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# Review on Free Piston Engine

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***Abstract*— The research of the Free-Piston Engine is taking up pace since the last two decades mainly carried by the Dutch companies NOAX and the Innas. The research in free piston engines has recently concentrated on hydraulic versions but some development in electric version has also been reported. This seminar mainly discusses the case study of the CHIRON (Pronunciation ky'-Rahn) Free Piston Engine, which is a hydraulic free piston engine developed by the Dutch companies Innas, and NOAX. CHIRON in the Greek mythology was a Centaur: neither a horse nor a man but a synthesis of a man and a horse. Similarly, the CHIRON discussed in this paper is neither an engine nor a pump: it is a combination – or better – an integration of an engine and a pump. In CHIRON the combustion energy is directly converted into Hydraulic energy. The CHIRON features direct electronic control of the injection parameters, the flow, and the compression ratio. The flow output is controlled by means of Pulse Pause Modulation of the piston frequency. The CHIRON is designed for the common pressure rail systems. In these systems, the hydraulic energy is supplied through a common rail. Special attention will be paid specific characteristics of the CHIRON compared to conventional engines and pumps.**

***Index Terms*— Piston, combustion cylinder.**

## I. INTRODUCTION

Complexity is never a goal in designing a new product. Products are designed to have low fuel consumption and reduced emissions and most importantly to satisfycustomers. Yet, the products are complex though the simpler solutions are feasible A good example is the motor pump combination one can find on site machines. In these machines, the energy of the combustion process is converted in to mechanical energy by means of a piston. On the other side, the mechanical energy is converted in to hydraulic energy by translating piston. If we are able to connect the combustion piston directly to the hydraulic piston, then we can eliminate all mechanisms in between. This would then result in the 'free piston engine'. However, the currently the engine and pump are defined as two separate machines, both having rotating shaft to connect one machine to the other. This problem arises due to the reasons that the hydraulic industry is relatively young and when hydraulic motors and pumps arrived in the market, the crankshaft engine, mechanical drives and the electric motor had already defined a quasi standard; the rotating shaft.

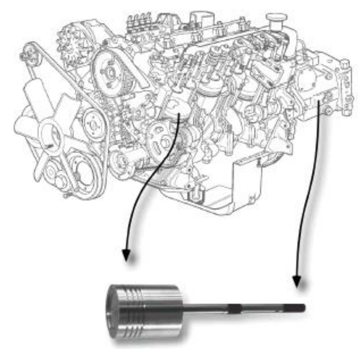

***Figure: Free Piston Combination of Combustion Piston and Hydraulic Plunger***

The hydraulic industry had to adapt to this 'standard', especially since in most cases the hydraulic systems were seen as an accessory, leaving the main drive functions to gears, chains and belts. Furthermore, the diesel engine was already produced in large quantities and there was no reason to construct a new engine for the small beginning hydraulic market.Nevertheless, many attempts have been made to design and built a combination of an engine and a pump without the mechanical complexity of piston rods and crankshafts. Since the combination of the combustion piston and the hydraulic plunger is not connected to a mechanism, and the combined piston has the degree of freedom in the axial direction, these machines are called as the 'free piston engines'.

### 1.1. Free Piston Engine vs. Conventional Engine

Reasons, why there are research and development activities

 

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concerning the hydraulic free piston engine, are based on the benefits, which could be achieved by the free piston concept. The HFPE (Hydraulic Free Piston Engine) has some fascinating advantages over the conventional crankshaft engine – hydraulic pump combination, CSEP (Crank Shaft Engine Pump):

The power density of the HFPE is higher than the CSEP; this means less weight and less space required by the engine.

Lower friction losses, because of fewer parts and piston have no side forces, which are induced by crank mechanisms.

The last but not least is the price of the engine because of production costs, which are much lower in the HFPE because of simple design. The lack of crank mechanism creates some disadvantages as well, the control system have to be more complicated than in the conventional engines. The compression ratio is indefinite and it depends on the energy balance of each stroke. The low emission level and efficient burning require controlled piston motion. On the other hand, reliable compression ratio control enables the optimization of the compression ratio in different operation conditions, which is not possible with conventional engines. The other disadvantage of the HFPE is the lack of controllability of the output of the HFPE compared to conventional engine-pump combination because the pump is constant displacement or step wisely variable displacement pump.

## 2. CHIRON Free Piston Engine

### 2.1 Descriptionofthe Engine

The main design characteristics of the CHIRON are:

- Single piston configuration
- Stepped hydraulic piston with three piston areas:
- The compression piston for supplying the compression energy to the piston
- The pump piston which delivers part of the effective hydraulic power
- The pump and the rebound piston which delivers the other part of the hydraulic power and limits the bouncing movement of the piston in the bottom dead center due to the compressibility of the oil
- Flow control by means of pulse pause modulation (PPM) of the piston frequency
- Direct injection, compression ignition
- 2-stroke, loop scavenged, naturally aspirated
- Variable compression ratio
- Closed loop electronic control of the fuel injection
- Bore combustion cylinder: 110 mm
- Variable stroke: nominal 120-125 mm
- Pump pressure260-320 bar
- Piston frequency 0-42 Hz
- Net effective flow output: 0-35 L/min
- Dimensions:
- Length: 82 cm
- Height: 35 cm
- Width: 30 cm
- Dry weight: 90 kg

Above parameter that controls the piston frequency and consequently the flow output of the CHIRON (PPM or Pulse Pause Modulation Control).

### 2.2 Combustion Cylinder

The combustion part of the CHIRON is a two stroke naturally aspirated diesel engine with loop scavenging and direct fuel injection.

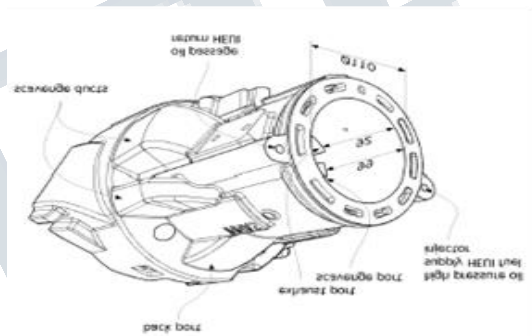

*Figure: Cylinder Block of CHIRON showingsome Dimension*

For injection system, a Hydraulic Electronic Unit Injector is used. The hydraulic actuation of the fuel injector is directly realized by means of the hydraulic pump partof the CHIRON. The supply and the return lines are integrated in the casting of the cylinder block.

### 2.3 Selling Ring

The combustion part is separated from the hydraulic part by means of sealing ring.

The major sealing function is realized by means of a sealing gap. At the right side of this seal stands the pressure of the high-pressure line. At left side the pressure of the low-pressure line is standing.

The step seals perform the secondary sealing function, sealing between the pressure line and the tank pressure. The excluder is needed to reduce the thickness of oil layer. Without the excluder the oil would get in to the scavenge case and finally in to the

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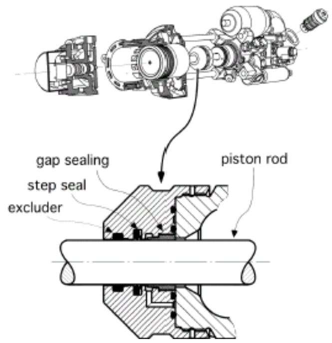


*Figure: Cross Section of a Sealing Ring*

combustion chamber. Not only would this be unacceptable to the hydraulic system, the leaked will also disturb the fuel control and deteriorate the emissions of the CHIRON. By means of the excluder, this is avoided.

### 2.4 Piston

The piston is assembly of several parts. The hydraulic piston is segmented. The rods and cylindrical pump and compression rings are fixed to the combustion piston by means of an interior rod and the tension bush. The support ring is needed to reduce the stress on the combustion piston. The pump and compression ring can move a little in the radial direction. The sealing gap is in the axial direction.

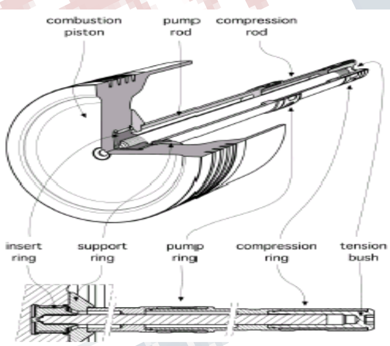


*Figure: Piston Assembly*

### 2.5 Piston Dynamics

The combustion part of the CHIRON looks like two-stroke combustion engine with compression ignition. Is difficult however to compare the combustion process of the CHIRON to a conventional engine.The piston of the CHIRON free piston engine unlike the crankshaft engine has a displacement, which is a result of the forces acting on the piston and the piston mass. In a simplified model the piston acts like a small mass attached between two springs: the nitrogen in the hydro pneumatic accumulators on one side and the fresh charge of air and the residual combustion products in the combustioncylinder on the other side. The natural speed is the natural frequency of this system, which is in case of the CHIRON about 42 Hz.The frequency of operation can be changed by stopping the piston in the BDC. As seen in the figure, the CHIRON FPE differs considerably from CSEP.At the TDC (Top Dead Center), in the free piston engine the piston displacement velocity and acceleration are directly related to the forces that act on the piston. Around the top dead center, the pressure in combustion cylinder dominates the resulting forces on the piston. At that point, the accelerating forces on the piston are at maximum. Consequently, also the acceleration has a maximum value around the TDC. In comparison to the crankshaft engine the piston acceleration in the CHIRON is about 9 times higher.

### 2.6 Combustion Process

If the piston has high velocity the gases in the combustion cylinder must also move at high speed. This will improve mixing of fuel and the air in the combustion cylinder. As a result, the rate of combustion will increase as well. Both the specific fuel consumption and emissions are lowered because of the faster combustion.In the free piston engines and specifically in CHIRON, the combustion parameters pressure and volume are interrelated in a two-way relationship:

As in crankshaft engine, a change of the cylinder volume results in a change of cylinder pressure.

But also, will an increase of the cylinder pressure results in an increased piston acceleration and therefore in a faster change of volume of the combustion chamber.

If the combustion in the CHIRON would have duration of about 5 ms, which would be normal for the engine of this size, the piston in the CHIRON would have moved around 100 mm and the exhaust ports would already have opened. In that situation, part of the combustion would not be completed due to the rapid decrease of the combustion pressure and temperature.In reality, the FPE piston has high acceleration because of high rates of heat release.

### 2.7 Indicated Efficiency

The high acceleration and high velocity of the piston and the combustion products have several effects on the efficiency. They are:

The high gas velocity results in high heat transfer coefficient, which results in increased heat loss and therefore a reduction of efficiency.

High piston velocity results in rapid drop of average temperature in the combustion chamber, which will reduce the heat loss and thus have a positive effect on the efficiency.

At an optimal timing of the start of combustion the rapid combustion results in an almost constant volume combustion process, which increases the indicated efficiency.

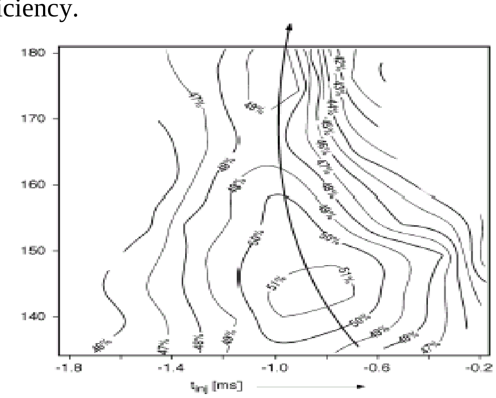

*Figure: Indicated Efficiency Measured on Earlier Model of the CHIRON.*

## III. APPLICATION OF 'CHIRON' FREE PISTON ENGINE

### 3.1 CPR-Systems

The free piston engine is developed for a new approach in the design in hydraulic networks called CPR(Common Pressure Rail) systems. In these systems the hydraulic motors and cylinders are no longer controlled by imposing a flow by means of a pump, like in current flow controlled systems. Instead, the motors and cylinders are connected to a common rail, which offers the same pressure to all the connected devices. The CPR configuration is similar to the electricity grid. Instead of common pressure, the grid offers a constant voltage to all the machines and devices connected to this grid and needs electric energy. On the other side of the grid, power plants are connected to the grid. These plants have one task: to maintain common voltage level of the grid. The grid itself separates the power plants from the power consumers. By means of a grid, a simple and clear definition is created for myriad electric devices, allowing combination of simplicity (the grid) and complexity (the application). In the hydraulic equivalent, the common pressure rail is the hydraulic grid, separating the hydraulic power plants from the motors and cylinders. The pressure of the hydraulic grid need not be constant. By means of the hydro pneumatic accumulators the pressure level of the CPR system can be controlled way. This energy stored in accumulators is used for power management and energy recuperation.

### 3.2 Application in The Fork Lift Truck

The CPR-systems have an advantage only if multiple hydraulic loads have to be controlled in the hydraulic system. This advantage is used in the forklift truck.

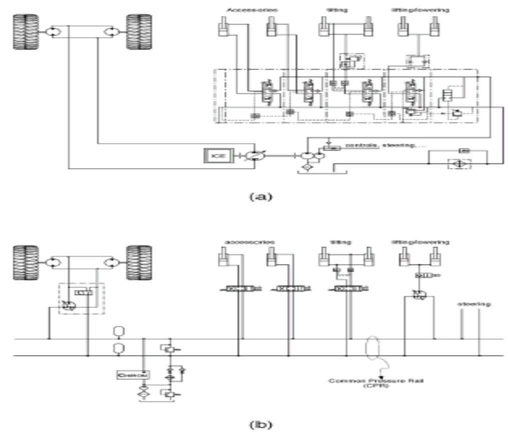

*Figure: Comparison of a Modern Load Sensing Hydraulic Diagram for a Forklift Truck (a) with aCPR system (b)*

This system: one for the hydrostatic wheel drive and one for the lift cylinders. Although this results in energy losses, the energy consumption of these loads is low compared to the other loads, and the throttle losses will not have a large effect on the total fuel consumption of the lift truck.

## IV. CONCLUSION

Although much work still has to be done, it has been proven that it is possible to avoid the mechanical complexity of the current crankshaft engines and hydraulic pumps and to build a new hydraulic unit with extra electronic control possibilities. These engines allow a better optimization towards lower fuel consumption and reduced exhaust emissions than current drive lines. Leading companies in the fields of construction machines and hydraulic components now continue the development of these Free Piston Engines. These free piston engines will turn out to be the best alternative for the IC engine driven pumps and will revolutionize the old concept of using a rotating shaft for a pump where a much simpler piston and plunger arrangement can suffice.

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