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MILLER – ATKINSON INTERNAL COMBUSTION ENGINE

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Abstract: *In this article the authors have proposed a study of engines that use Miller-Atkinson cycle. In this article in shown that engines that use Miller-Atkinson cycle have many unsolved aspects. A theoretical approach is used for explaining some particularities of engines and an experimental approach to determine one or more engine characteristics.*

Keywords: Miller, Atkinson, variable valve timing.

INTRODUCTION

Ever more stringent environmental regulations continue to motivate the need to improve efficiency and reduce emissions of internal combustion engines. In August of 2012 the Environmental Protection Agency (EPA) and Department of Transportation's National Highway Traffic Safety Administration (NHTSA) issued a regulatory announcement outlining the fuel economy and greenhouse gas standards for 2017-2025 [1]. This announcement outlines the reduction in CO_2 emissions and sets the miles per gallon (mpg) for automotive manufactures entire fleet. The announced regulation calls for combined CO_2 emissions to be 163g/mile, which corresponds to a Corporate Average Fuel Economy (CAFÉ) of 54.5 mpg by model year 2025.
In an effort to achieve the mandated fuel economy targets, extensive research is being dedicated to various strategies with much of the effort being focused on two high level areas. Reducing pumping losses at part load operation without sacrificing peak performance, and increasing the amount of work extracted from the power cycle for a given fuel input. In order to apply these strategies in production engines, various concepts are being implemented including the use of charging systems (like a turbo or supercharger), smaller displacement engines, cylinder deactivation, electric hybridization, or alternative thermodynamic cycles.
The use of a charging system with a smaller displacement engine is a growing trend among automotive manufactures. Charging allows an engine to maintain peak performance while reducing the pumping losses at part load. During high load conditions the charge system is used to increase the peak power of the engine by increasing the density of the air entering the cylinder. At part load the output of the charge system is reduced which allows the throttle valve to stay open wider. By allowing the throttle valve to stay open the pumping losses of the engine are reduced leading to improved part load efficiency during normal cruising conditions. Due to the limit on the amount of charging that is possible before knock occurs and the losses associated with both turbo- and super-chargers this approach has a limited level of improvement.
Cylinder deactivation is another method used to reduce pumping losses during part load operation. During high load conditions all of the cylinders are active allowing for peak power to be produced by the engine. During part load conditions, instead of closing the throttle to reduce power, cylinders are turned off (deactivated). This is commonly done by keeping both the intake and exhaust valves closed which results in the deactivated cylinder acting like a

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pneumatic spring. As cylinders are deactivated the other cylinders have to produce more work, which means that the throttle has to be open more leading to a reduction in pumping losses. This method however does not remove the friction losses as the deactivated cylinder is still moving. Due to the limit on the amount of work that can be produced by a cylinder, and that friction losses still exist in the deactivated cylinder, the amount of efficiency improvement achievable by this strategy is reduced.

Hybrid power systems used in automobiles come in two general forms, series, and parallel [2]. A series hybrid system consists of four major components, an IC engine, generator, battery, and electric motor. In a series hybrid system the IC engine drives a generator that provides energy to the battery where it can either be stored for use later or provided to the electric motor to drive the wheels. A parallel hybrid system consists of just the IC engine, battery, and electric motor. In a parallel hybrid system, the IC engine can provide energy to both the wheels and the electric motor at the same time. This means that when the engine produces more power than required by the wheels the electric motor serves as a generator and charges the battery. Once the battery is charged, the IC engine can be turned off and the electric motor can drive the wheels. Alternatively, if more energy is required then what can be provided by the IC engine, the electric motor provides additional power to the wheels to meet the demand. The goal of the hybrid system is to improve efficiency by allowing the engine to operate at a steady state point where the engine has been optimized to operate. This allows for improved thermal efficiency and reduced emissions with the drawback being that hybrid systems increase the weight, cost, and control systems required to control energy delivery.

Alternative cycles are derivate from classics cycles Otto and Diesel. To obtain those cycles several methods are used (opening valve time modifications, modifications of compression or expansion stokes) to increase engine efficiency.

In recent years alternative cycles were studied by researchers and automotive companies because they have a significant energetic potential. Miller Atkinson cycles are a great alternative to classical cycles because they improve engine efficiency, reduce fuel consumption, decrease cylinder temperature, reduce occurrence of knocking phenomenon and decrease engine emissions.

STATE OF THE ART IN RESEARCH OF MILLER ATKINSON ALTERNATIVE CYCLES

The Atkinson cycle was firstly presented by James Atkinson in 1882, by using a differential engine. It was developed as the Miller cycle and patented by Ralph Miller in 1952; the Miller cycle can be used both for 2 and 4 stroke, gasoline or diesel engines.

The main characteristics of the Miller/Atkinson cycles are: the compression ratio is smaller than the expansion ratio (for this reason a Lysholm compressor is used); higher thermodynamic efficiency; higher expansion ratio; compact size of the engine and up to 20% lighter; a lower exhaust temperature; uses existing manufacturing technology; sometimes twin inlet valves are used; switchable exhaust valve to turbo; direct injection. Sometimes the Miller is called the 5 stroke cycle.

In Reference [3] it was proved that the internal combustion engines which work after the Miller cycle lead to the diminishing of the NOx reduction, but the diminishing depends on the angle of the late intake valve closing. This diminishing goes up to 30% for the diesel engines. The authors do no remark the decreasing of the emissions of HC and CO.

The reference [4] proved that the Miller cycle increases the efficiency based on longer expansion ratio. The longer expansion ratio can be achieved both by early or late intake valve closure, enabled by distinct variable valve actuation mechanisms. Turbocharger and intercooler are used frequently to increase the intake air density and to recover the power lost due to reduced intake stroke. The authors show that the perfect solution for the profiles and fast valve events is the camless solution. Another solution is the use of mechanical systems, with nonconventional oscillatory systems which could improve the advantages of the Miller cycle.

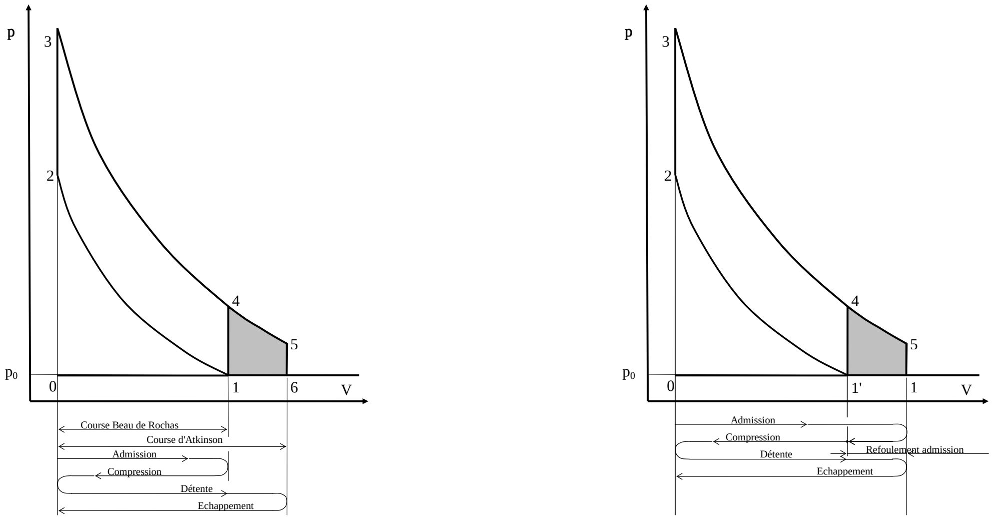
In [5] the performances of a standard Atkinson engine were analyzed with the aid of the finite-time thermodynamics. It was proved that if the compression ratio is less enough then power output decreases when the mean velocity of the piston increases. If the compress ratio exceeds a critical value, then power output first increases and then decreases when the mean velocity of the piston increases. Great values of the compression ratio lead to the decreasing of the power output. Moreover the power output increases when the cylinder wall temperature increases. A more complex law of variation is presented for the equivalence ratio.

Early Inlet Valve Closure offers benefits at certain range of loads and speeds for a Ford engine [6]. Both Late Inlet Valve Closure and Early Inlet Valve Closure lead to the reduction of soot [7] and NOx [8], but the effect on the levels of HC and CO is a small negative one by increasing them.

Other authors [9] realize a complex theoretical and experimental study using a 3 cylinder engine in which 2 cylinders realize 4 strokes cycles, while the third one performs a 5 stroke cycle. The conclusion is that this engine is heavier, larger and more expansive than a classical one, delivering the same power but a lower efficiency.

Some authors [10] consider a turbocharged Dual cycle model studying, with the aid of a Matlab simulation, the effects of different parameters, and proving the existence of an optimum excess air coefficient and the increasing of this optimum value with the increasing of the turbocharger efficiency and the decreasing of the engine load. The Miller cycle can only increase the engine performance for small size turbine, low temperature; in these conditions the authors obtain fuel economy.

The problem in which the knock and NOx are affected by the gas pressure and temperature, that is, by the geometrical compression ratio, while the thermal efficiency of the cycle is determined by the work during the expansion stroke is studied in [11]. The authors make an investigation of higher-expansion cycle in a spark engine, performing also a comparison between the Otto and Miller-Atkinson cycles. Results are obtained with the aid of the thermodynamic analysis.



a) *b)*

Figure 1. Theoretic a) Atkinson and b) Miller cycles [11].

The classical Beau de Rochas cycle is described by the loop 0-1-2-3-4-1-0 (Fig. 1, a), b)). The Atkinson cycle performs the loop 0-1-2-3-5-6-0 (Fig. 1, a)), while the Miller cycle is characterized by the loop 0-1-1'-2-3-5-1-0 (Figure 1, b)).
The advantages of using the Miller cycle concerning its use for variable distribution, reduction of pollution, and increasing of the performances of engine are highlighted.
The analytical synthesis of the intake cam in order to obtain the Miller cycle is described in [12].

MILLER ATKINSON CYCLES IMPLEMENTED IN AUTOMOTIVE INDUSTRY

Some of the most known implementations are presented bellow.

NISSAN HR12DDR Engine. In general, a gasoline engine vehicle can use around 20% of the vehicle's energy gained from burning the gasoline. The HR12DDR engine, though, has succeeded in enhancing this 20% efficiency level by introducing several technologies.

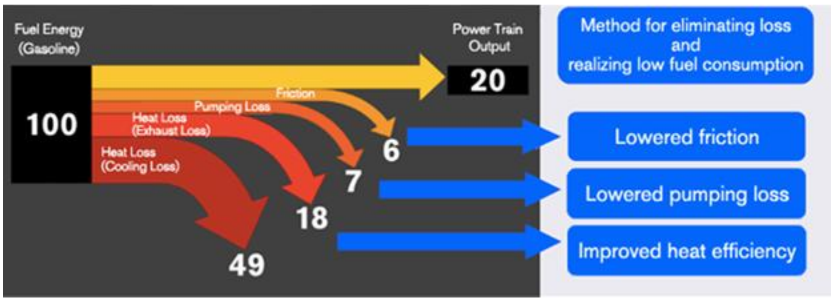


Figure 2. Fuel energy [13]

A four-stroke gasoline engine creates energy through a cycle of intake, compression, combustion and exhaust.
In the intake stroke, when there is difficulty in the suction of air, there is waste and reduced efficiency. In order to have air intake that is as easy as possible, the HR12DDR uses a Miller Cycle with a more delayed intake closure than a regular engine.
As in the diagram below, Miller Cycle engine's intake valve is open even during the compression stroke, when the valve in conventional four-stroke engines is closed.

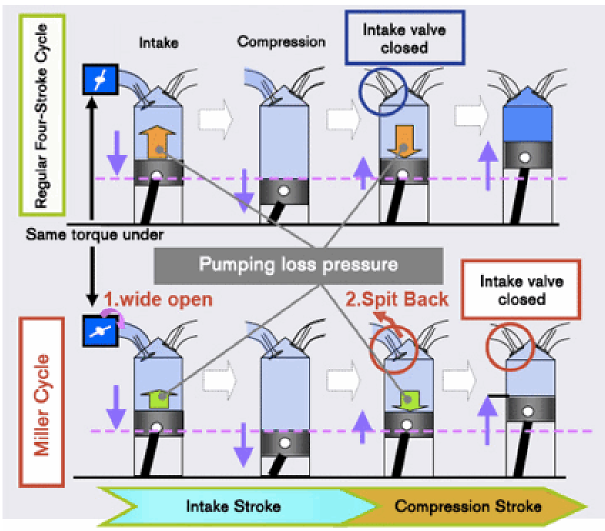


Figure 3. Reduction of Pumping Loss [13]

The HR12DDR engine improves efficiency but when focusing only on fuel consumption, there is a risk that the driving experience will be less enjoyable. In this way, the system utilizes a 1.2-liter supercharger that provides the power equivalent to a 1.5-liter class engine. The supercharger was adopted for its high responsiveness to the accelerator pedal and excellent emission performance.

FIAT "MULTIAIR" System. The MultiAir system replaces the twin camshafts of a four-valves-per-cylinder engine. The single camshaft opens up all four valves. Exhaust valves are not variable and are opened in the usual way by mechanical cam lobes. But between the inlet cam lobes and inlet valves are hydraulic chambers from which oil can be released by electronic solenoid valves.

When the electronic solenoid valve is closed, the chamber becomes a solid body and the valve follows the profile of the cam exactly. But if the electronic solenoid is opened to release some of the oil, the chamber shrinks to absorb the cam movement and the valve opens less. Choosing when to bleed the oil from the chamber, as well as by how much, makes it possible to control timing and lift as well as the duration of opening on an individual, valve-by-valve basis.

The mechanical inlet cam profile is 'hot', that is to say designed for high power at high rpm. For maximum power, the chambers remain full so the valves are opened to their maximum for longer. At slow speed, the solenoid is opened near the end of the cam's 'ramp' to close the valve early, maximizing the amount of air trapped in the cylinder and improving torque. At part throttle, different strategies are used, partially opening the valves to trap just the right amount of air and speed up air flow.

Claimed results are impressive. Maximum power is up 10%, consumption and CO_2 down by around 15% and downsized MultiAir turbocharged engines can achieve 25 percent better fuel economy than larger naturally aspirated engines of the same power. And because the inlet valves can be opened at the same time as the exhaust valves to promote internal exhaust gas recirculation, emissions of HC and NOx drop by 40% and 60%.

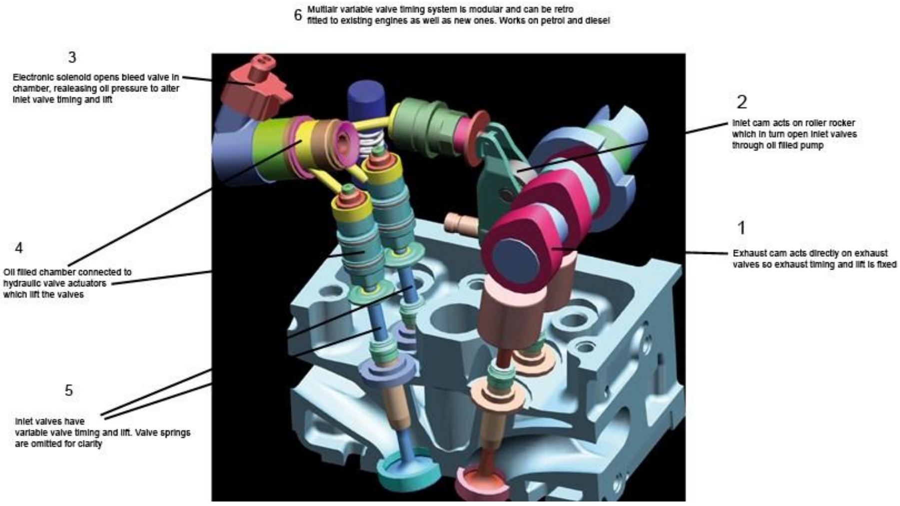


Figure 4. Fiat "MultiAir" system [14]

CONCLUSIONS

The references above show that the study of the Miller-Atkinson internal combustion engine is still at the beginning, many aspects remaining unsolved. The researchers are either theoretical ones trying to explain some aspects of the functioning, or experimental ones by determining some characteristic of such engines.

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