LABORATOIRE D'AUTOMATIQUE DE MECANIQUE ET D'INFORMATIQUE INDUSTRIELLES ET HUMAINES
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Title: ***Heat transfer investigations during recovery thermal energy lost in the exhaust of an internal combustion engine to improve the performance of a Stirling engine***

In the automotive field, the efficiency of existing internal combustion engines does not exceed 35% on their best operating point. In the most cases, this efficiency is lower than 20%. Indeed, a significant part of energy losses is under the form of heat, which is dissipated by the engine cooling system and also through the exhaust gas. To recover some quantity of this lost energy, several technical devices can be considered, including external combustion engines (Ericsson cycle, Rankine cycle, or Stirling cycle). These thermal engines, are currently underdeveloped and key systems are mainly available for cogeneration applications of very high power (>100kW) for industrial companies where their operation requires steady state.

In term of micro-cogeneration, the automotive industry has so far been less studied, although this subject has now an important interest. To have a simplified idea, a Stirling engine (also called hot-air engine or hot gas engine) uses two rooms, a hot and a cold connected together by a regenerator and containing a working fluid (gas). This fluid across alternately these two sources of heat through the regenerator (a porous medium), which is the important key of the Stirling engine. The first room (expansion room) is supplied by a flowing hot gas and the second one (compression room) by a cold gas flow. The movement of each one of these pistons (in the both rooms), is mechanically synchronized by a crankshaft. Several types of this Stirling machine (configurations: Alpha, Beta, Gamma and free piston Stirling) can then be distinguished, by the arrangement of their pistons and their rooms.

In this thesis, the proposed study (which can be only preliminary and exploratory), can be an ambitious project (national and/or international). It could be, for example, the establishment of a practice thermal energy recovery system used in a "classical" vehicle equipped with an internal combustion engine (Fig. 1). However, before embarking on a such adventure, it will be necessary to develop a scientific approach and technical basis to explore possible ways for the improvement of such systems that can be adapted to new types of hybrid and/or fuel-efficient vehicles of the future. For this reason, in this thesis, some scientific and technological locks should be addressed.

Figure 1: Gasoline internal combustion engine (ICE) coupled via its exhaust gas line to a Stirling engine

From the scientific point of view, several problems related to energy quantification, optimization and control are still poorly known. In particular, how to model both globally and locally heat transfer under dynamic conditions during operation of a Stirling engine using heat recovery, how to optimize the valorization of the loosed thermal heat in exhaust gases to optimize the Stirling engine operation and its generator for generating electrical power?

On the technological side, some important locks as compactness of a Stirling engine and its implementation within a powertrain as well as the necessity of the presence of a hot source and a cold gas stream source nearby should be known.

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On the experimental side, a complete new setup acting as a test rig is currently implemented thanks to the LAMIH funding. This facility, actually containing an internal combustion engine (ICE), is coupled with a free pistons' Stirling engine via the ICE exhaust gas line. CFD simulations will concern the evaluation of heat recovery from exhaust gases to supply the hot source of the free pistons' rooms and the heat transfer of working fluid (gas) inside these cold and hot rooms of the Stirling engine. This working fluid, when crossing the Stirling engine regenerator, will operate this machine to produce a mechanical power before its conversion into an electrical power in order to dissipate it inside the vehicle (and to charge a battery for the case of a hydride vehicle). Experimental investigations will concern measurements of instantaneous temperatures, pressures and flow rates in several locations along the exhaust gas line and inside the Stirling engine.

Keywords: Heat and mass transfer, Fluid mechanics, CFD simulation, Stirling machines, Energetic optimization, Thermodynamic modelling, Heat recovery, ICE

Background of candidate: Expected PhD student candidate should have interesting knowledge on Fluid Mechanics, Thermodynamics, Energetics, Basic skills to undertake CFD simulations using commercial codes and basics of programming.

References:

[1] H. Hachem, R. Gheith, F. Aloui, S. Delprat, S. Paganelli (2019). Energetic and exergetic investigations of an innovative heat recovery exhaust system using a double acting type Stirling engine based on theoretical analysis. Int. Journal of Exergy 28 (3), 273-300, 10.1504/IJEX.2019.098615.
[2] H. Hachem, R. Gheith, F. Aloui, S. Ben Nasrallah (2018). Technological challenges and optimization efforts of the Stirling machine: A review. Energy Conversion and Management 171, 1365-1387.
[3] H. Hachem, R. Gheith, F. Aloui, S. Ben Nasrallah (2017). Optimization of an air-filled Beta type Stirling refrigerator. International Journal of Refrigeration 76, 296–312, https://doi.org/10.1016/j.ijrefrig.2017.02.019.
[4] H. Hachem, R. Gheith, F. Aloui, S. Ben Nasrallah, I. Dincer (2016). Exergy assessment of heat transfer inside a Beta type Stirling engine, International Journal of Exergy, Vol. 20 (2), 186-202.
[5] R. Gheith, F. Aloui, S. Ben Nasrallah (2016). Improvement of a non energy-consuming system: A gamma Stirling engine, Environmental Engineering & Management Journal (EEMJ), Vol. 15 (1), 133-141.
[6] R. Gheith, H. Hachem, F. Aloui, S. Ben Nasrallah (2015). Experimental and theoretical investigation of Stirling engine heater: Parametrical optimization, Energy Conversion and Management, Vol. 105, 285-293.
[7] H. Hachem, M. Creyx, R. Gheith, E. Delacourt, C. Morin, F. Aloui, S. Ben Nasrallah (2015). Comparison Based on Exergetic Analyses of Two Hot Air Engines: A Gamma Type Stirling Engine and an Open Joule Cycle Ericsson Engine, Entropy, Vol. 17 (11), 7331-7348.
[8] H. Hachem, R. Gheith, F. Aloui, S. Ben Nasrallah (2015). Numerical characterization of a γ-Stirling engine considering losses and interaction between functioning parameters, Energy Conversion and Management, Vol. 96, 532-543.
[9] R. Gheith, F. Aloui, S. Ben Nasrallah (2015). Determination of adequate regenerator for a Gamma-type Stirling engine, Applied Energy, Vol. 139, 272-280.
[10] R. Gheith, F. Aloui, S. Ben Nasrallah (2014). Study of temperature distribution in a Stirling engine regenerator, Energy Conversion and Management, Vol. 88, 962-972.
[11] R. Gheith, F. Aloui, S. Ben Nasrallah (2013). Optimization of Stirling engine performance based on an experimental design approach, International Journal of Energy Research, Vol. 37 (12), 1519-1528.
[12] R. Gheith, F. Aloui, M .Tazerout, S. Ben Nasrallah (2012). Experimental investigations of a gamma Stirling engine, International Journal of Energy Research, Vol. 36 (12), 1175-1182.
[13] R Gheith, F Aloui, SB Nasrallah (2012). Study of the regenerator constituting material influence on a gamma type Stirling engine, Journal of Mechanical Science and Technology, Vol. 26 (4), 1251-1255.

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