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Internal Combustion Engine (ICE)

[1]Soumik Dhar, [2]Saurabh Saini, [3]Sarthak Verma, [4]Dr. J P Kesari

[1,2,3,4] Delhi Technological University

ABSTRACT

In this manuscript, research on hydrogen internal combustion engines is discussed. The objective of this project is to provide a means of renewable hydrogen based fuel utilization. The development of a high efficiency, low emissions electrical generator will lead to establishing a path for renewable hydrogen-based fuel utilization. A full-scale prototype will be produced in collaboration with commercial manufacturers. The electrical generator is based on developed internal combustion engine technology. It is able to operate on many hydrogen-containing fuels. The efficiency and emissions are comparable to fuel cells (50% fuel to electricity, ~ 0 NOx). This electrical generator is applicable to both stationary power and hybrid vehicles. It also allows specific markets to utilize hydrogen economically and painlessly.

INTRODUCTION

An **internal combustion engine** (**ICE** or **IC engine**) is a heat engine in which the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine, the expansion of the high-temperature and high-pressure gases produced by combustion applies direct force to some component of the engine. The force is typically applied to pistons (piston engine), turbine blades (gas turbine), a rotor (Wankel engine), or a nozzle (jet engine). This force moves the component over a distance, transforming chemical energy into kinetic energy which is used to propel, move or power whatever the engine is attached to. This replaced the external combustion engine for applications where the weight or size of an engine was more important.

The first commercially successful internal combustion engine was created by Étienne Lenoir around 1860, and the first modern internal combustion engine, known as the Otto engine, was created in 1876 by Nicolaus Otto. The term *internal combustion engine* usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the six-stroke piston engine and the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described. Firearms are also a form of internal combustion engine, though of a type so specialized that they are commonly treated as a separate category, along with weaponry such as mortars and anti-aircraft cannons. In contrast, in external combustion engines, such as steam or Stirling engines, energy is delivered to a working fluid not consisting of, mixed with, or contaminated by combustion products. Working fluids for external combustion engines include air, hot water, pressurized water or even liquid sodium, heated in a boiler.

While there are many stationary applications, most ICEs are used in mobile applications and are the primary power supply for vehicles such as cars, aircraft and boats. ICEs are typically powered by fossil fuels like natural gas or petroleum products such as gasoline, diesel fuel or fuel oil. Renewable fuels like biodiesel are used in compression ignition (CI) engines and bioethanol or ETBE (ethyl tert-butyl ether) produced from bioethanol in spark ignition (SI) engines. As early as 1900 the inventor of the diesel engine, Rudolf Diesel, was using peanut oil to run his engines. Renewable fuels are commonly blended with fossil fuels. Hydrogen, which is rarely used, can be obtained from either fossil fuels or renewable energy.

COMBUSTION APPROACH

Homogeneous charge compression ignition combustion could be used to solve the problems of burn duration and allow ideal Otto cycle operation to be more closely approached. In this combustion process a homogeneous charge of fuel and air is compression heated to the point of autoignition. Numerous ignition points throughout the mixture can ensure very rapid combustion (Onishi et al 1979). Very low equivalence ratios ($\varphi \sim 0.3$) can be used since no flame propagation is required. Further, the useful compression ratio can be increased as higher temperatures are required to auto ignite weak mixtures (Karim and Watson 1971).

Most of the HCCI studies to date however, have concentrated on achieving smooth releases of energy under conventional compression condition (CR ~ 9:1). Crankshaft driven pistons have been utilized in all of these previous investigations. Because of these operating parameters, successful HCCI operation has required extensive EGR and/or intake air preheating. Conventional pressure profiles have resulted (Thring 1989, Najt and Foster 1983). In order to maximize the efficiency potential of HCCI operation much higher compression ratios must be used, and a very rapid combustion event must be achieved. Recent work with higher compression ratios (~21:1) has demonstrated the high efficiency potential of the HCCI process (Christensen et al 1998, Christensen et al 1997). In Figure 1, the amount of work attained from a modern 4-stroke heavy duty diesel engine is shown at a 16.25: 1 compression ratio. The results show that under ideal Otto cycle conditions (constant volume combustion), 56% more work is still available. This extreme case of non-ideal Otto cycle behaviour serves to emphasize how much can be gained by approaching constant volume combustion.

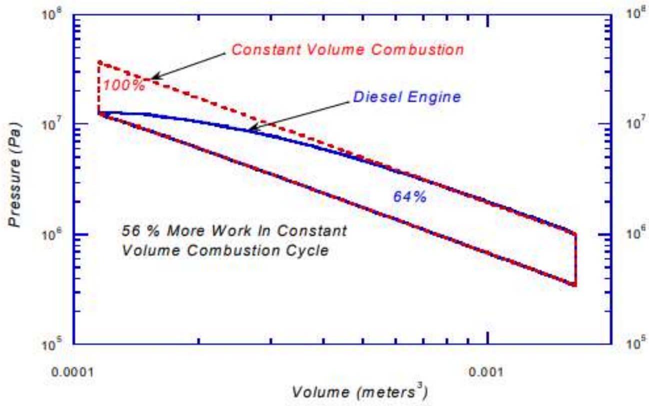

Figure 1 – Modern 4-Stroke Heavy Duty Diesel Engine

ENGINEERING CONFIGURATION

The free piston linear alternator illustrated in Figure 2 has been designed in hopes of approaching ideal Otto cycle performance through HCCI operation. In this configuration, high compression ratios can be used and rapid combustion can be achieved.

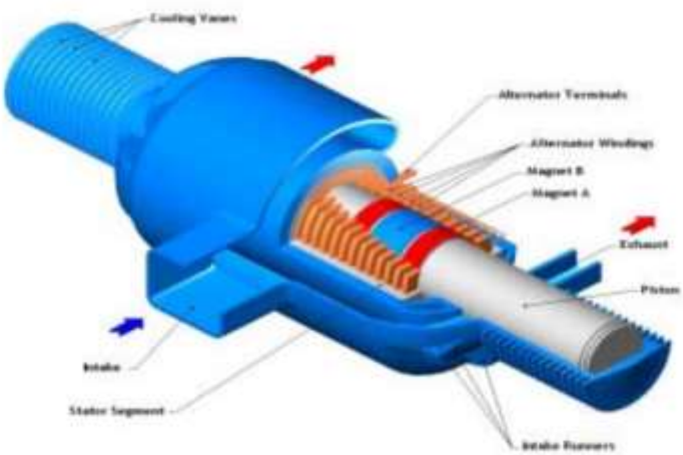

Figure 2 – Free piston linear alternator

The linear generator is designed such that electricity is generated directly from the pistons oscillating motion, as rare earth permanent magnets fixed to the piston are driven back and forth through the alternator's coils. Combustion occurs alternately at each end of the piston and a modern two-stroke cycle scavenging process is used. The alternator component controls the pistons motion, and thus the extent of cylinder gas compression, by efficiently managing the pistons kinetic energy through each stroke. Compression of the fuel/air mixture is achieved inertially and as a result, a mechanically simple, variable compression ratio design is possible with sophisticated electronic control. The use of free pistons in internal combustion engines has been investigated for quite some time. In the 1950ís, experiments were conducted with free piston engines in automotive applications. In these early designs, the engine was used as a gasifier for a single stage turbine (Underwood 1957, Klotsch 1959). More recent developments have integrated hydraulic pumps into the engines design (Baruah 1988, Achten 1994). Several advantages have been noted for free piston IC engines. First, the compression ratio of the engine is variable; this is dependent mainly on the engines operating conditions (e.g., fuel type, equivalence ratio, temperature, etc.). As a result, the desired compression ratio can be achieved through modification of the operating parameters, as opposed to changes in the engines hardware. An additional benefit is that the mechanical friction can be reduced relative to crankshaft driven geometries since there is only one moving engine part and no piston side loads. Also, combustion seems to be faster than in conventional slider-crank configurations. Further, the unique piston dynamics (characteristically non-sinusoidal) seem to improve the engines fuel economy and NOx emissions by limiting the time that the combustion gases spend at top dead centre (TDC) (thereby reducing engine heat transfer and limiting the NOx kinetics). Finally, one researcher (Braun 1973) reports that the cylinder/piston/ring wear characteristics are superior to slider/crank configurations by a factor of 4. The combination of the HCCI combustion process and the free piston geometry is expected to result in significant improvements in the engines thermal efficiency and its exhaust emissions. The following advantages should be found:

1. For a given maximum piston velocity, the free piston arrangement is capable of achieving a desired compression ratio more quickly than a crankshaft driven piston configuration. This point is illustrated in Figure 3 where the piston position profiles of both configurations are plotted. The reduced compression time should result in higher compression of the premixed charge before the onset of autoignition.

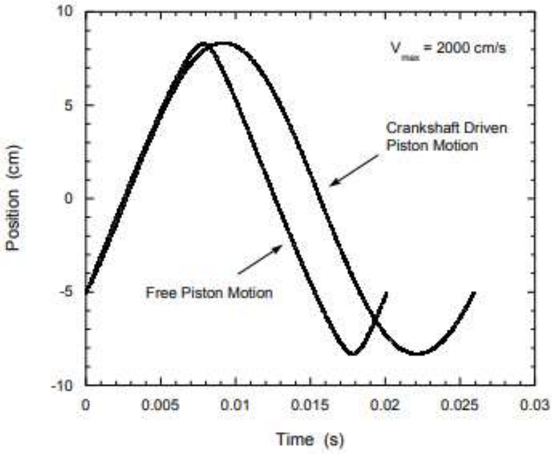

Figure 3 – Piston position vs. time

2. High compression ratio operation is better suited to the free piston engine since the piston develops compression inertially, and as such there are no bearings or kinematic constraints that must survive high cylinder pressures or the high rates of pressure increase (shock). The use of low equivalence ratios in the HCCI application should further reduce the possibility of combustion chamber surface destruction (Lee and Schaefer 1983, Maly et al 1990).

3. The free piston design is more capable of supporting the low IMEP levels inherent in low equivalence ratio operation due to the reduction in mechanical friction. Integration of the linear alternator into the free piston geometry provides further benefits to the generator design. In this arrangement mechanical losses in the system are dramatically reduced since there is essentially one moving part, and this allows engine operation at a more or less constant piston speed. These points aid in the generator design, and further improve the fuel-to electricity generation efficiency of the device. The linear alternator itself is based on technology developed for brushless DC motors. This class of motors is characterized by high efficiency and high-power density, typically 96% efficiency and 1 hp per pound density. Put simply, the rotary configuration is unrolled until flat, then rolled back up perpendicular to the first unrolling to arrive at the linear configuration. Relative to the rotary geometry the linear device is approximately 30% heavier due to not all of the coils being driven at the same time. Efficiency will be comparable.

THE FUTURE OF IC ENGINES

"Are engine development opportunities of the future down to the wire or up the ante?" In this 'viewpoint', an in-depth analysis of the development opportunities, as well as future market trend of IC engines is discussed in detail in the succeeding paragraphs.

Emissions: the technology enforcer

Fortunately, or unfortunately automobile emissions, drive present day engine technologies. As outlined by National Academy of Sciences, a concept of the standards-setting method for mobile source emissions is "technology forcing". "The technology forcing refers the establishment by a regulatory agency of a requirement to achieve an emissions limit, within a specified time frame, that can be reached through use of unspecified technology or technologies that have not yet been developed for widespread commercial applications and have been shown to be feasible on an experimental or pilot-demonstration basis". Over the last 150 years, human activities are liable for the majority increase in Greenhouse gas emissions. Among the other primary sources that contribute to Greenhouse gases, emissions from burning of fossil fuels need more effective control measures. Year by year, rising global temperatures have been accompanied by dangerous shifts in climate and weather. A recent report by NOAA (National Oceanic and Atmospheric Administration) National Climatic Data Centre on global climate analysis for the year 2013 disclosed that the year 2013 (tied with 2003) was recorded to be the fourth warmest year globally since records began in 1880. In concurrence, the global CO2 emissions more than doubled over the last 40 years. Also, in the year 2012, China, the United States and EU27 were the world's three largest CO2 emitters. However, it is anticipated that there would be a stable decline of emissions, if China achieves its own energy targets for 2015 and 2020. When the U.S. continues to increase its share of gas and renewables in the energy mix. EU by restoring the effectiveness of the Emissions Trading System. In addition, according to the report on EU, the CO2 reduction target was set at 50% by 2050 and around 20–30% by 2020. Besides, the U.S. Environmental Protection Agency (EPA) has recently finalized tight vehicle and fuel standards (release date: 03/03/2014) to substantially reduce emissions and protect public health.

Bio-fuels: a prudent step

In fact, bio-fuels would be one of the feasible solutions to cut Greenhouse gas discharges into the air. In this view, the researchers from the Swiss federal institute for materials science and technology have provided a perfect characterization of environmental benefits and costs of different bio-fuels. The survey disclosed that most bio-fuels considerably reduced the Greenhouse emissions when compared to fossil fuels. Also, the survey exposed that the fuels which showed over 50% reduction in Greenhouse gases when compared with fossil fuels were biodiesel prepared from several sources. And, according to the estimate of The International Energy Agency (IEA), world bio-fuels consumption would annually increase at an average pace of 7%, which intends that by 2030 bio-fuels would account for approximately 5% of the total road transport. Also, the projected world bio-fuels consumption up to 2015 and 2030. One could comprehend from the table that there would be tripling of the world bio-fuels production from 16 Mtoe in 2004 to almost 55 Mtoe in 2015 and over 90 Mtoe in 2030. Contrariwise, it572was recognized that each state faces several issues in implementing a viable bio-fuel market primarily due to climate, economic or supply security, food-fuel conflicts, and impacts of the bio-fuel policy on agricultural markets and land use. Despite fragile bio-fuel market of present day, the demand for bio-fuels will grow all over the world in near future. For instance, the European Union aims at 10% bio-fuels of the entire road transport demand by 2020. The majority of bio-fuels will continue to be produced and consumed domestically, although the international trade in bio-fuels is also anticipated to extend appreciably. And, bio-ethanol produced from sugar cane will account for the major share of exports. Also, the ethanol supply and demand outlook reveal that there will be regional inequity that will require trade between the regions. Specifically, North and Latin America are expected to have a surplus of ethanol production while Asia Pacific and the EU are expected to rely on imports. Both Africa and the Commonwealth of Independent States (CIS) should be balanced regions. A recent study by Hart Energy has forecasted a shortfall of 500 million gallons of ethanol for the EU by 2015 and 140 million gallons of ethanol for Japan in 2015. These two regions and countries are estimated to entail Brazilian ethanol for reasons of Greenhouse gas savings and sustainability. However, Brazilian ethanol exports are not expected to arrive at that level in 2015. Overall, the technology is a key component to enhance bio-energy production and increase the output without adverse economic and environmental implications. Although the engine development opportunities of the future are not substantial due to the economic and environmental consequences, as well as the likely future opportunities in electric powertrains which would someday eventually replace IC engines. Nevertheless, the present-day research and development activities can be cantered on substantially reducing the emissions from automobile sources so as to safeguard the human race from the contrary effects of pollution.

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