can explore the potential of pneumatic engines as a viable option over IC engines. The paper deals with analysis on RPM variation with corresponding compressed air injection at different crank angles from TDC keeping constant injection time period. Similarly RPM variation can also be observed at different injection pressures with similar injection angle variation. A setup employing a combination of magnetic switch (reed switch), magnets and solenoid valve is used in order to injection timing control. A conclusive data is obtained after detailed analysis of RPM variation that can be employed in newly modified pneumatic engines in order to enhance the running performance. With a number of benefits offered by pneumatic engine over IC engines such as no emissions, better efficiency, low running cost, light weight accompanied by optimized injection conditions can cause a significant development in pneumatic engines without any major alteration.

Keywords: *Compressed air engine, Alternative Energy, Pneumatic engine, Injection timing optimization*

1. INTRODUCTION

In this era of fluctuating fuel prices and globally effected environment by the harmful exhaust from the tail pipes of on road vehicles, Chemical reactions occurring in our atmosphere involving air pollutants can produce acidic and toxic compounds which can cause great harm to flora and fauna even causing formation of acid rain responsible for huge damage of infrastructure and environment [1]. Since Energy consumption is necessary for human existence. There are number reasons for the search of alternative fuels that are

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environmentally acceptable, economically competitive, and readily available. The first foremost reason is the inflated demand for fossil fuels in all major sectors of the world, be it transportation, power generation, industrial processes, and residential consumption. This demand leads to environmental concerns such as increased CO2 and greenhouse gas emissions, and also global warming. World energy consumption doubled between 1971 and 2001 and the world energy demand will increase 53% by the year 2030. For instance, petroleum day in USA until year 2030 [2].

The global consumption of fossil fuels in the last couple of decades in the wake of rising emerging nations of east and south Asia coupled with surge in industrial activity of the third world nations have mandated the search of alternative sources of energy for the survival and growth of mankind. In this context the mobility sector needs innovations to reduce dependence on traditional fossil fuels not only for supply side constraints but also to reduce the environmental consequences of exhaustive petroleum fuel consumption for mobility These factors are leading automobile manufactures to develop cars fueled by alternatives energies. Other promising technologies and Hybrid cars, fuelled by hydrogen as fuel for combustion and fuel cells powered cars One possible alternative is the air powered car. Air, which is abundantly available and can be easily compressed to higher pressure at a very low cost and complexities, is one of the option since atmospheric pollution can be permanently eradicated [3]. Pneumatic engines seem to have a promising scope in the field of transportation sector as the engine of the future for a greener atmosphere with new possibilities. The concept of using compressed air is not new that is Compressed Air Technology (CAT) which is being employed in various pneumatic tools including rock drills, train brake systems, riveters, forging presses, paint sprayers, and atomizers [4]. It is an innovative and different concept of using a pressurized air up to a certain pressure to run the engines of vehicles. After consideration of different factors that are involved in the process of manufacturing of such air powered light weight engines can have practical applications in small motor cars, bikes and can be used in the vehicles to be driven for shorter distances [5]. The Basic of operation remains same with thermodynamic reversible adiabatic expansion of the principle compressed air which is used to mechanically drive any component such as fan, motor, piston. Similar concept is being observed in the working of pneumatic engine where compressed air pushes the piston downwards in the cylinder similar to power stroke in I C engines creating enough amount of energy to generate appreciable torque with ample amount of power. Pneumatic engines are very similar to positive displacement compressors (piston type) in which reversible adiabatic compression takes place compressing the air at high pressure while in pneumatic engines reversible adiabatic expansion takes place. Compressed air can be used to deliver motive power to an engine at full pressure or expansively, or somewhere in between partial expansion. When working at full pressure air is feed to the cylinder throughout, practically the entire length of the stroke, that is without cutoff, so that nearly a cylinder full of air at ambient pressure is exhausted at each stroke. When air is used with complete expansion the operation in the cylinder is the reverse of adiabatic compression in a compressor occurs the final pressure equal to that of the atmosphere but as air does not undergo condensation, the lowest terminal pressure in the cylinder must still be sufficiently above atmospheric pressure to produce a proper exhaust, and to overcome the friction of the engine at the end of the stroke Replacing engines with freshly manufactured pneumatic engine seems to be a very hectic job accompanied by several constraints such as manufacturing cost, technical complications. Another alternative is to modify the exiting engines with few necessary modifications to a pneumatic engine keeping the cost factor in consideration making it a more economically viable option for an individual. Modification of the engine is performed keeping in consideration that structural integrity of the engine is not lost and changes in modified engine can be reverted back to its original form. A two stroke S I engine can be easily converted into a Pneumatic engine with help of few additional component such as Storage tanks, new injection system, and other key components, combined together they can be termed as Advanced Compressed Air Kit, for modification of any two stroke S I engine of similar specification [6]. Offering this type of flexibility of switching from a S I engine to a pneumatic engine gives freedom to optimize its performance for higher efficiency providing a satisfied and balanced solution for environmental related issues arising from the accelerated use of I C engines fuelled by non-renewable fuel resources. The modifications performed on pneumatic engines are not only advantageous in terms of cost but also it offers huge scope for customisation for optimised performance in various running scenarios. As the operational working is different from traditional IC engines so the injection conditions can't be assumed to be similar. With help of key components such as reed switch and solenoid valve an circuit is created which actuates the solenoid valve [7] . which (acts as a compressed air injector) by receiving electrical signals from the reed switch, the circuit is designed to provide one or multiple (discrete signals) set of step signals for every rotation of flywheel since it's a two stroke cycle of constant amplitude. The injection timing can be easily varied by arranging small neodymium magnets on the circumference of the flywheel. The magnets are arranged on the flywheel forming an arch which subtends an angle at the centre of the flywheel, since the reed switch acts as magnetic sensor which gets activated and actuates the solenoid valve for air injection when the magnets approaches towards it during every rotation of flywheel. The flywheel is calibrated to different crank angle from 0 to 360 degrees from TDC, which makes it easier to vary injection timing by changing the position of the magnets hence changing the angle subtended by the magnets arch which acts as an injection angle. The injection can be varied as continuous injection over a specific angle range or it can also be varied as discrete injection for different angle range for every rotation for example injection for 0-40 degree is a single continuous injection whereas 0-10, 20-40, 45-65, degrees keeping overall injection period to be constant for every rotation of the flywheel also constant for every two stroke cycle. With similar variation in Injection angle at different injection pressures a pattern in RPM variations is observed which is strictly dependent on change in injection timing. By studying the changes observed in RPM variation important results and conclusion is obtained for their implementation in similarly modified pneumatic engines (by employing Advanced Compressed Air Kit in order to achieve better performance accompanied by efficient running. With its capabilities and its potential in hand supported by a number of advantages pneumatic engine can really improve and change the whole scenario of our environment and also simplifying other complexities arising due to rapid use of fossil fuels resources. Pneumatic engine works best in hot ambient conditions developing maximum Mean Effective Pressure (More Expansion at increased temperatures by Charles Law)[8]. In the cylinder for better performance and improved efficiency hence there it seems to have bright scope in hot conditions or in hotter places expelling out cool exhaust as fresh air providing other benefits such as no emissions smoother running, Zero knocking [9]. Pneumatic engines provides a wide range of applications in transportation sector such as small engines for two wheeler vehicles, rickshaw, light weight cars such as Air Car from MDI (Motor Development International SA (MDI) a French company) [10]. With the Implementation of this technology to existing engines an improved and healthy environment can be expected in future for sure.

2. DESIGN CONSIDERATION

Initially the idea of converting an existing S I engine to a pneumatic engine seem a bit challenging by considering a number constraints and hindrances involved, such as cost factor , economical availability, and etc. At very first an existing engine has to be selected as the base engine for further modification and development. Two stroke S I engine provides all necessary key features required for being a perfect base engine, such as compression ratio, high RPM, light weight. It also supports further customization needed.

Components and modification required

Cylinder head and intake port

Another benefit of choosing a two stroke engine as a base engine is very few modifications are need in order to introduce the new injection system, existing port for spark plug on the cylinder head can be used as new port for injection of compressed air. The only alteration need on the cylinder head is removal of the spark plug and machining of new internal threads according to the adapter nipple for exact mating. This specific modification serves two purposes first introduction of the new injection system second removal of an unwanted component in this case the spark plug.

Intake Port

The carburettor serves as a vestigial component to a pneumatic engine. Therefore it is advantageous to remove the carburettor which further helps in weight reduction of the engine. It is also beneficial as it reduces back pressure which was earlier created by the carburettor as it resist the free flow of partial exhaust as the major portion of the exhaust flows from the main exhaust port of the engine. Reed switch can also be installed next to the carburettor which provides required signals for accurate injection timing.

Flywheel

The existing flywheel of the two stroke S I engine is magnetized and a stator coil lies underneath the magnetized flywheel. The internal coil and magnet could interfere with the field of the external magnet which leads to malfunctioning of the magnetic sensor. Therefore, the flywheel along with the coil is removed with the help tools. A steel disc of equivalent weight is attached to a separate fan wheel using nuts and bolts in the manner as shown in the figure 2. The steel disc and fan wheel assembly is then mounted on the crankshaft of the engine. This type of arrangement has an advantage of adding or removing additional weight later without any modification. At present reciprocating compressed air engine is modified version of 2-stroke S.I engine which gives one power stroke at every 360° rotation of crank shaft due to which there is fluctuation and variations in output torque, this type of jerky motion of the crank shaft is corrected by the help of flywheel [11].

Reed switch

Reed switch is a small device when it is exposed to a magnetic field, the two ferrous materials inside the switch pull together and the switch closes. When the magnetic field is removed, the reeds separate and the switch opens. This makes for a great non-contact switch.[12]. The very first purpose of reed switch is provide accurate signal for perfect injection timing at certain angle of the crankshaft which is controlled by a magnetic coil on a certain location of the flywheel for closing of reed switch which closes and completes the circuit which is connected in series with solenoid valve which controls the injection of the compressed air.

Solenoid Valve

The solenoid is an electromagnetic part of a valve, comprised of a coil, core tube, core and enclosure. It is designed to handle the most demanding fluid control applications have one inlet and one outlet, and are used to permit and shut off fluid flow. The two types of operations are “Normally Closed” and “Normally Open”. It activates when current flows through it.

The valve shown in Figure 4 is a normally-closed solenoid valve. Normally-closed valves use a spring which presses the plunger tip against the opening of the orifice. The sealing material at the tip of the plunger keeps the media from entering the orifice, until the plunger is lifted up by an electromagnetic field created by the coil [13]. As mentioned earlier solenoid valve gets activated the current passes through the circuit which is closed by or opened by reed switch.

Additional components

Apart from components needed for modification other additional components are also required for various purposes such as for connecting, storing compressed air etc.

Storage Cylinder or tank

Storage cylinder acts as a carrier of potential energy required to drive the engine in form of compressed air stored at highpressure inside the cylinder. Few key specifications of the storage cylinder effect the performance pneumatic engine such as storage volume of the cylinder can provide approximate running time for the engine another maximum pressure of the storage cylinder setting a maximum pressure for inside engine cylinder while running.

Pressure Regulator

A pressure regulator is a valve that automatically cuts off the flow of a liquid or gas at a certain pressure. Regulators are used to allow high-pressure fluid supply lines or tanks to be reduced to safe and/or usable pressures for various applications. Gas pressure regulators are used to regulate the gas pressure and are not appropriate for measuring flow rates.[14].

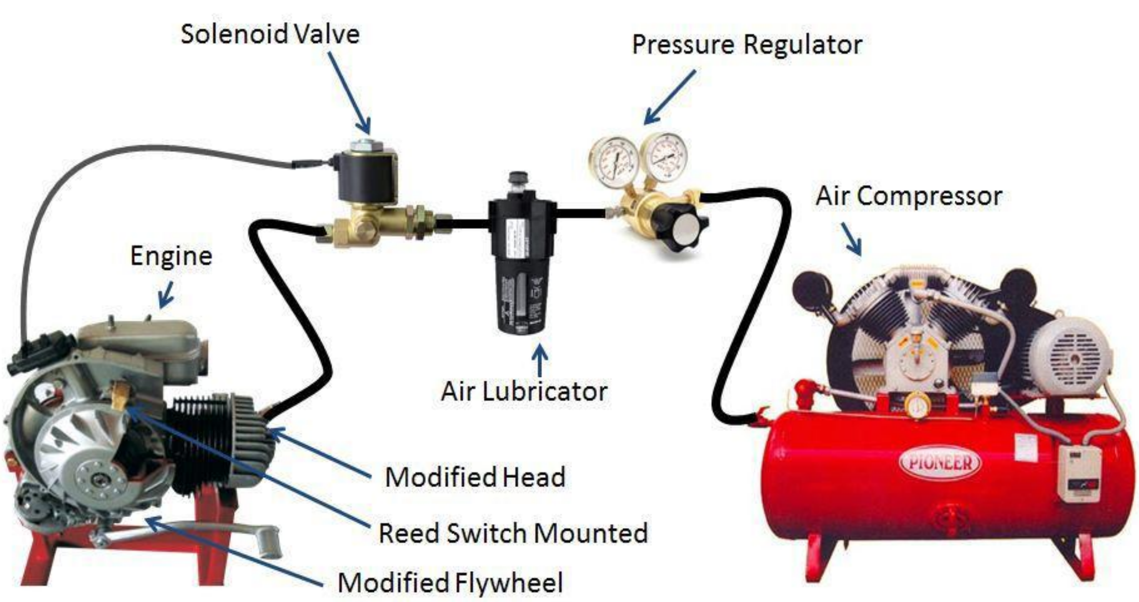

Figure 1. showing all components connected in sequence

Air Filter and Lubricator

This unit usually is a combination of components that filters the air and adds lubricants for moving parts in the circuit. Compressed air contains dust, condensed water, and rust and oil sludge which must be removed to keep moving parts of the machine working properly. Some of the components of the engine require a small amount of lubrication to extend their life and maintain torque.

Hoses and Fittings

Hoses are used for carrying compressed air from storage cylinder to the engine. Hoses are made from one or a combination of many different materials. Polytetrafluoroethylene (PTFE) hoses are preferred because it is chemically inert and usable at temperature ranging from -70℃ up to +260℃. PTFE hoses have excellent dynamic flex life and perform well at high pressures in flexing or vibrating applications. The famous non-stick nature of PTFE ensures that material passing through does not become 'hung up' inside the hose [15].Hose-barb to male-pipe fitting is used to connect hose to the components like pressure regulator, air filter and lubricator and solenoid valve. The hose is lubricated and pushed in the fitting until it bottoms against hex and a hose clamp is positioned and secure with a screwdriver or wrench.

Engine Working

Working principle of a pneumatic engine is very much similar to an I C engine, where the pressurized air generates enough pressure in the cylinder equivalent to mean effective pressure of an I C engine which pushes the piston down resulting in similar mechanical working of an I C engine. Working principle of a pneumatic engine can also be divided into stages: 1. Compression stage, 2. Expansion stage.

Compression stage

This stage is achieved by a two stage compressor that purely runs on electricity it compresses the air from ambient pressure of 1 bar to a pressure 25 bar in this process the compressed air which has been reduced to a much smaller volume. Highly compressed air is now stored in storage tank of 200 litre capacity strong enough to withstand the pressure in it. Storage tanks serves as medium for storing potential energy in form of compressed air

Expansion stage

Fixed volume of compressed air is being fed into cylinder chamber through an inlet port. Pressurized air expands adiabatically inside the cylinder cools down in the process attains a much lower temperature than the ambient temperature. Temperature and pressure drop are observed at the exhaust of the engine. In order to understand the operational working of the pneumatic engine the whole expansion process can also be further sub-divided into four basic stages completed in two stroke cycle.

Stage 1

It is the injection stage where the compressed gas from the storage tanks enters the engine cylinder through pressure regulator and solenoid valve. The injection occurs when the magnets comes in close contact with the reed switch and hence causing opening of the solenoid valve

Stage 2

At this stage the expansion of the compressed has which has been introduced into the engine cylinder expands and generates force on the piston surface causing the crankshaft to rotate at this stage no injection takes place as the magnets on the flywheel are not in contact with the reed switch

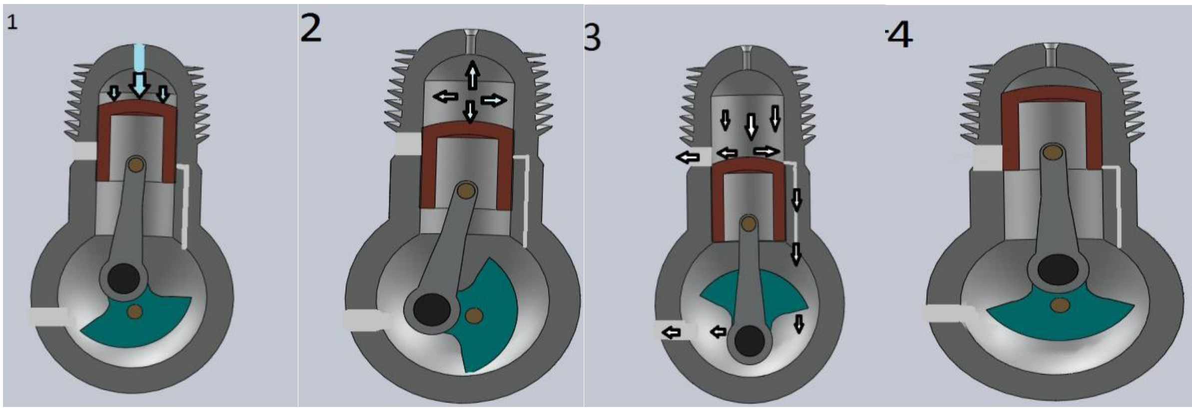

Figure 2. showing all stages of two stroke cycle

Stage 3

The Expanded air is expelled from the cylinder through the exhaust port during this stage which still at higher pressure from the ambient pressure.

Stage 4

The piston returns back TDC and during the process some amount of residual air is also compressed and the cycle is repeated.

3. INJECTION ANGLE AND TIMING VARIATION SETUP

In order to inject compressed air at a specific crank angle from TDC a very basic and simple setup is designed consisting of solenoid valve and a reed switch as the key components. Solenoid valve, reed switch and a battery is connected in series completing the circuit. The reed switch which acts as a magnetic switch gets activated by the influence strong magnetic field closing the circuit and actuating the solenoid valve. The magnets are arranged according to the desired variations for angle and timing. The figures shows working of the setup, as the magnets arranged on circumference of the flywheel which is calibrated with crank angle calibrations, as the flywheel rotates magnets approaches towards the reed switch and hence closing the circuit. Since the circuit is closed solenoid valves gets activated and compressed air is injected in the cylinder

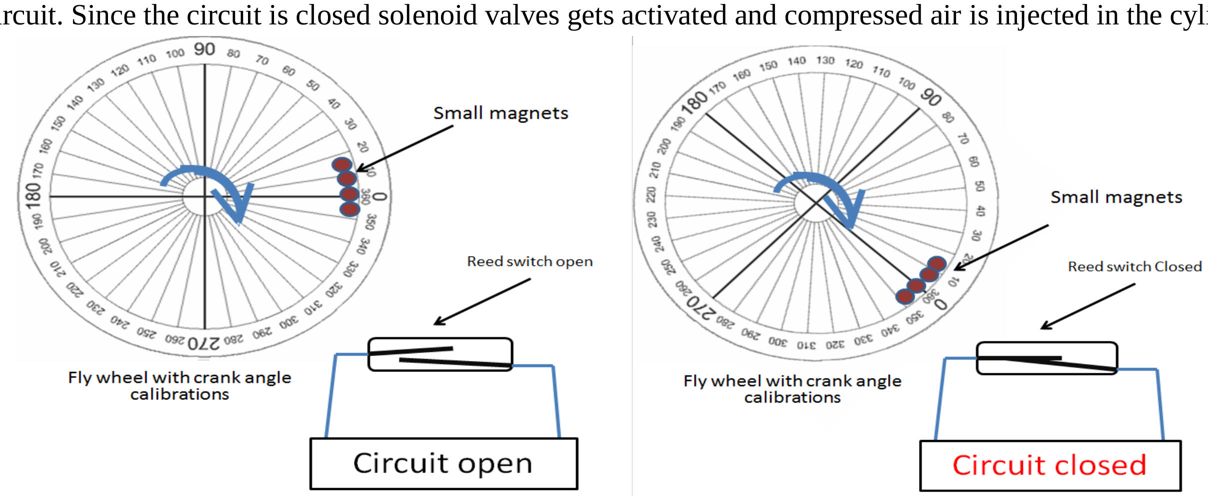

Figure 3. Injection Timing Variation Setup

Different input signal variations

By varying the number of magnets and their arrangement on the flywheel (Figure 4)for different types of variation is obtained that is injection timing and injection range variation. These variations are very helpful for performance analysis providing more scope and different timing parameters for accurate testing.

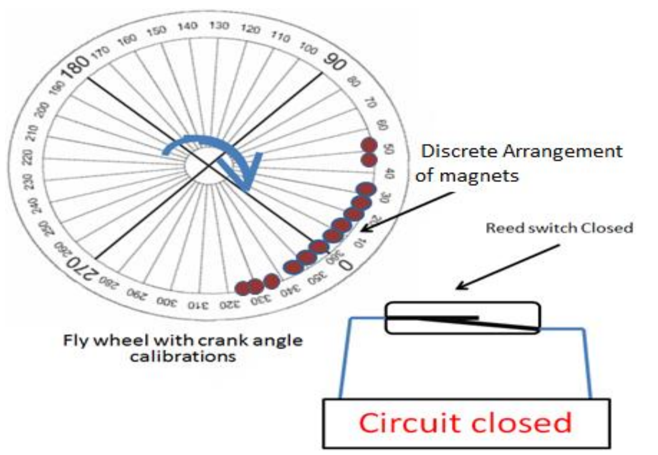

Figure 4. showing discrete injection timing variation

Discrete injection

With the help of the injection timing variation setup, injection at different-different angle ranges for every single intake stroke can be achieved very easily, simply by arranging the magnets in intervals on the circumference of the flywheel. The motive behind employing injection at intervals rather than a continuous injection over the same range as a single continuous injection is to compare RPM variation at same mass flow rate keeping the overall injection time for compressed air injection is kept constant

4. RESULTS AND FINDINGS

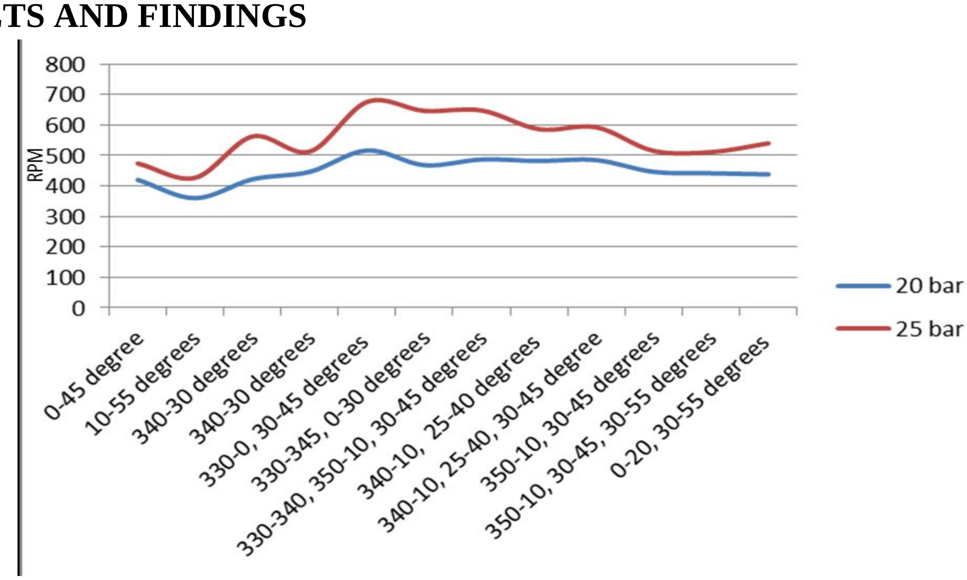

Figure 5. RPM VS injection angles

5. RESULTS/DISCUSSIONS

The following things can be seen from the above tests:

1. The optimum point of injection of air is about 330-340, 30-45 degrees in both the cases (20 and 25 bars).
2. The lowest RPM observed for the injection angle 10-55 degrees for both 20 and 25 bar pressures respectively.
3. The rpm increases as the injection angle is brought near to the top dead centre in both the 20 and 25 bar pressures.
4. Smooth Operation was observed with 330-340 degree angle injection.
5. Dimensions of the Modified Flywheel used whose weight is equivalent to the weight displaced due to removal of electrical windings.

6. CONCLUSIONS

The CA Engine kit is designed to explore further avenues to optimize and increase the efficiency of the engines. The current study shows that optimization of the injection timing/angle in a modified. CA Engine, The CA Engine retrofit Kit is installed on a Single cylinder 2 stroke 147 cc Engine. The injection pressures used were 20 and 25 bar. Various tests were performed in order to determine the optimum injection timing which was observed to be 330 -340,30-45 degrees. This system would ultimately be powered through the electrical grid .Transportation of the fuel would not be required which will result in significant cost benefits and reducing pollution. Compressed air technology reduces the cost of vehicle production significantly, as there is no need to build a cooling system, such robust fuel tanks and ignition systems. Compressed-air system components are unconstrained by the degradation problems associated with current battery systems and the tanks can be disposed of or recycled with less pollution than batteries. The tank may be refilled more often and in less time than batteries can be recharged, with re-fuelling rates comparable to liquid fuels if a full-fledged system exists.

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