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Constant power spark ignition engine

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Abstract. Modern IC engines are used on different technical field. Over the past years, there is a more and more electric cars. Electric motors can deliver their full power over a wide RPM range, actually these motors have better power characteristics. Internal combustion engines have several disadvantages, but besides this fact these engines are dominant as propulsion systems. One of the main disadvantages is in close relation with engines power. Modern IC engines his own power release at high engine speed. In this article was presented one new engine with relatively constant engine power at wide range of engine speed.

1. Introduction

Since the very birth of the IC engine by, the desire to improve its performance was the prime mover force both for experimental and theoretical research. Although, over the decades, much progress was made on both the practical and the theoretical side, virtually all technical advances were achieved by intuition or experimental trial and error methods rather than by rigid derivations and implementations based on fundamental laws. It is well known that transport is almost totally dependent on fossil, particularly, petroleum-based fuels such as gasoline, diesel fuel, liquefied petroleum gas (LPG) and natural gas (NG). Fuel consumption, emission by the transport sector and overall motor vehicle efficiency are important topic these days. There is a strong drive towards legislation limiting the fleet average CO₂ emission. Conventional IC engines are based on a relatively simple solution to achieve a thermodynamic cycle while providing mechanical power. While the performance, emissions and reliability of IC engines have been improved significantly, the fundamental principle of crank-rod-piston slider mechanism still remains largely unaltered. In theory, the most efficient thermodynamic cycle for IC engines is the Otto cycle, which consists of isentropic compression and expansion processes and constant volume heat addition and rejection processes. In this article was presented one idea of variable volume IC engine in order to achieve constant power characteristics.

2. Constant power IC engines

In the following section will be presented basic parts and shape of a new IC engine concept. Variable piston motion (VPM) IC engine is presented on the Figure 1. On Figure 1 is presented following parts: 1-engine block, 2-engine head, 3-power shaft, 4-intake manifold, 5-camshaft, 7-valves, 8-spring, 9-gear housing, 10-flywheel, 11-14 - non-circular gears, 15-16 - electric motors and 17-oil pan. As can be seen from the described illustration toroidal piston make a movement conditioned by the mechanism consisting of two pairs of non-circular gears. In this article will not be presented detailed description of this concept, since it is not the intention of the authors to propose a kinematic and thermodynamic features and advantages over ordinary spark ignition engines.



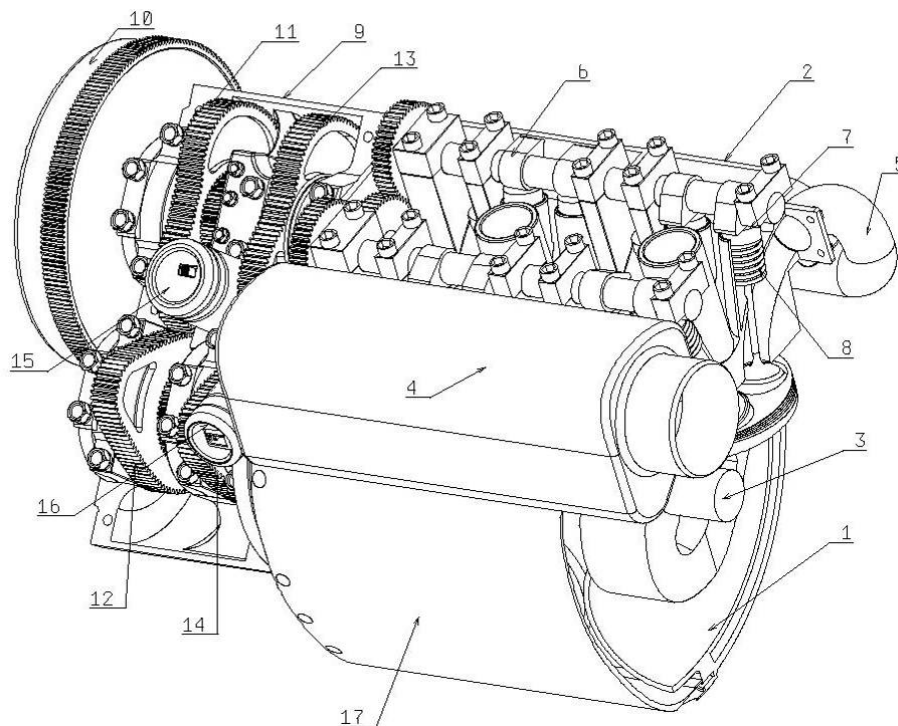


Figure 1. Variable piston motion IC engine.

VPM IC engine has a two pairs of non-circular gears (NCG). A NCG is a special gear design with special characteristics and purpose. While a regular gear is optimized to transmit torque to another engaged member with minimum noise and wear and with maximum efficiency, a non-circular gear's main objective might be ratio variations, axle displacement oscillations and more. In fact this feature of NCG is very important for synthesis of mechanism where is intermittent-motion required. This intermittent-motion mechanism combines circular gears with non-circular gears in a planetary arrangement. With such planetary differential gear it is possible to achieve very complex movement, where toroidal piston is able to provide motion with variable displacement and variable compression, also because of the characteristics of NCG, piston dwell at TDC and BDC is also feasible. Dwell time or dwell angle is important fact during combustion process. In conventional engine this dwell angle can be changed due to variations of ratio between connecting rod and crank radius. Piston dwell at TDC and at BDC are often mentioned, it should be noted that strictly, there is no dwell period in ordinary mechanism. The piston comes to rest at precisely the crank angle that the crank and rod are in line (TDC and BDC), and is moving at all other crank angles. At crank angles which are very close to the TDC and BDC angles, the piston is moving slowly. It is this slow movement in the vicinity of TDC and BDC that give rise to the term piston dwell. If the piston dwells longer near TDC and ignition is initiated properly, there will actually be a longer period of time for the pressure created during combustion to press against the top of the piston.

3. Unconventional piston motion

The ideal scenario is to initiate and complete the combustion event while the piston remains at the TDC position. This provides the maximum thermal potential and eliminates the negative work due to early ignition which is well into compression stroke with conventional engine strategies. In addition, if the combustion event completes at the TDC, the effective expansion stroke can be maximally extended to fully use the thermal energy as well as to provide sufficient time for post combustion reactions, thereby reducing partial burned emissions. During operation of conventional IC engines, the piston

can only reciprocate continuously between TDC and BDC at a frequency proportional to the engine speed. The chemical reaction process associated with combustion events, however, essentially takes a fixed-time to complete, which is relatively independent of the engine speed. In order to maximize the work obtained from the heat energy released by combustion, the air/fuel mixture has to be ignited prior to the piston reaching TDC, and the ignition timing should be adjusted according to the engine speed and the quality of the air/fuel mixture. Clearly, the early stage of the heat release before the piston reaches TDC results in negative work. In this section, the new unconventional piston motion law will be presented. With this movement, the piston is able to make such motion where heat addition can be done during piston dwell. The design geometry creates a pause or dwell in the piston's movement at the TDC and the BDC, while the output shaft continues to rotate for up to 35 degrees. Adding these constant volume dwell cycles improves fuel burn, maximizes pressure, and increases cylinder charge. Fuel burn can be precisely controlled by maintaining a minimum volume (TDC piston dwell) throughout the burn process, containment maximizes pressure and burn efficiency. Furthermore, holding the piston at maximum volume (BDC piston dwell) provides additional time for the cylinder to fully charge before closing the intake valves. The design creates unconventional four stroke cycle process. This unconventional cycle consists of the following strokes and processes. The first stroke consists of forced and free intake. During the forced intake, piston travels from TDC to BDC, which draws fresh mixture into the cylinder. This part of the stroke is the same as the intake stroke in the ordinary IC engines, the second part is the free intake. After the piston comes into BDC, it stops there for a while, this dwell time depends on the optimization of the intake process and it will not be explained in detail in this paper. However, it is very important that the piston dwell does not last longer or shorter than the optimal calculated value. After the piston comes into BDC, the column of fresh gases continues to flow into the cylinder by inertia, until the intake valve closes. In this way the intake volumetric efficiency is increased. The second stroke consists of the compression process and a combustion during constant volume. In the first part of this second stroke, the piston travels from BDC to TDC. The ignition occurs at TDC without any spark advance, thus saving the accumulated energy of the flywheel. Ignition begins when the piston is stopped at the TDC, while the piston stop lasts for the time calculated by optimization to complete combustion and prevent any back-pressure caused by the spark advance. Consequently, the use of energy obtained from the fuel is maximized and the fuel consumption is decreased. The third stroke is an expansion stroke, during which the piston comes from TDC to BDC like in a standard mechanism but with the exception that piston again makes a dwell in BDC. In this new unconventional four stroke cycle, the entire expansion stroke occurs between TDC and BDC.

4. Simulation

Within the automotive industry the most widely adopted technique for gas exchange studies is to solve the one dimensional coupled set of non-linear equations using the finite volume or finite difference method. This technique is used in several commercial softwares e.g., Ricardo/WAVE, GT-Power and AVL/BOOST. In this paper, Ricardo/WAVE software was used, which provides a fully integrated treatment of time-dependent fluid dynamics and thermodynamics by means of one-dimensional formulation. Internal combustion engine simulation modeling has long been established as an effective tool for studying engine performance and contributing to evaluation and new developments. Thermodynamic models of the real engine cycle have served as effective tools for complete analysis of engine performance and sensitivity to various operating factors. WAVE is the primary program and solver for all simulations of fluid dynamic systems, this software can be used to model the complete internal combustion engine. The piping and manifolds of the intake and exhaust systems are modeled using the basic WAVE flow elements. These networks are then linked together through engine elements and sub-models, which have been calibrated to provide accurate driving inputs for the intake and exhaust pressure-wave dynamics.

The details of the flow (as calculated in the flow network) are obtained as a solution of quasi-one dimensional compressible flow equations governing the conservation of mass, momentum and energy-

eq. (1-3). The flow network of both conventional and unconventional piston movement is discretized into a series of small volumes and the governing equations are then written in a finite difference form for each of these elementary volumes. A staggered mesh system is used, with equations of mass and energy solved for each volume and the momentum equation solved for each boundary between volumes. The equations are written in an explicitly conservative form as:

$$\frac{dm}{dt} = \sum_{boundaries} m_{flux} \quad (1)$$

Equation (1): mass continuity equation.

$$\frac{d(m_{flux})}{dt} = \frac{dpA + \sum_{boundaries} (m_{flux}u)}{dx} - \frac{4C_f \frac{\rho u^2 dx A}{2D} - C_p \left(\frac{1}{2} \rho u^2 \right) A}{dx} \quad (2)$$

Equation (2): Conservation of momentum equation.

$$\frac{d(me)}{dt} = p \frac{dV}{dt} + \sum_{bound.} m_{flux} H - h_g A (T_{gas} - T_{wall}) \quad (3)$$

Equation (3): Conservation of energy equation.

If the engine cylinder element has one zone, the entire cylinder is treated as one region. In the latter, the cylinder is divided into two regions (unburned and burned), which share a common pressure. The two-zone model is used to capture the chemical processes taking place during the combustion period in more detail. Combustion models may be used either with a single or two-zone engine cylinders, but for this research two zone models were used because of the problem with knock combustion that was also examined. For the single zone model there is the energy equation refer to (4) as below:

$$\Delta(mu) = \sum_{i=1}^{nvalves} m_i h_i - Q - P\Delta V \quad (4)$$

During combustion, the only term of enthalpy flow is $m_i h_i$ due to propagation of the flame front to the unburned zone. For the two-zone, refer to model (4), in the unburned zone we have:

$$m_{u1} u_{u1} - m_{u0} u_{u0} + P(V_{u1} - V_{u0}) + Q_u - \Delta m_{ui} h_{ui} = 0 \quad (5)$$

Using the equation of the state, it becomes:

$$m_{u1} u_{u1} - m_{u0} u_{u0} + m_{u1} R_{u1} T_{u1} - P V_{u0} + Q_u - \Delta m_{ui} h_{ui} = 0 \quad (6)$$

Similarly, for the burned zone we have:

$$m_{b1} u_{b1} - m_{b0} u_{b0} + m_{b1} R_{b1} T_{b1} - P V_{b0} + Q_b - \Delta m_{bi} h_{bi} = 0 \quad (7)$$

As a constraint, the volumes of the unburned and burned zones are summed up to the total cylinder volume:

$$m_{u1} R_{u1} T_{u1} + m_{b1} R_{b1} T_{b1} - P V_c = 0 \quad (8)$$

The last three equations are a complete set and are solved by using the Newton iteration method. Finally, after proper simulation of numerical engine model, curves of power in relation to torque and engine speed can be presented. As can be seen from Figure 2 engine deliver constant power through wide range of engine speed. This new feature of IC engine was achieved through variable piston motion.

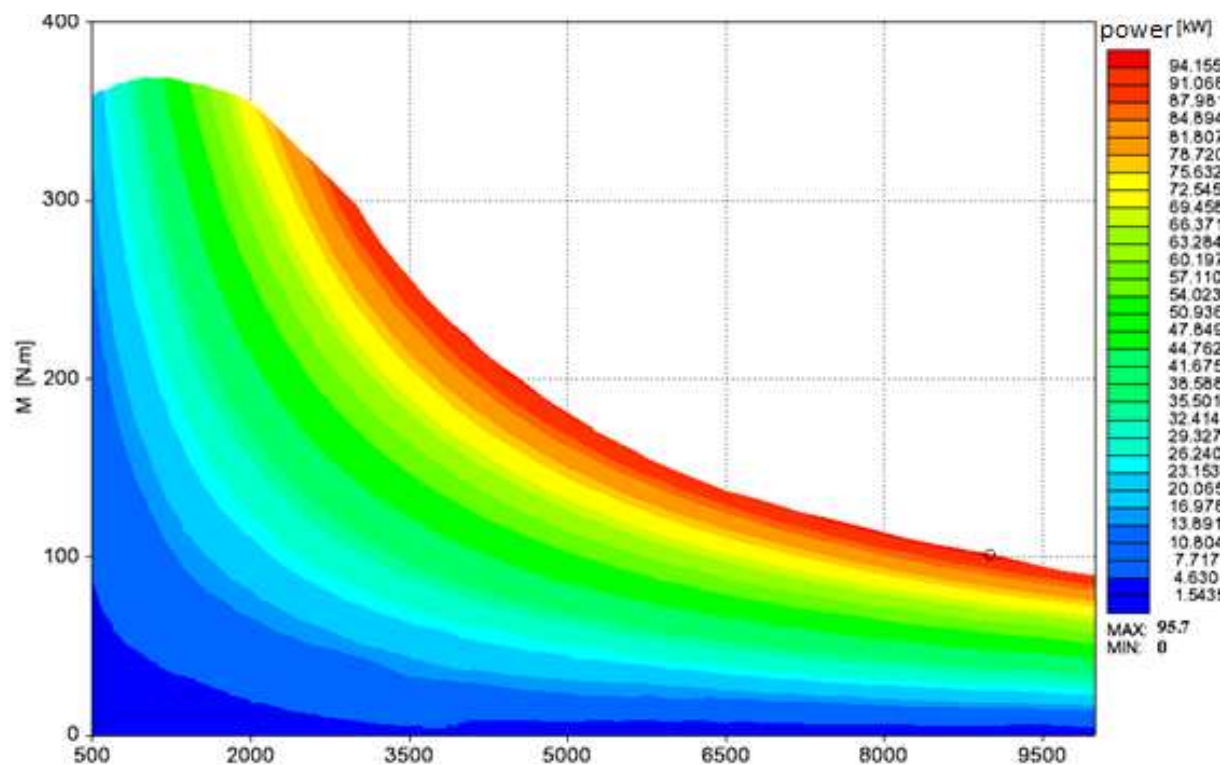


Figure 2. Constant power curves.

5. Conclusions

The engine used for most contemporary motor vehicles is the four-stroke spark-ignition (SI) internal combustion engine. A novel Otto cycle engine concept, in which intake and compression are carried out through unconventional piston mechanism, is presented. Numerical simulations were performed to optimize the cranking mechanism for achieving high thermal efficiency. The performance of a unconventional Otto heat engine is investigated by considering the zero dimensional modelling. It is found that there are optimal values of the piston dwell at which both the power output and efficiency attain their maxima, respectively. The thermal efficiencies and power output of the cycle are, in general, dependent not only on temperature and the thermal conductance between the working substance and the cylinder wall but also on the volume and other parameters, which are presented in this article. The system enabled reductions in piston velocity around the top dead centre region to a fraction of its value at constant crankshaft angular velocity typical in conventional engines. A quasi-constant volume combustion has thus been successfully achieved, leading to improvements in engine fuel consumption and power output which are discussed in detail. In this article was presented one approach for improvement of spark ignition engine efficiency. Described concept has several advantages over ordinary SI engines. First of all, this engine is able to provide heat addition during constant volume, than it is possible to achieve smaller values of spark ignition angle advance. Also with this concept there is no need for valve overlap. All of these mentioned advantages show that the potential to increase the efficiency of the SI engine conditions is not yet exhausted. As shown in the research results above, with the constant volume combustion cycle, the piston movement is significantly slower around TDC and BDC. Overall, the pressure integral of the quasi-constant volume combustion cycle is about 4% higher than that of the conventional cycle at full load.

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