

## SONIC PROPULSION SYSTEM, AN OVERALL VIEW OF POSSIBLE SOLUTIONS

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**ABSTRACT** – Recent research work on alternative propulsion systems has demonstrated that hydraulic energy transfer is an efficient way for energy transfer. Other qualities like power density, continuous speed change, easy brake energy recovery and constant speed for the internal combustion engine sustain further research. The main disadvantage is related to efficiency. Research work done by different fluid power companies have shown that 95% efficiency of hydraulic devices can be obtained. Losses are mainly dependent on flow speed. In this case transferring energy using waves propagated in liquids are considered under the generic name of sonic systems. Wave propagation in liquids is a low dissipation process and dynamical high power density processes are also available. Different structures of sonic propulsion systems are presented in the paper and compared, considering performances, using multi-domain software. The experimental vehicle structure is considered an ATV. It is demonstrated that sonic propulsion systems can be defined as a separate development direction for alternative propulsion system considering the acceptable technological requirements and the performances obtained.

### INTRODUCTION

The sonic propulsion system, based on periodically dynamically phenomena in liquids, has an theoretical potential for high efficiency energy conversion system due to its low dissipation rate and high power density compared even to hydraulic systems. The paper presents an analysis of the suitability of this energy conversion system for vehicle propulsion. Solutions for wave generators and motors capable to propel the vehicle wheels are identified, resulting finally a general structure of the vehicle propulsion system.

### ACTUAL DEVELOPMENTS OF HYDRAULIC HYBRID SYSTEMS

Recent developments of hydraulic hybrid propulsion systems described by the US Environmental Protection Agency Program, (1), or the Scottish Company Artemis (2) demonstrate that hydraulic hybrid are a valid high performance alternative to conventional propulsion systems considering multiple criteria like dynamic performances, packaging, technology. The EPA research demonstrated that overall efficiency is obtained not only due to the simple use of the hydraulic propulsion principle, but also the internal combustion engine may be optimised, having its overall contribution with 30% efficiency improvement. Both research works revealed that there is more need for improving efficiency. The hydraulic energy generator is an important element having a major contribution to the overall efficiency of the fluid power system. The solution presented by Artemis (3) is based on an internal combustion engine driven radial piston pump having electromagnetic actuated valves. This technology assures efficiency by a large degree of control facilities needed for the large variety of running conditions of a vehicle propulsion system. Efficiencies of 40% associated

similar green house gases emission reductions are reported. These efficiencies are given by the minimum 95% efficiency of the hydraulic pump and motors developed by Artemis. INNAS, a Dutch research company (4), (5), uses also high efficiency technologies for the hydraulic pumps. The technologies of EPA, Artemis or INNAS are at present well developed having a high potential for applications, EPA together with the parcel delivery company running fleet test for this technology (2). The disadvantage in terms of efficiency and effectiveness of driving hydraulic rotating pumps by rotating conventional engines have been recognised by different research works. So INNAS, developed a free piston engine for direct generation of hydraulic energy from the translational movement of a piston that is directly actuated by the engine piston. The compression stroke is assured by the energy stored in a hydraulic accumulator charged during the expansion stroke. Easy control of a variable stroke can be obtained associated with engine efficiencies at part loads, the running condition that is used often for vehicle propulsion. Further research in order to improve combustion efficiency is conducted for application of external continuous combustion, resulting in a free piston Stirling engine or Liquid piston Stirling engine, conducted at Worcester University, USA (6). The main advantages of this structure are a low emission, efficient combustion of a large variety of fuels and a free control of piston movement. The few moving parts assure low maintenance effort.

All described structures have as focus a continuous flow of a pressurised liquid, but all this systems generate primarily a periodic time-dependent flow, that is damped by an dissipating procedure.

The sonic principle developed by Gogu Constantinescu presented in (7), (8), (9) is included as a fluid power transmission. The energy carrier is the wave propagated in a liquid. Considering a periodic time-dependent flow defined by a mean value and wave parameters, like amplitude and period, the sonic transmission is defined by a zero mean value for the flow. In this case dissipations during energy transfer are related only to losses associated with wave propagation that are normally very low. Additional dynamic phenomena are present in a sonic wave transmission system that can improve the overall energy transfer process.

#### THE PRINCIPLE OF THE SONIC PROPULSION SYSTEM

In figure 1 is presented the principle of the sonic propulsion system. A translational movement induced in a liquid trapped in a pipe is propagated through the liquid to the other end of the pipe where a piston transforms the wave energy in a translational mechanical movement that can be used both for a linear or rotational actuator, the sonic motor. This basic device is called a "sonic cell". The generation of waves in a liquid may be used in a pure sonic system, as described by the sonic cell, or overlapping this process with the conventional flow process of a hydraulic fluid power system, having as a goal the energy efficiency improvement.

The sonic system has to be considered from the point of view of the dynamic flow processes that are the bases of sonic systems

#### THE PROCESSES IN A SONIC SYSTEM

The sonic process is based on a dynamic (time-dependent) wave generation, wave propagation in a pipe system and wave reflection at the moving closed end, the active piston. Dissipation is caused by wall friction of the waves and wave reflection at local changes of the



The disadvantage of this structure is related to the translational – rotational change of piston displacement at internal combustion engine (i.c.e.) level and the rotational – translational to rotational movement at generator level.

A structure that avoids the previous disadvantage and adds efficiency improvement possibility due to a free control of the i.c.e. piston movement is the free piston solution (fig. 3). The working stroke drives directly the sonic generator's piston. Using the sonic propulsion principle the design of the general structure is simplified.

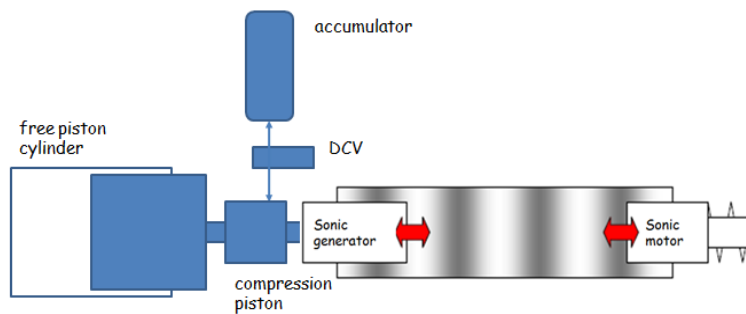


Fig. 3. The sonic cell with the free piston engine

Gas turbine application in order to use also the advantages of continuous combustion is a solution only for high frequencies. The high rotational speed of the gas turbine shaft and the need for eccentric solutions needed for wave generation raises problems of shaft balancing. The solution is characterised by very high power density because of high rotational speed.

A solution for low emissions is the application at generator level of a pneumatic energy source (fig.4). The compressed air is used to drive the piston of the sonic generator. Using different piston diameters for the air and liquid side, low flow – high pressure devices are obtainable that are particular suitable for sonic systems. In this case the low energy density of pneumatic storage is better used.

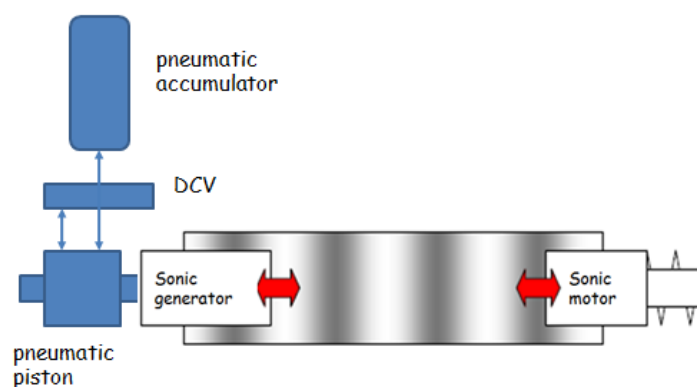


Fig. 4. The sonic cell with the pneumatic primary energy source

Special solutions may also be considered with the reserve of more detailed need for research. Examples, without pretending to indicate a complete list, are the magneto- hydrodynamic wave generation, the electrical capacitor discharge in a liquid or the controlled cavitations.

## THE OVERALL STRUCTURE OF THE SONIC PROPULSION SYSTEM

An alternative solution for present vehicle propulsion systems has to fulfil at least the properties of the actual conventional solution, adding as values a significant consumption reduction associated with lower emissions, including green house gases. Additional costs, reduction of installed power or displacement range are practically unacceptable. The sonic propulsion, in order to assure the propulsion needs has the structure in figure 5. The stored energy converted by one of the previous described methods is converted in wave energy. The amplitude of the pressure waves can be influenced by a proper structure, given by a parallel or converter type connection. The sonic motor converts the wave energy. The assincronus structure also a strat having a coupled load, so that a wheel placement of the motor can be considered. Acceleration can be obtained for a constant working frequency by influencing sonic parameters like capacity or coupled inertia. The rotation direction may be changed by changing the actuation order of the piston of the motors. A differential effect can be obtained by a parallel connection of the motors. Locking the “differential” is obtainable by a flow control valve.

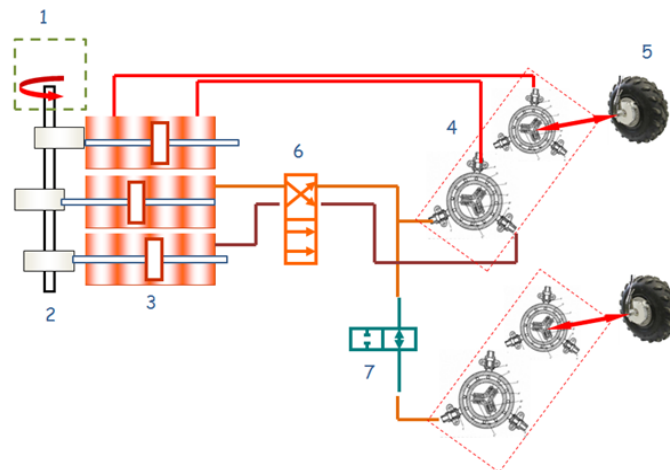


Fig. 5. . The sonic propulsion system

## CONCLUSION

The sonic propulsion system is a compact alternative to actual propulsion systems, having a variety of structural options. Its physical principle can be maintained for the whole transfer process. The wave generation principle is a low dissipation process, because of the very low medium flow speed. It is able to facilitate high energy intensive processes. Very important the prime mover that converts the energy of the fuel is very simple and allows efficient combustion processes and thermodynamically cycles. Pneumatic energy storage may also be a low cost, zero emission solution that can be considered, because the stored energy may be early in the conversion process changed to sonic energy. Energy recovery like brake and shock absorber are also easily integrated. The sonic structure in its overall image appears as an optimised hydraulic hybrid solution, integrating the advantages of this solution like power density, flexible placement of sonic motors, and modular construction for efficient technology.

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