A NOVEL INTERNAL COMBUSTION ENGINE WITHOUT CRANKSHAFT AND CONNECTING ROD MECHANISMS

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Abstract

A novel internal combustion engine without a crankshaft and connecting rod mechanisms, which the author would like to present, is partially acting on another law of physics. The invention titled 'Nano-Magneto-Rheological Mechatronic Commutator Internal Combustion Engine', which is concisely termed the Fijalkowski engine by some, is based on a completely new propulsion engineering solution that has no analogies in the world. Thus, this paper focuses on a novel internal combustion, which may use a nano-magneto-rheological mechatronic commutator that may replace the crankshaft and connecting rod (conrod) mechanisms. This mechatronic commutator may let nano -magneto-rheological rotary ratchets oscillate in a controlled wobble while keeping the output shaft spinning smoothly; and although opposed pistons and opposed cylinders similar to those in automotive 'boxer' engines may power the Fijalkowski engine, it may also use opposed cylinders containing four pairs of two end-to-end opposed pistons for higher power densities. The nano-magneto-rheological mechatronic commutator is used for converting between one form of mechanical motion that is linear, reciprocating motion of pistons and another -- that is the rotary motion of the output shaft.

Keywords: *internal combustion engine, mechatronic commutator, nano-magneto-rheological fluid*

1. Introduction

The automotive world is moving towards the **hybrid-electric vehicles** (HEV) in every respect other than actual conventional automotive vehicles. Enthusiasm for **all-electric vehicles** (AEV), a feature of the early 1990's has declined a little. It is now certain that HEVs are within reach of the advanced **hybrid power source** (HPS) that is an advanced **internal combustion engine** (ICE) without **crankshaft and connecting rod (conrod) mechanisms** (C^2M), conceived and developed by the author [1]. As a result, generation changes in C^2M, which acts as **linear reciprocating motion to rotary motion** and vice versa (LM-RM/RM-LM) mechanical commutator are taking place in the entire world. The author is focusing on the main innovations and trends for tri-mode **hybrid-electric** (HE) **all-wheel-driven** (AWD) **drive-by-wire** (DBW) propulsion and **all-wheel -braked** (AWB) **brake-by-wire** (BBW) dispulsion mechatronic control systems as well as a two- or four- or even five-stroke thermodynamic cycle, twin-opposed-piston, *'crankless'* reciprocating ICE, termed the Fijalkowski engine, with a **nano-magneto-rheological fluid** (NMRF) LM-RM /RM-LM and/or RM-RM mechatronic commutator.

Despite the recent emphasis on fuel cells, ICEs will continue to be the **chemo-thermo -mechanical** (CH-TH-M) energy converters of choice in automotive applications for the next few decades.

However, the decades ahead are likely to be characterised by a fragmentation of the engine market, with the emergence of many competing technologies and a blurring of the distinction between engine families. The driving forces behind these technological developments are, and will continue to be, dominated by energy efficiency, emission regulations and drivability, coupled with great emphasis on reliability, manufacturability, cost, diagnostics, serviceability and recyclability. Emerging technologies in sensors, actuators and advanced mechatronic control systems are opening many parallel paths, and the future of ICE is likely to be shaped by the economic and regulatory climate on a global (worldwide) scale. This paper provides an overview of emerging trends, opportunities and challenges in ICE technology. Most conventional ICEs are reciprocating ones. Pistons that move back and forth inside enclosed cylinders power reciprocating IC engines. The LM of the pistons is converted to RM by a conventional crankshaft or geared crankshaft, bent axis, swash plate, wobble plate, transition arm or cam mechanism to convert LM to RM or vice versa to perform useful work such as turning the wheels of an automotive vehicle or the rotors of a helicopter.

The crankshaft, sometimes colloquially abbreviated to *'crank'*, is that part of an ICE, which converts LM of the pistons into RM of the crankshaft. It typically connects to a flywheel to reduce the pulsation characteristic of the two- or four-stroke thermodynamic cycle and sometimes a torsion or vibration damper at the opposite end, to reduce the torsion vibrations often caused along the length of the crankshaft by the cylinders furthest from the output end acting on the torsion elasticity of the metal.

The crankshaft is subjected to various forces but it needs to be checked in two positions. Firstly, failure may occur at the position of maximum bending. In such a condition, the failure is due to bending and the pressure in the cylinder is maximal. Secondly, the crank may fail due to twisting, so the crankpin needs to be checked for shear at the position of maximal twisting. The pressure at this position is not the maximal pressure, but a fraction of the maximal pressure.

Thus, the most important mechanical motions of the ICE are the LM of the pistons and connecting rods (conrods) and the RM of the crankshaft. The latter converts the LM of the pistons into the RM of the crankshaft. Then, the RM can be output to the driving wheels of the automotive vehicle through the clutch, transmission and shafts. During the combustion and expansion processes, the high cylinder pressure pushes the piston motion to **bottom dead centre** (BDC). During compression and intake/exhaust processes, the inertial of the flywheel and the cylinder pressure of other cylinders drive the piston motion to **top dead centre** (TDC).

The novel ICE without a C^2M that the author would like to offer is based on another law of physics. The invention titled *'Nano-Magneto-Rheological Mechatronic Commutator Internal Combustion Engine'*, that is concisely termed the Fijalkowski engine by some [2, 3], is based on a completely new propulsion engineering solution that has no analogies in the world. Furthermore, with the elimination of the conventional C^2M, its friction and mass are substantially reduced that results in even greater mechanical energy output.

The Fijalkowski engine, as has been conceived in the 1980s and first presented and published in October 1986 at the *8th International Electric Vehicle Symposium* in Washington, DC [1], has only one or more moving parts, the piston-rod assembly. It may be constructed of one or more pairs of directly opposed pistons with the respective opposed cylinders and heads, and one or more IPM arrays fixed to the piston rod between them, or driven by a LM-RM/RM-LM and/or RM-RM NMR mechatronic commutator that replaced the conventional C^2M. The piston-rod assembly may shuttle back and forth in a straight line from compression-ignition to compression-ignition in its opposing cylinders. Mechanical energy from combustion and expansion of a fuel mixture is concentrated in a straight line, and because the pistons are not experiencing angular loading in the cylinders (as seen in conventional crankshaft reciprocating ICE configurations); friction is substantially reduced that translates to greater mechanical energy output.

The Fijalkowski engine has major advantages, it can burn a large variety of liquid-fossil as well as gaseous-nitrogen fuels and has a high potential of depollution. The new technology, which was discovered by the author in 1986 [1], is a highly efficient method of converting LM to RM in advanced reciprocating ICEs, **mechano-fluidic** (M-F) pumps or compressors and **mechano-vacuum** (M-V) pumps as well as **fluido-mechanical** (F-M) and **pneumo-mechanical** (P-M) motors. This new method may also provide for an effective way of varying the capacity of M-F pumps and M-P compressors, as well as the compression ration of the Diesel and Otto engines. Particular result is an advanced opposed piston, opposed cylinder compression ICE that is much more fuel-efficient than conventional ICEs and may therefore save users millions of dollars in fuel cost each year.

Taking into account the instantaneous ICE friction torque is decisive to recognising the ICE components that are contributing the most towards the overall frictional losses of the ICE. Attenuation of frictional losses for such components may also rationalise the fuel consumption and increase the power output of the ICE. Therefore, an aim ought to be developing, above all, a tool for reckoning the instantaneous friction torque of the C^2M.

The invention that is being offered is from the area of propulsion engineering, especially from the area of the opposed-piston, opposed-cylinder ICE that is widely spread. It is a popularly known fact that ICEs have a C^2M, except for rotary ICEs. The C^2M has a crankshaft that is a main part of that mechanism. The manufacturing and servicing of that part is costly. According to various sources, about *30%* of the cost of the entire ICE is spending on the crankshaft alone. The presence of a C^2M causes the reciprocating ICE to vibrate, which as a result leads to many technical problems. Therefore, the attempts to create an ICE without a C^2M have been made for quite a while, however up until the present days the majority of the ICEs still use them. So-termed rotary ICEs are an exception (like the Wankel engines, for instance), which are used extremely rarely due to difficult servicing procedures and complicated structure of the rotary ICE.

The necessity of separating the lubrication system will lead to designs with outside scavenging such as a mechanically blower, or maybe a design solution similar to the Fijalkowski engine can be found. Fig. 1 shows the design animation of the Fijalkowski engine's NMR mechatronic commutator.

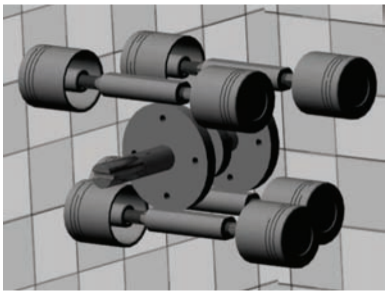
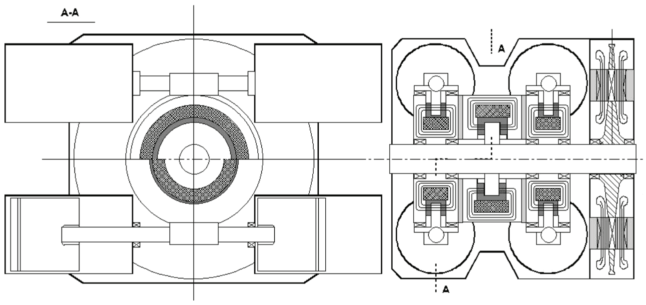


Fig. 1. Design animation of the Fijalkowski engine's NMR mechatronic commutator

The four pairs of two opposing pistons of a *'boxer'* ICE arrangement are solidly connecting to each other as well as to a NMR mechatronic commutator by means of round piston rods. There are separating walls between the NMR mechatronic-commutator case and the underside of the pistons. Because the piston rods are guiding and are supporting by bearings in the separation wall, the pistons hardly touch the cylinder walls, there are no side forces, and there is no piston tipping at the dead centres. As is the case with the conventional two-stroke thermo-dynamic cycle reciprocating ICE, the bottom side of the pistons may function as charge pumps, one for each cylinder. Because the ceramic pistons do not need to be lubricated, the combustion air would remain free of lubrication oily-fluid. As can be seen in this Fijalkowski engine, two-stroke thermodynamic cycle may allow putting great expectations in novel non-metallic composites such as fibreglasses (e.g. *Kevlar* or *Technora*) or ceramic materials.

Ceramics are presumed to construct a highly loaded piston that would be thermally stable. It seems possible that cylinders constructed from ceramics would develop less thermal energy (heat) distortion and less wear. Components of the Fijalkowski engine that may be constructed of ceramic materials are pistons; piston rings (if any); piston rods' mover (forcer) blocks inside the NMR mechatronic commutator; cylinder sleeves and exhaust channels. There are many advantages in the design of the Fijalkowski engine. Because of the absence of a gudgeon pin and short skirt, the piston can then only be about half the mass of its conventional counterpart. This in turn means that primary vibration forces may be reduced by about *50 %*. Since the pistons may be connected rigidly, because of the absence of a gudgeon pin, the angular motion of the sliding followers (piston rods), and therefore the secondary vibration forces, may be eliminated. This all means that such an unconventional reciprocating ICE with fewer cylinders than a conventional one is without unacceptable levels of vibration. Because combustion-gas forces act perpendicularly to opposed pistons, their resultant (as the total outcome of these forces) in the Fijalkowski engine may always be reacted by pure compression in the sliding followers (piston rods). This and the reduction of lateral acceleration forces owing to the light mass of the opposed pistons, may virtually eliminate piston slaps. The value of the inertia force may be at all times less than the values of the combustion-gas force between the rings and the bores, nor do the maximum values of each may occur simultaneously -- lateral components of inertia forces are zero at the ends of each stroke. Consequently, ring flutter should not occur and the rate of wear of the rings and bores should be low. By virtue of the shortening of a piston skirt, oily-fluid drag (if any) ought to be about *5 %* of that of a conventional piston. Therefore crankless ICE's cold cranking (starting) should be easier so a smaller **starting, lighting & ignition** (SLI) **chemo-electrical/electro-chemical** (CH-E/E-CH) storage battery and a DC-AC commutator starter motor would be needed.

Additionally, the length of cylinder bore to be machined may be only about two thirds of that conventionally required. Many of these advantages would be of special benefit for the Fijalkowski engines for HEVs, and the author has also designed two- or four- or even five-stroke thermo-dynamic cycle versions with tri-angular, rectangular and oval twin-opposed pistons, instead of circular twin-opposed pistons that may also be utilised. The Fijalkowski engine's concept presented below may operate on the **high-pressure direct injection** (HDI) and constant-volume four-stroke thermodynamic cycle principle. The twin-opposed pistons move almost symmetrically in their horizontal ICE cylinders, and each of their LMs may be converted into the RM of the ICE's output shaft, by means of a pair of sliding followers (piston conrods) with their bearings, and the main shaft's NMR rotary ratchets, and NMR rotary clutch, with NMR rotary ratchets' mechanical harmonic oscillators shifted at *π rad*. The Fijalkowski engine has a simple and low cost supercharging system, which may have compact volume and the freedom to position its components. The HEV may have lower values of under-bonnet (under-hood) temperature.



(A) (B)

Fig. 2. Principle layout of the Fijalkowski engine with its LM-RM/RM-LM and RM-RM NMR mechatronic commutator transverse (A) and longitudinal (B) sections – two- or four- or even five-stroke thermodynamic cycle rigidly connected twin-opposed piston configuration

The Fijalkowski engine may have small dimensions, but a lot more power than a conventional reciprocating IC engine does. With small cylinder sizes (three times smaller than a conventional reciprocating IC engine has), this particular crankless reciprocating IC engine may develop the power *2 - 3* times more than a conventional one. This crankless reciprocating IC engine may be describing as *'square'* – a term indicating that the bore and stroke are equal. The Fijalkowski engine may have a high velocity, it may have no C^2M but may have only piston rods and pistons, and it may be successfully utilised in technologies and in productions that necessitate high-velocity small-size crankless reciprocating ICE

2. The Fijalkowski Engine Conception

An advanced **hybrid power source** (HPS), termed the Fijalkowski engine has been at once preferred from other solutions with conventional crankshaft reciprocating ICEs.
In this HPS, that is, the Fijalkowski engine (see Fig. 2) with its silent '*four-in-one*', electronically commutable, magneto-electrically-excited, high-temperature superconductor, brushless AC-DC /DC-AC macrocommutator **interior permanent magnet** (IPM) flywheel/damper generator /motor, may be provided **chemo-thermo-mechano-electrical** (CH-TH-M-E) or CH-TH-M energy conversion for HE AWD DBW propulsion.

At the very heart of this novel HPS is a **nano-magneto-rheological fluid** (NMRF). This is essentially suspension of micro-sized, magnetically polarisable nano-magnets *'embedded'* on micro-particles in oily-fluid or other liquid. Under normal operation conditions, NMRF is a free-flowing liquid with a consistency similar to that of ICE oily-fluid [4]. Exposure to a magnetic field, however, may transform the NMRF into a nearly solid state in milliseconds.

Just as quickly, the NMRF may be returning to its liquid state with removal of the magnetic field. The degree of change in an NMRF is proportional to the magnitude of the applied magnetic field. When subjected to the magnetic field, an NMRF actually develop yield strength and behave as *Bingham* solids. The flow ratio of NMRFs may be varying by the application of a magnetic field as shown in Fig. 3 [4].

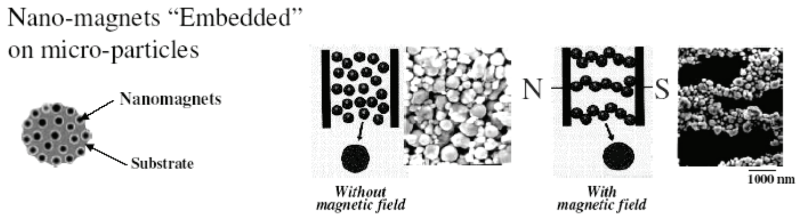


Fig.3. Nano-magneto-rheological fluid (NMRF) action
[Source: CENTRO RICHERCHE FIAT; 4]

Advantages of working with nano-magnets over micro-particles are as follows:

- Reduced wear;
- Reduced aggregation;
- Reduced power consumption;
- Faster response time.

Applications may be as follows:

- High-speed NMR mechanical components;
- Active NMR shock absorbers (dampers);
- NMR rotary ratchets;
- NMR brakes;
- NMR clutches.

The change may appear as a very large change in effective viscosity. NMRF is similar to a **giant-electro-rheological fluid** (GERF) but is from *20 ÷50* times stronger [5, 6]. It may also be operating directly from low-voltage (*14* V_{DC} or *28* V_{DC} or even *42* V_{DC}) automotive onboard **electrical energy distribution** (E^2D) system, and is far less sensitive to contaminants and extremes in temperature.

Applied to a novel NMR mechatronic commutator prime mover, that is, the Fijalkowski engine NMR technology may provide flexible mechatronic control capabilities in designs that may be far less complicated and more reliable than conventional crankshaft reciprocating ICEs.

With an efficient, low-voltage E^2D system and a few milliseconds response time, two fully-controllable NMR rotary ratchets, which are real bipolar mechanical valves in a novel NMR mechatronic commutator prime mover offer one of the most effective means available for interfacing mechanical components with a HE AWD DBW propulsion mechatronic control system [1, 7, 8].

The simple design of the NMR rotary ratchets, which are real NMR fully controllable bipolar mechanical valves featuring few moving parts translate into high reliability and quiet operation.

NMR rotary ratchets are real NMR rotary-ratchet composite mechanical harmonic oscillators provided with NMR fully controllable bipolar mechanical valves, operating with a mechatronic catch or a pawl that prevent the outer composite mechanical harmonic oscillator from slipping back and allow them to move in only single sense of rotary direction (rotation).

They are smooth acting; proportional brakes that are more compact and require substantially less power to operate than magnetic-hysteresis or eddy-current ones. Their simplicity and ease of mechatronic control makes them a cost effective choice for a novel NMR prime mover. They may be capable of high-torque and low-velocity, and can be used in lock/unlock applications.

The author has focused attention on the complexity as well as physical mass and size of the conventional IC engine's gudgeon-pin arrangement, the close tolerances entailed in their manufacture and time spends in assembly. He conceived and developed an advanced HPS, termed the Fijalkowski engine that is nearly conventional except that its pistons and their sliding followers (piston rods) are rigidly connecting (see its transverse section in Fig. 2 (a).

The Fijalkowski engine in question may have eight ICE's cylinders that are arranging co-axially with the ICE output shaft and rotate the latter by means of two NMR rotary ratchets and single NMR rotary clutch on it, and sliding followers (piston rods). The two pistons of each pair of ICE cylinders are of the opposed type and are therefore balancing dynamically. The Fijalkowski engine's pistons longitudinal travel that is LM may be converted to RM by unconventional cylindrical NMR rotary ratchets, with sliding followers (piston rods), mounted in the housing, engaging sinusoidal harmonic oscillators around the shanks of the piston assembly units, and splines couple the pistons' rotation to an output shaft passing through the axe of housing, as shown in Figs 2 and 4. If further development proves will be satisfactory, it could have a considerable impact on the Fijalkowski engine design.

For vehicular applications, a high thermal efficiency is important for good fuel economy, but it is also important that the power plant be simple and compact.

Preliminary design optimization studies are resulted in an advanced NMR mechatronic commutator, four-stroke thermo-dynamic cycle, reciprocating ICE concept with a relatively high thermal efficiency.

This IC engine has not generally been favoured for HEV applications in the past. However, use of a direct-coupled automotive silent *'four-in-one'* composite flywheel damper onboard **mechano -electrical** (M-E) generator/starter **electro-mechanical** (E-M) motor, with macro- and micro-electronic control of electrical energy transmission may make the constant IC engine's output shaft angular velocity running feasible, maintaining near-optimum ICE conditions over a wide power range.

The Fijalkowski engine, that is, the crankless reciprocating IC engine with reciprocating twin -opposed pistons – may have an output shaft connected to an NMR rotary clutch with MRF rotary ratchets, and several radially located opposed pistons engaging NMR rotary ratchets' mechanical harmonic oscillators and mechatronically controlled so that their power strokes balance opposing pistons (see Fig. 4).

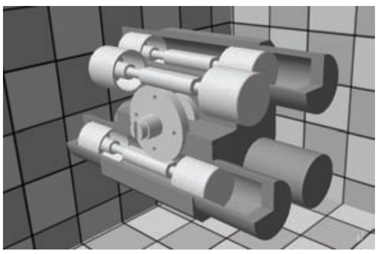


Fig. 4. Design animation of the Fijalkowski engine

The crankless reciprocating ICE may include housing, and an output main shaft radially connected to the NMR rotary ratchets. Eight ICE's cylinders in the housing may be spaced about the NMR rotary clutch's axis of rotation so that each cylinder may be coupled to a sliding follower (piston rod) that engages the NMR rotary ratchets so that the piston's movement between BDC may drive it round, thus imparting torque through the NMR rotary clutch to the output shaft.

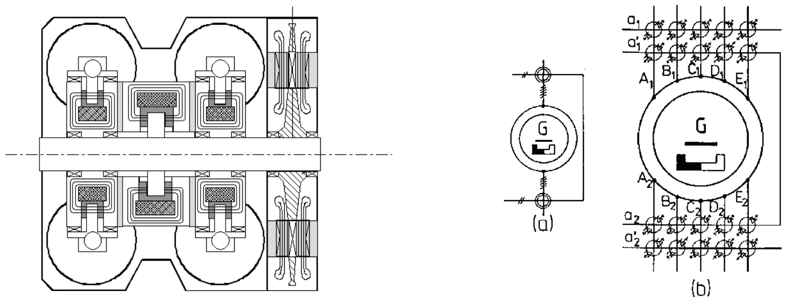
The Fijalkowski engine's thermodynamic cycle may be mechatronically controlled so that the power stroke of any one piston precedes that of the one, which is the most radially distant from that one and the approaching TDC. This may keep the crankless ICE well balanced. The Fijalkowski engine may have low friction vibration, overall mass and combustion pressure, resulting in a high efficiency, low NO_x emissions and component wear, and runs coolly and quietly.

The Fijalkowski engine will be an unconventional ICE, with eight ICE's cylinders of approximately the same length of the conventional IC engine's cylinders, giving the same power output of a conventional *'boxer'* IC engine; and eight or twelve opposed pistons with their sliding followers (piston rods) and rotating output shaft's *'four-in-one'* automotive silent, electronically commutable, magneto-electrically excited, high-temperature superconductor, brushless AC-DC /DC-AC macrocommutator composite-flywheel/damper onboard generator/starter motor that may directly convert into electrical energy the mechanical energy supplied to the opposed pistons by the combustion of usual hydrogen or hydrocarbons.

As regards the CH-TH-M part of the Fijalkowski engine, it may have the following adventages:

- Use of the constant-volume four-stroke thermodynamic cycle principle;
- Use of automotive mechatronics to ensure starting, synchronization and delivery of usable mechanical energy, and the ability to ignite either of the opposed pistons on many short circular ICE cylinders;
- Use of ICE output shaft' with *'four-in-one'* generator/motor rotor's inertias to return the opposed pistons;
- Use of sliding-followers/output-shaft LM-RM/RM-LM and RM-RM mechatronic commutators in replacement C^2M, that may permit to eliminate the inlet (intake), and outlet (exhaust) valves, pushrods, lifters, cam-shafts, timing gear, timing belt or chain required in conventional ICEs; thus it may require fewer parts and may be simpler to manufacture and lowers consumption of metal reserves and may not require a separate ICE flywheel.

As regards the M-E/E-M part of the Fijalkowski engine that is, the *'four-in-one'*, automotive silent, electronically-commutable, magnetoelectrically-excited, high-temperature, super-conductor, brushless-type AC-DC/DC-AC macrocommutator composite-flywheel/damper onboard generator/starter motor (see Fig. 5).



(A) (B)

Fig. 5. Principle layout of the Fijalkowski engine – (A) that comprises its silent 'four-in-one', electronically -commutable, magnetoelectrically-excited, high-temperature superconductor, brushless AC-DC/DC-AC macrocommutator IPM flywheel/damper generator/motor – (B)

It may have two *2 x 5*-phase pentagon-connected wire-wound (slotted-core) disc-shaped outer stators and unwound IPM disc-shaped inner rotor (see also Fig. 5). Armature alternating voltages, which are real AC-DC macrocommutator-input alternating voltages, can be rectified to an armature direct voltage, that is, AC-DC macrocommutator-output direct voltage; or alternatively, an armature direct voltage, that is, the DC-AC macrocommutator-input direct voltage. The latter can be inverted to armature alternating voltages, which are real DC-AC macrocommutator's output alternating voltages modulated both in amplitude and frequency is **sinusoidal pulse-width modulation** (SPWM) mode to produce armature's sinusoidal phase-current waveforms into the electrical energy, or vice versa, in advantageous conditions as regards mass and volume as well as efficiency. The Fijalkowski engine may be designing to perform three key functions: reduce fuel consumption by *20 %* over previous reciprocating IC engines, increase drivability and minimize exhaust emissions. The first objective may be achieving by implementing the latest fuel HDI technology -- **common rail** (CR) -- involving mechatronically-controlled high-pressure injection. The Fijalkowski engine architecture may also be designed to reduce fuel consumption. The second objective is to get consumers to forget finally about the Fijalkowski engine's poor image. The HDI may provide *50 %* additional torque at low values of the Fijalkowski engine's output shaft angular velocity and adds more power while reducing noise and vibration. Bettered environmental performance may also be achieving. The Fijalkowski engine may be one of the cleanest reciprocating ICEs on the automotive market while offering considerable potential for further development in the future. Longitudinal section of the NMR reciprocating prime mover, that is, a '*crankless'* reciprocating, constant-volume two- or four-stroke thermodynamic cycle, eight-cylinder opposed IC engine termed the Fijalkowski engine is shown in Fig. 6.

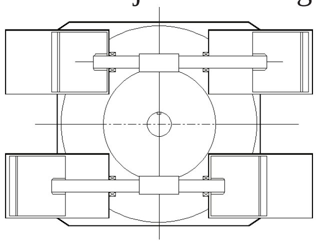


Fig. 6. Longitudinal section of the Fijalkowski engine

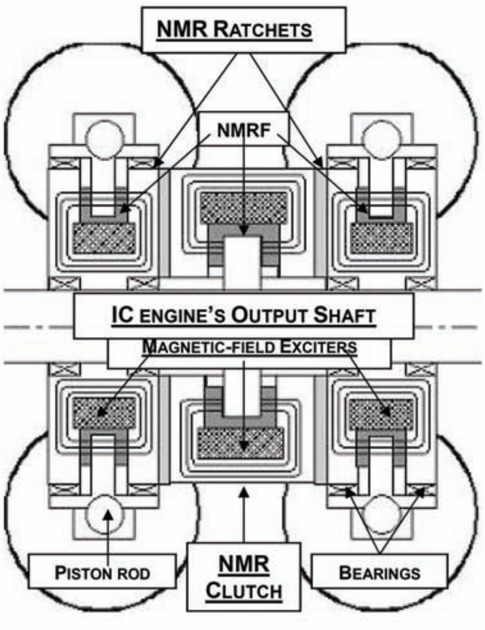


Fig. 7. Transmission drum that consists of an outer NMR rotary ratchet LM-RM/RM-LM mechatronic commutator acting as a floating composite mechanical harmonic oscillator, and an inner NMR rotary ratchet composite mechatronic common drum

Its transmission by which power may be transmitted from the ICE to the live axle(s) in an HEV, may represent transmission drum, that consists of an outer NMR rotary ratchet mechatronic LM -RM/RM-LM commutator (see Fig. 7), acting as a mechatronic LM-RM rectifier (during ICE operating action), or RM-LM inverter (during ICE cranking action), a floating composite mechanical harmonic oscillator, and an inner NMR rotary ratchet's composite mechatronic common drum.

The reciprocating motion of two parallel acting IC engine pistons' straight piston rods of the crankless reciprocating, constant-volume four-stroke thermodynamic cycle, eight-cylinder opposed reciprocating ICE may be transferred tangential to a pair of NMR rotary ratchets, which are real NMR rotary ratchet's fully-controlled bipolar mechanical valves. The NMR rotary ratcheting action may result from locking of the NMR rotary ratchet's composite mechanical harmonic oscillator when a magnetic-field exciter's current pulses solidify the NMRF. This may cause the inner NMR rotary ratchet composite mechanical common drum to rotate with uniform RM (see Figs 7 - 9). The uniform RM may be it turns transferred to a central NMR rotary clutch's composite mechanical common hub by a continuously variable-velocity NMR rotary clutch. The latter controls the mechanical energy throughout (see Fig. 7). Principle layout of the Fijalkowski engine's LM-RM/RM-LM and RM-RM NMR mechatronic-commutator's matrixer is showing in Fig. 8. Mechanical energy is mechatronically-controlled either by variation of the NMR rotary -clutch's magnetic-field-exciter current of the outer NMR rotary-clutch's composite mechanical common hub's NMR layer or by current-pulse controlled '*passing quickly*' the outer-clutch composite mechanical common hub from pushing to dragging current pulses. A very advanced novel HPS that is the Fijalkowski engine (see Figs 1 – 9) supply reciprocating mechanical energy to a pair of its straight piston rods that in turn supply reciprocating mechanical energy tangential to a pair of NMR rotary-ratchet's composite mechanical harmonic oscillators of the NMR rotary ratchets that is NMR rotary-ratchet's fully controlled bipolar mechanical valves. Synchronized NMR rotary-ratchet magnetic-field-exciter's current pulses latch the presently forward RM outer rotary-ratchet's composite mechanical harmonic oscillator to an inner NMR rotary-ratchet's composite mechanical common drum whilst the alternate outer NMR rotary-ratchet composite mechanical harmonic oscillator slips backward to reset.

Upon resetting, the situation is reversing and the previously latched NMR rotary ratchet deactivates and slips backward to reset whilst the previously slipping NMR rotary ratchet is re-activating to latch onto a forward stroke of the straight piston rod.

In this manner the sum of the two alternating NMR rotary ratchets action provides continuous forward RM to the central NMR rotary-clutch's composite mechanical common hub (see Figs 1 -- 9).

***Magnetic-field-exciter's electric-current sequencing for rotary motion* -** Reverse of RM can be easily realising by swapping NMR rotary ratchets' magnetic-field-exciter's electric-current -pulse sequencing as shown in Fig. 9. Thus, the sense of RM direction (rotation) is changed by skipping one pulse on the left-hand NMR rotary-ratchet's fully-controllable bipolar mechanical valve to allow the left-hand NMR rotary-ratchet composite mechanical flywheel cylinder to slip, whilst one NMR rotary-ratchet's magnetic-field-exciter's electric-current pulse is added to the right-hand NMR rotary-ratchet's fully-controllable mechanical valve to latch the right-hand rotary-ratchet's composite mechanical common drum to the backward RM. The NMR rotary-ratchet's magnetic-field-exciter electric-current-pulse sequence is in opposite phase and the transmission is in the drag mode supplies reverse torque to the central NMR rotary-clutch's composite hub.

Engine's output-shaft angular velocity control - The inner NMR rotary-ratchet's composite mechanical common drum contains the central NMR rotary-ratchet's composite mechanical common hub and is separating from its NMR layer by means of the diamagnetic-material layer. Transmission of torque between the inner NMR rotary-ratchet's composite mechanical common drum and a separate clutch magnetic-field-exciter's electric-current-pulse driver achieves the central NMR rotary-ratchet’s composite mechanical common hub. During acceleration, either of two methods of controlling the torque transmitted may be taken into account.

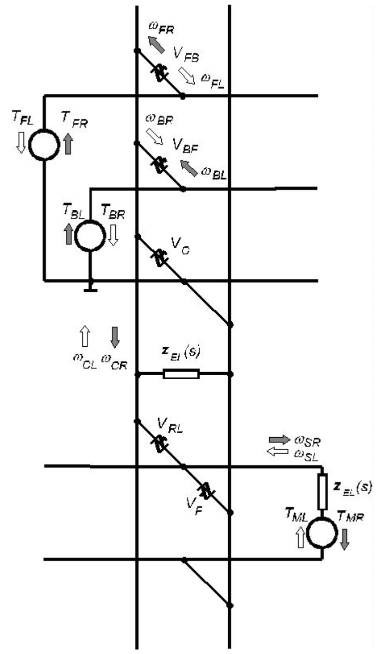


Fig. 8. Principle layout of the Fijalkowski engine’s LM-RM/RM-LM & RM-RM MRF mechatronic commutator matrixer: T_{FR}, T_{FL} -- NMR rotary-ratchet’s composite harmonic oscillators’ forward torques for right- and left-hand IC engine’s output-shaft rotations, respectively; T_{BR}, T_{BL} – NMR rotary ratchet’s composite harmonic oscillators’ backward torques for right- and left-hand IC engine main-shaft rotations, respectively; T_{MR}, T_{ML} -- AC-DC/DC-AC macrocommutator flywheel/damper generator/motor electromagnetic torques for right- and left-hand IC engine main-shaft rotations, respectively; ω_{FR}, ω_{FL} – NMR rotary-ratchet composite harmonic oscillators’ forward angular velocities for right- and left-hand IC engine main-shaft rotations, respectively; ω_{BR} , ω_{BL} – NMR rotary-ratchet composite harmonic oscillators’ backward angular velocities for right- and left -hand IC engine’s output shaft rotations, respectively; ω_{CR} , ω_{CL} – NMR rotary-ratchets and clutch’s composite mechanical common drum angular velocities for right- and left-hand IC engine’s output shaft rotations, respectively; ω_{SR} , ω_{SL} – NMR rotary-ratchets and clutch’s composite common drum angular velocities for right- and left-hand IC engine’s output shaft rotations, respectively

Either the NMR rotary-clutch’s magnetic-field-exciter’s applied voltage may be progressively raised to solidify the NMR, or the NMR rotary-clutch’s magnetic-field-exciter’s electric -current-pulse control techniques may be used, to vary the electric-current-pulse width, and/or frequency of force impulses between the inner NMR rotary-ratchet’s composite mechanical common drum, and the central NMR rotary-ratchet’s composite mechanical common hub by means of the RM-RM NMR mechatronic commutator acting as the bipolar four-quadrant RM-RM NMR mechatronic chopper, with the **pulse-width-modulation** (PWM), and/or the **frequency modulation** (FM).

***Engine’s output-shaft deceleration and reverse* -** The action for slowing the Fijalkowski engine comprises sequential operations. Firstly, by switching off the applied control voltage, the NMR layer between the inner NMR rotary-ratchet’s composite mechanical common drum and the output central NMR rotary-clutch’s composite common hub (see Figs 4 and 5) is de-activated. Secondly, the electric-current-pulse sequence is shortly tripping to give reverse RM to the inner NMR rotary-ratchet’s composite mechanical common drum. Thirdly, the NMR rotary-ratchet’s composite mechanical common drum is progressively re-connected to the output central NMR rotary-clutch’s composite mechanical common hub by one of the methods mentioned above to transmit reverse torque to decelerate the Fijalkowski engine. This introduces another unique feature of the advanced NMR mechatronic commutator, twin-opposed-piston-type reciprocating ICE. If the deceleration torque is continuing after the reciprocating IC engine has come to a halt, the Fijalkowski engine may begin to move backwards.

This can facilitate parking/deparking and HEV manoeuvring. It should be pointing here that the conventional AWB BBW dispulsion mechatronic control system might have to be retained for emergency stopping at least.

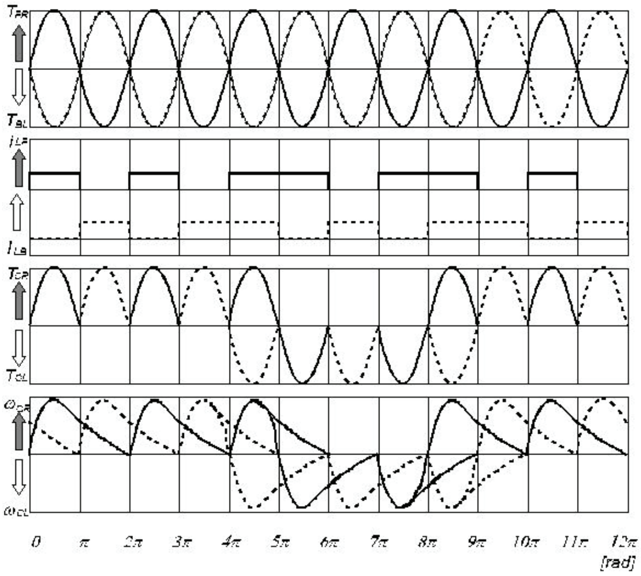


Fig. 9. Principle layout of the Fijalkowski engine 's NMR LM-RM/RM-LM & RM-RM mechatronic commutation waveforms of the Fijalkowski engine 's NMR LM-RM/RM-LM & RM-RM mechatronic commutator matrixer: T_{FR}, T_{FL} -NMR rotary-ratchet's composite mechanical harmonic oscillators' forward torques for right- and left-hand IC engine output shaft rotations, respectively; T_{BR}, T_{BL} – NMR rotary ratchet's composite mechanical harmonic oscillators' backward torques for right- and left-hand IC engine's output-shaft rotations, respectively; T_{MR} , T_{ML} -- AC-DC/DC-AC macrocommutator IPM flywheel/damper generator/ motor electromagnetic torques for right- and left-hand IC engine's output-shaft rotations, respectively; ω_{FR} , ω_{FL} – NMR rotary-ratchet composite mechanical harmonic oscillators' forward angular velocities for right- and left-hand IC engine's output-shaft rotations, respectively; ω_{BR} ω_{BL} – NMR rotary-ratchet composite mechanical harmonic oscillators' back-ward angular velocities for right- and left-hand IC engine's output-shaft rotations, respectively; ω_{CR}, , ω_{CL} – NMR rotary-ratchets and clutch's composite mechanical common drum angular velocities for right- and left-hand IC engine's output-shaft rotations, respectively; ω_{SR}, ω_{SL} – NMR rotary -ratchets and clutch's composite mechanical common drum angular velocities for right- and left-hand IC engine's output-shaft rotations, respectively

3. The Fijalkowski Engine Advantages Vs Conventional Internal Combustion Engines

As compared to the conventional reciprocating ICEs, the Fijalkowski engine has the following advantages:

- It does not have C^2M (there is no necessity to utilise ICE's lubrication oily-fluid), crank-case, cooling jacket or coolant; the demands to the metal or ceramics that the block of cylinders are made of are thereby be lowered;
- It does not have a radiator, an M-P fan, a M-F pump, a cylinder head, an overhead camshaft or all auxiliary systems accordingly;
- The torque of the efficient force in it may be increased many times without increasing the piston's power stroke; for example, if a conventional reciprocating ICE has *1.5 revs* during idle strokes in the working range, in it there are no idle strokes at all; in it the torque may sharply be increased because of the jet of the exhausts;
- It will have virtually no vibrations that the present conventional reciprocating ICEs with a C^2M have and that eventually destroy the driveshaft and weaken the joints in HEVs;
- Without the C^2M, it may almost perfectly be balanced, reducing bearing loads to a mini-mum;

- Without the side loading common to conventional reciprocating ICEs, it may improve mechanical efficiency by 5 to *8 %*, as were demonstrated in estimations, according to its inventor;
- A threefold increase in power-to-mass over the Diesel engines, and that it may be run in reverse as an M-F pump or M-P compressor or even an M-F pump.

What is wrong with the highly developed conventional C^2M? Nothing at all is with the crankshaft. The problem is the *'mechanism'* remains with the statement that the piston connecting rods flip from side to side with each cycle, in effect shortening their length in the process. If ones imagine that the crank is extremely smoothly, the *'big-end'* bearing may be described a sinusoidal motion, in view of the fact that the *'flipping'* has altered it. For illustration of this effect, the Fijalkowski engine's *'sinusoidal'* harmonic piston motion compared with the conventional reciprocating ICE's crankshaft driven piston motion is exemplified in Fig. 10.

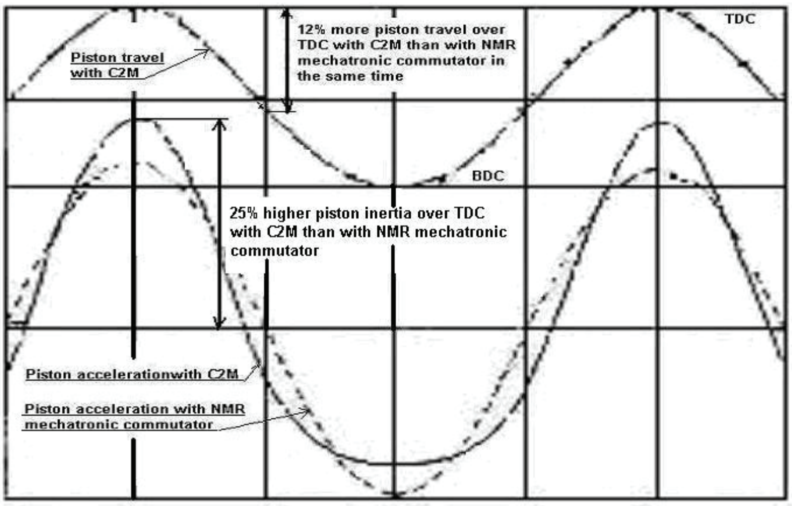


Fig. 10. The Fijalkowski engine's 'sinusoidal' harmonic piston motion compared with the conventional reciprocating ICE's crankshaft driven piston motion

Are the conventional C^2M mechanisms really so defective? No if drivers do not necessitate higher values of the ICE's output crankshaft angular velocity, and they may take steps to prevent continued dangerous resonance. Increased values of the IC engine's crankshaft angular velocity mean increased ICE power output – without an increase in size and mass. For example, the average crank reciprocating ICE is approaching its possibility at *12,000 rpm* – the average crankless reciprocating ICE with the *'NMR mechatronic commutator'* that is the Fijalkowski engine, may be composed with *20,000 rpm.* The NMR ratchet mechanism is efficient, it is smooth and it is easy to engineer. It may reduce the number of significant moving parts, it doesn't necessitate high-pressure oily-fluid lubrication, it's less expensive, and it requires less skill, and takes precise *'sinusoidal'* harmonic motion as the C^2M (see Fig.10), so it doesn't generate spurious harmonics, and the piston movement is more efficient, a *'plus'* that may rise with the crankless reciprocating IC engine's output-shaft angular velocity, to become very significant at *20,000 rpm*.

NB: Although *20,000 rpm* seems very fast by modern reciprocating IC engine standards, the Fijalkowski engine may be expected to reach *40,000 rpm* with further development.

Controllable NMRF stems are interesting because of their ability to provide simple, quiet, rapid-response (within few milliseconds) interfaces between mechatronic controls and mechanical systems. The ability of controllable NMRF to be directly utilized as fast-acting, NMR ratchet's fully-controlled bipolar mechanical valves (with no moving parts) in the NMR mechatronic commutator has been one of the principle motivating factors for the development of such NMRFs. The Fijalkowski engines in the *20,000 – 40,000-rpm* range may be using for stationary applications such as **distributed generation** (DG), **combined heat and power** (CHP), and shaft power as well as other stationary power plant applications. Let us look at the negatives. It looks funny, seems to be the most common reaction, but the author may skip that one. It does necessitate lateral stabilising *'oily-fluid slides'*. This is because a piston must have a little *'play'*, that is to say, that it must not scrape the piston walls, and because the *'rings'* those may be employed to effect this gap without loss of compression have to allow for thermal energy (heat) expansion, a tiny amount of *'slap'* may occur at mid-stroke, just when the piston rods alter a sense of motion direction. This may be adequately dampening out by the slides (which may constantly be feeding with oily-fluid) except when the dreaded resonance may occur. However, because the assembly may have a very simple, and fundamental resonant frequency, and because the *'whole'* design of the crankless reciprocating ICE, M-F pump, or M-P compressor, and F-M or P-M motor may recognise the necessity to stay away from this problem, the NMR ratchet mechanism may be equipped with *'resonance dampers'* – the universally accepted *'best method'* of dealing with unavoidable resonance problems. A quick look at the animation sketches (see Figs 1 and 4) may reveal all. What the author might have thought may be a crankless reciprocating ICE's combustion chamber with an air inlet and exhaust gas outlets, a fuel injector and a couple of spark plugs (with an excess of air) – may be also a *'tuneable'* damper. There may be a theoretical *'resonance'* hazard, but by *'tweaking'* the liquid fuel input, and the exhaust port trimming and duration, resonance amplification may be evading. The conventional C^2M are a relatively simple mechanical device to build, and with its soft bearings and high-pressure oily-fluid cooling system, it is made to work well enough for most applications. On the other hand, the advanced NMR mechatronic commutator has to be precision-engineered, with significant attention given to stress relief.

4. Conclusions

A generation change in C^2M is taking place in the entire world. The author has been performed **research and development** (R&D) work on an advanced NMR mechatronic commutator, reciprocating IC engine, that is, two- or four- or even five-stroke thermodynamic cycle, twin-opposed piston, crank-less reciprocating IC engine termed the Fijalkowski engines for over twenty years [1 - 3].

In most conventional reciprocating IC engines, the reciprocating motion of the pistons drives a rotating crankshaft. The notable exception to this general configuration; the Fijalkowski engine, may utilise an NMR mechatronic commutator instead of M-RM/RM-LM **mechano-mechanical** (M-M) commutators, those are C^2M. Compared with earlier LM-RM/RM-LM M-M commutators, those are C^2M; NMR mechatronic commutators are more practice-oriented, especially from the viewpoint of the operating convenience and space requirement of ultra-modern innovative NMR mechatronic techniques.

The LM-RM/RM-LM and/or LM-LM or RM-RM NMR mechatronic commutators adapt the characteristics of the mechanical energy to the operation requirements. The inventor is ready to negotiate with all interested parties regarding the application of this invention to manufacture. He is currently seeking seed funding from investors and government grant funds to build an alpha-prototype to establish the feasibility of proposed high-efficiency crankless opposite-piston reciprocating IC engine.

The experimental physical model of the Fijalkowski engine that the author will be offering ought to be assembling and tested. Average capacity of the experimental physical model of the Fijalkowski engine will be *25 kW* with *2,000 rpm*. The objective of this paper is to get feedback by exciting interest from those HPS (prime movers) designers who are working in the automotive, aerospace, marine and other industries. The Fijalkowski engine may be much more practical as conventional, reciprocating IC engines and likely to be manufactured by the automotive, aerospace, marine and other industries in the not-too-distant future. Such is the hope of the author who is working towards this goal utilising several artificial intelligence innovative mechatronic techniques.

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