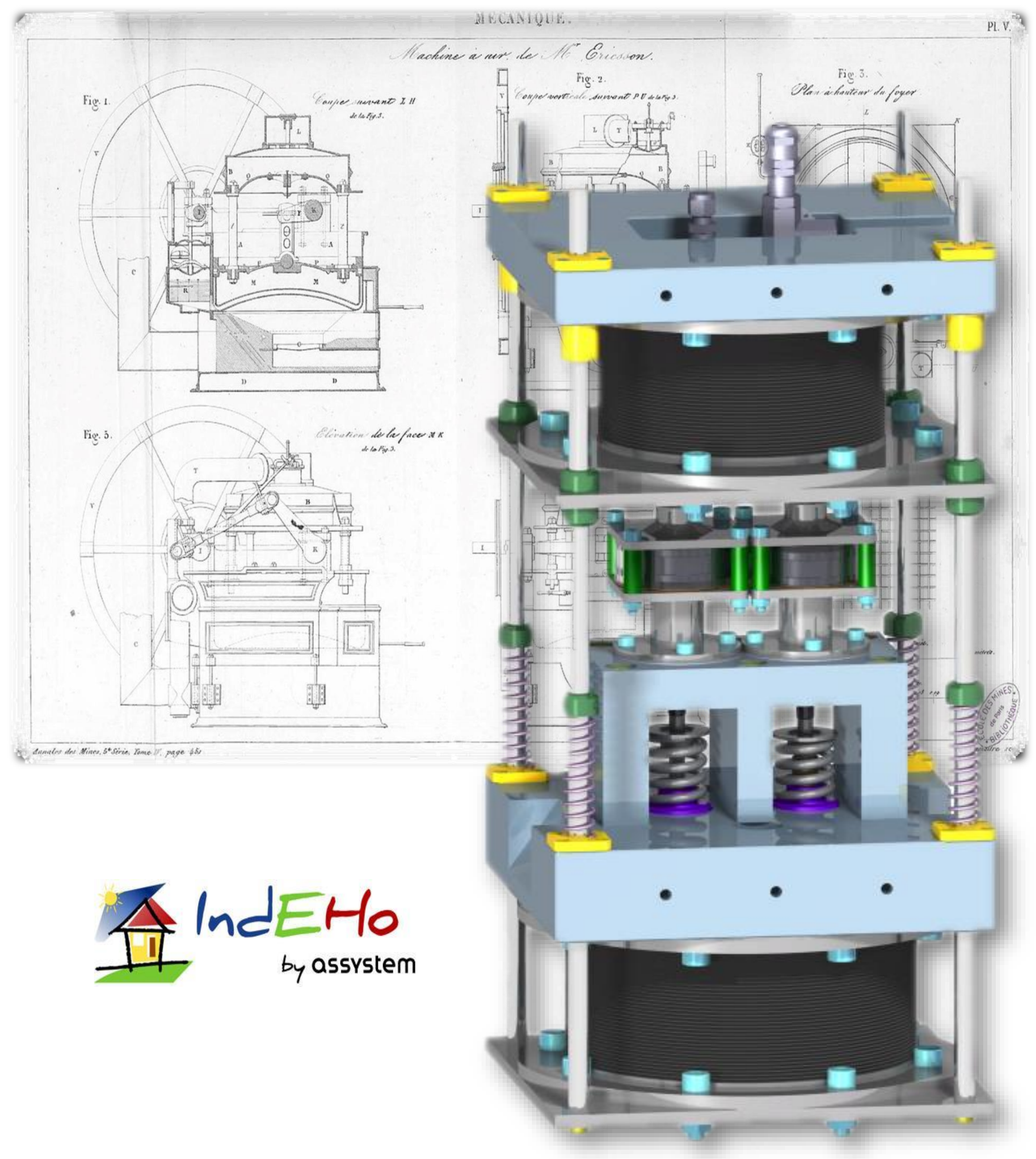
An experimental and theoretical comparison of Ericsson engine expander chamber

M. Doubs(1,*), G. Layes (2), P. Nika(2), F. Lanzetta(2), E. Gavignet(2), P. Ranc(2), M. Mille(3), T. Cartigny(3), B. Bryon(3)

* Corresponding author: mathieu.doubs@femto-st.fr



Introduction

The present world is facing a challenge of providing a sustainable development due to the increase in worldwide energy demand whereas the global fossil energy resources are diminishing. To meet that expectation, housing seems the main object for efficient actions and most of all, the first field for energetic savings. *Buildings are responsible for approximately 40% of the total world annual energy consumption*.

Assystem, an international engineering services consulting company, has made energy efficiency one of its priority. That is why it developed a self-sufficient building through the project IndEHo, that stands for **Ind**ependent **E**nergy **Ho**me project.

The IndEHo team is currently working on an **e**xternal **c**ombustion engine (EC engine), also named "**e**xternally **h**eated **v**alve **e**ngine" (EHVE), mainly based on the Ericsson cycle. Such family of engines, that includes the Stirling engine, was created in the 19th century but really used since the middle of the 20th century.

Nowadays, it can have major improvements thanks to advanced technologies and materials. Our version of the "Ericsson" EHVE which has been patented is a part of these improvements. As for all EC engines, some non-conventional heat sources can be used, such as solar, biomass or any waste heat from industrial process.

Since 2012, research works are conducted through a collaboration between the public research institute Femto-ST and the Assystem Company. Its objectives are the validation and improvement of the thermodynamic model of this new EC engine, through a set of tests done by different versions of an experimental engine. The present paper takes interest on the sole expansion chamber behaviour (presently a Brayton one).

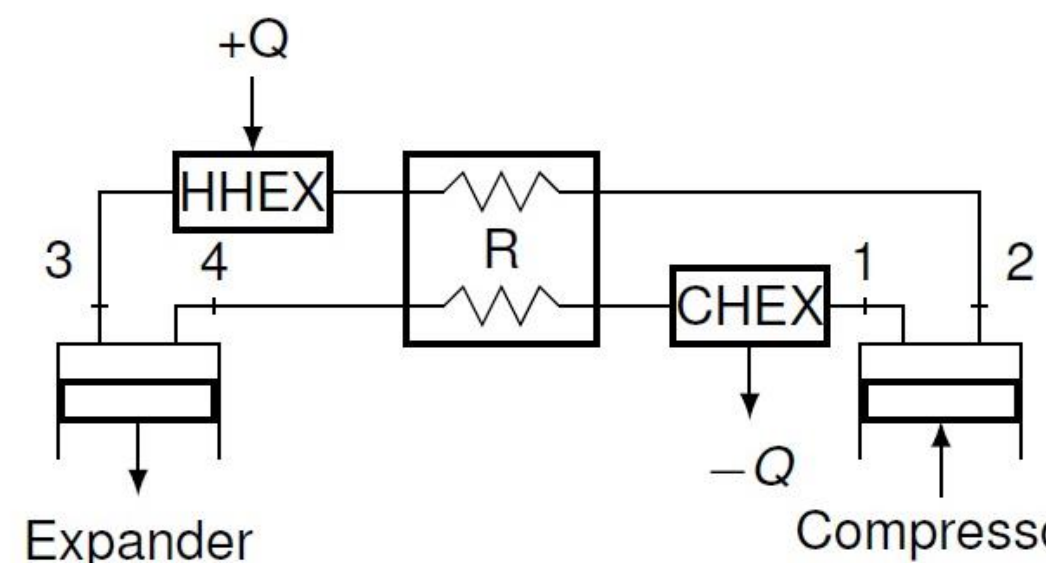


Fig. 1. Schematic representation of the engine

Operating principle

When the moving part of the compressor moves down, it allows the working fluid to enter the chamber through the opening of the suction valve (point 1).

When this mobile part reaches its bottom dead centre, the suction valve (1) closes. This indicates the end of the intake stroke. During the mobile part's ascent called the "compression stroke", the fluid is compressed until the discharge valve (2) opens, allowing the fluid to exit at higher pressure. The fluid flow is then heated throughout two heat exchangers. First, it passes through a heat recovery exchanger (R), that preheats the gas flow before entering in a "hot" heat exchanger (HHEX). Once heated and pressurized, the gas flow is ready to be introduced into the expansion chamber throughout an intake valve located in (3).

The injection of the gas into the expander occurs when its mobile part is at its top dead centre. When enough gas has been introduced, the intake valve (3) closes. The injected fluid is then expanded and at the same time pushes the mobile part of the bellows until its bottom dead centre. This constitutes the power stroke. That step can be controlled by either the displacement of the mobile part or the pressure within the expansion chamber depending on the chosen control parameter. The sequence of opening/closing valves as well as the load and the pressure before and after the expansion chamber - determines the operating point of the engine and thus its power and its efficiency. Obviously, any mechanical load, as a generator, can be connected to the mobile part to generate power. The return of the mobile part expelling the gas out of the expansion chamber through the exhaust valve (4), constitutes the exhaust stroke.

Before a new cycle is initiated by admitting new air into the compression chamber, the gas passes through a heat recovery exchanger (R) and then through a cold heat exchanger (CHEX).

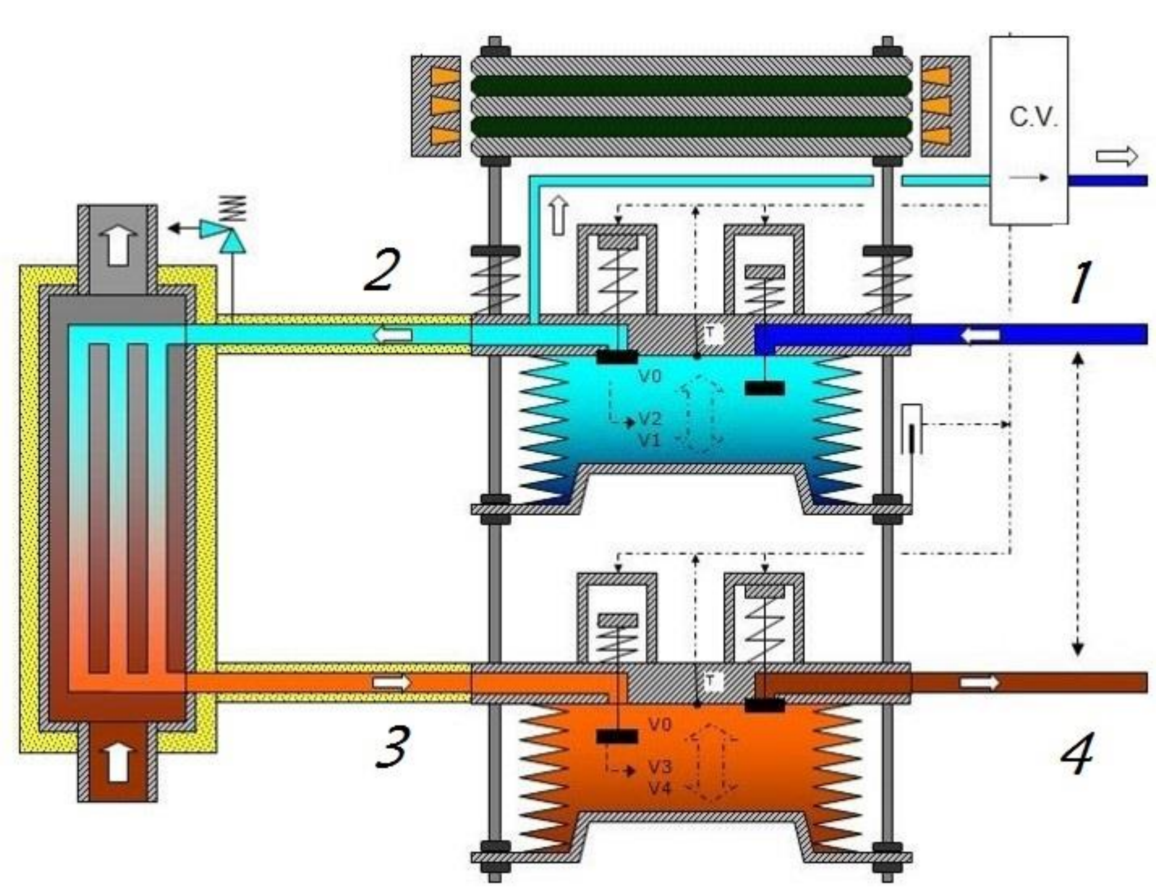


Fig. 2. Metallic bellows based external heat engine

It has to be noted that, if in the present configuration, the compression chamber isn't cooled and the expansion chamber isn't heated, the working theoretical cycle is the Joule-Brayton, as in the Ericsson M1833 engine. In the other case, if compression and expansion are done with some thermal exchanges, as in M1851 Ericsson engine, the working theoretical cycle is Ericsson one.

Introduction to a comparison between experimental and theoretical

The results of similar experiment have been compared to numerical simulation and have showed a good agreement (Fig. 3).

The model used for the simulation is a zero dimension one, based on a filling and emptying method. This model, presented in our article earlier, uses the classical equations of conservation of energy and mass for the entire machine. This applies for each subsystem, particularly for the valves where the conservation of mass law is completed by Saint-Venant equation. So the model is dynamic and implemented within a bond graph formalism.

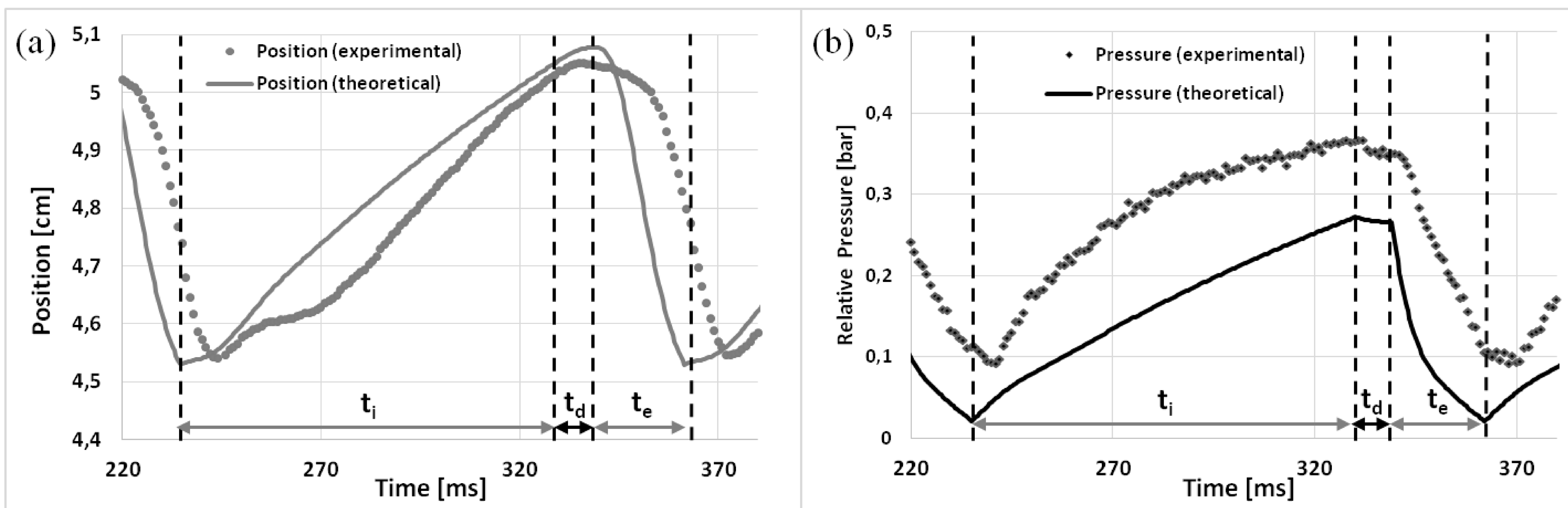
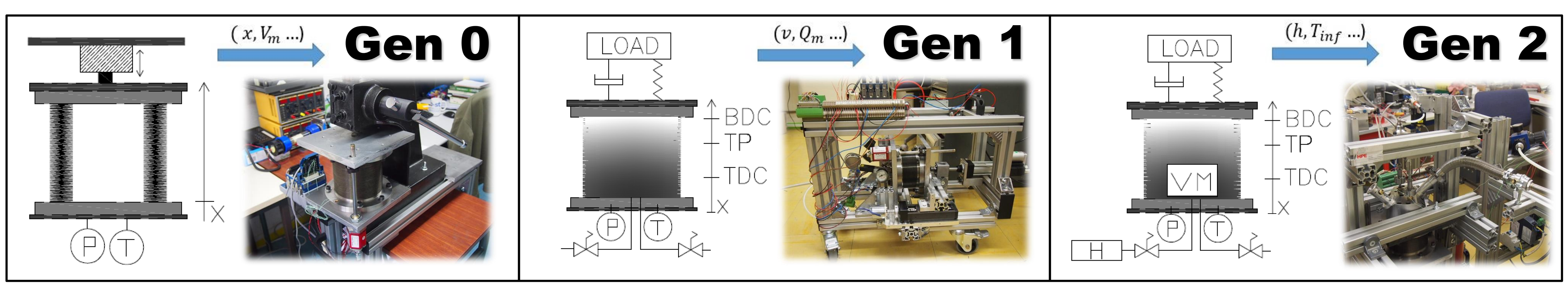


Fig.3 Comparison between the theoretical and experimental results for position of the bellows' bottom (a) and the bellows' pressure (b) for a single expansion-compression cycle. For a 8.3 Hz cycle composed by injection time of 80 ms, followed by a 15 ms expansion time and so, a 25 ms exhaust time.



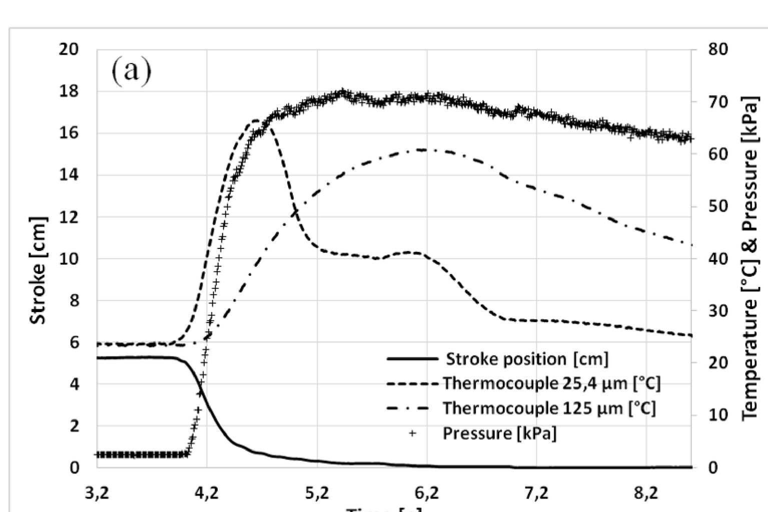


Fig.4 Comparison of thermocouples response regarding their size for a single high compression .

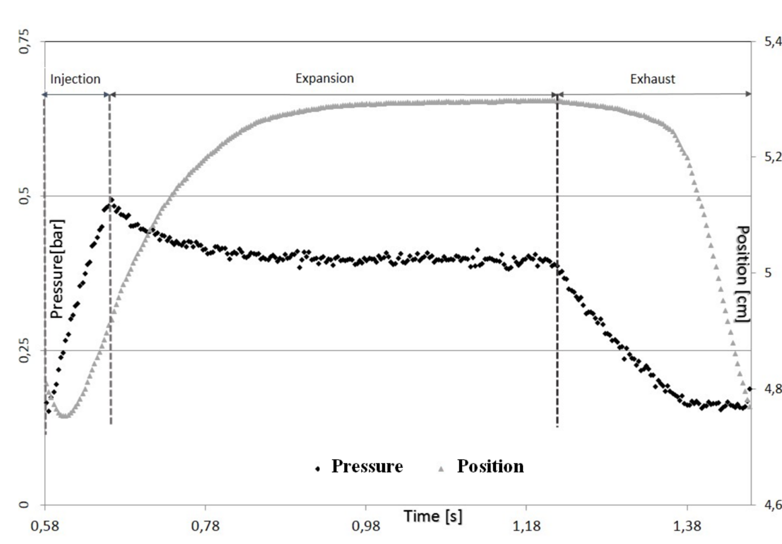


Fig.5 Relative pressure and bellows displacement as a function of time for a single input/output valves opening/closing cycle.

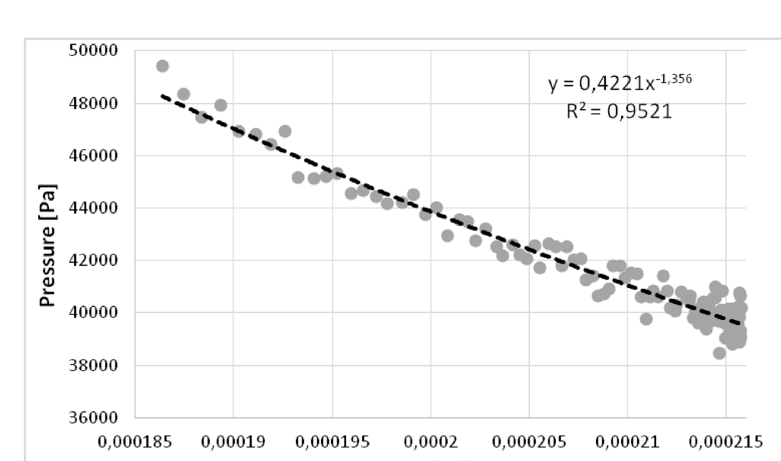


Fig.6 PV diagram of the expansion time with a dead volume of 0,2l

Overview of M1851 engine

M1851 engine, produces $2kW$ to $3kW$ with an efficiency of 2,5% at 30 to 50 rpm and 1,4 to 1,65 bar of pressure. Compressor's air is aspirated at $85{,}5°C$ and pulled out at $146{,}4°C$, expander's air comes at $244°C$ and goes out at $311{,}4°C$, the heater's temperature is $343°C$. Compressor diameter is $1240mm$ and expander diameter is $1504mm$ with same stroke of $230mm$.

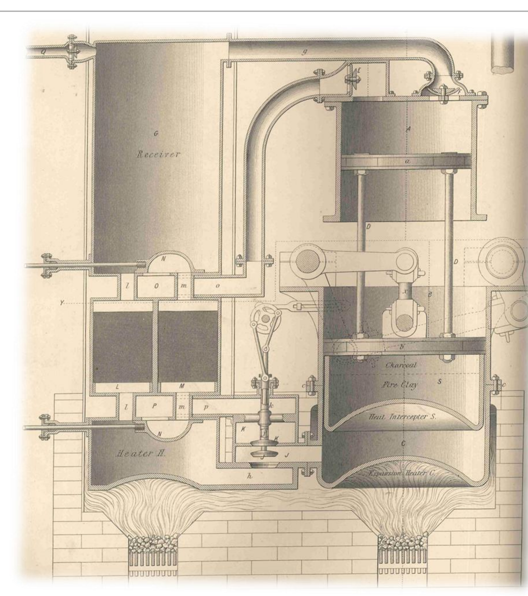


Fig.7 M1851 from The imperial cyclopedia of machinery (1853)

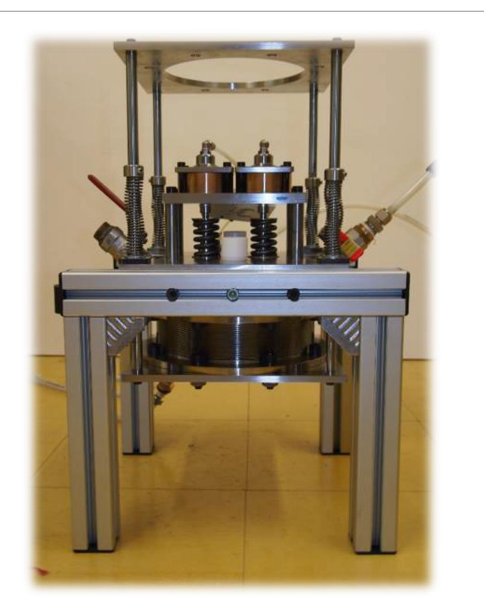


Fig.8 First assembly of our motor

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