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An experimental and numerical analysis of the performances of a Wankel steam expander

Marco Francesconi[a,*], Gianluca Caposciutti[a], Marco Antonelli[a]

[a] Universitá di Pisa, D.E.S.T.eC., Largo Lucio Lazzarino, Pisa 56122, Italy

Abstract

In the last decades, the energy market increased its interest towards the smart grids and electrically isolated systems. These systems utilize small size power generator, which often feature volumetric expanders that are very robust and reliable for a wide range of operative conditions. In this work a study that focuses on a Wankel volumetric expander was carried out. In order to predict the extractable specific work from the expander, a thermodynamic lumped parameters numerical model was developed. The model was validated by means of experimental data obtained using water steam as working fluid. The experimental results encouraged the need to improve the research of this expander, as well as the capability of the numerical model to predict the effective performances of the device.

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Keywords:
Wankel Expander, Experimental tests, Numerical modelling, ORC technology.

1. Introduction

The increment of energy consumptions, the need to reduce pollutant emissions and the limited reserves of fossil fuels increase the necessity of energy production from renewable sources. In order to produce useful power, solar energy, biomass, geothermal heat and waste heat recovery are technologies that may provide low grade heat. In this context, the Organic Rankine Cycle is a suitable technology that allows the exploitation of these sources [1–3]. Considering low size plants, a key components of an ORC cycle is the expander whose performances and costs results in an higher plant efficiency, than using turbines [1,4–6].
As reported in [7,8], several devices, such as scroll and vane expanders, are suitable for low output powers (up to 10 kW), while reciprocating expanders are employed for power range between 25 and 100 kW. On the other hand, turbines are attractive to produce power higher than 1 MW [4]. Nevertheless, volumetric expanders are suitable for the systems in which a low vapor quality is obtained at the end of expansion process.

* Corresponding author. Tel.: +39-050-2217133; fax: +39-050-2217160.
E-mail address: marco.francesconi@for.unipi.it

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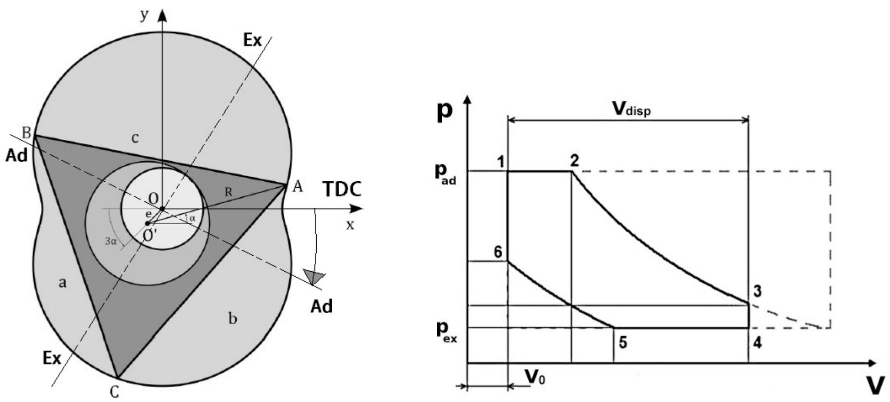
The literature reports several studies about different volumetric devices [8], even if only few prototypes are commercially available in the range 10-50 kW. In particular several studies investigated the performances of volumetric expanders for waste heat recovery focusing the analysis on piston, scroll and screw machines [9–11]. The design of a volumetric expander, obtained by a Wankel engine, was developed at Pisa University to match this power range. The technical feasibility of this project, was demonstrated considering previous studies [12–15]. Particularly, a Wankel expander may be suitable for technical applications because of a series of advantages in terms of compactness, economy and reduced mechanical vibrations [6]. Moreover, the main troubles due to wear of seals as well as poor fuel economy and emissions are avoided because of the lowest values of the operating pressure and temperature together with the absence of the combustion process.
Previous studies about the Wankel device investigated the effects due to the timing variation [16] and the influence of the discharge coefficient of the valves [17], while in [18] a comparison of the first experimental results, employing compressed air and saturated steam, was shown.

In this study, several experimental tests based on the use of saturated water steam as working fluid, were performed on the Wankel prototype. The main purpose was to investigate the global performances of the expander in terms of rotating speed, indicate cycle and mechanical power. The experimental data were then compared with numerical results predicted by a numerical model of the device and a good agreement was found. Particularly, the differences between the indicated cycle work simulated and measured were less than 15%. Finally, it was proved that the developed code may be suitable to predict the real performances of the Wankel expander fueled with organic fluid for ORC micro-generation applications.

2. Features of the Wankel prototype

The Wankel device was developed at the University of Pisa employing the bearings, the main shaft and the seals of an original Wankel engine used in karts and ultra-light flight vehicles. In order to increase the compression ratio, the original rotor was replaced by another one without cavities, while the stator was newly built to accommodate rotating valves. A pulleys system, connecting the engine to the shaft, drove the valves (Figure 2) whose timing was enabled by a vernier system. The first admittance valve is situated 17° after the Top Death Center (i.e. TDC) and the first exhaust valve is situated after 115 ° from the TDC; the other couple is symmetrically displaced. The geometry and the kinematic of the device (see Figure 1(a)) allowed to perform two thermodynamic cycles for each operating chamber during a full rotation of the rotor, requiring two intake and two exhaust valves overall. In particular, the stator shape of a Wankel device is determined by the ratio of of the value of the eccentricity e to the rotor radius R shown in in Figure 1(a).



(a) Wankel expander geometry. Ad and Ex are the admittance and exhaust valves position respectively

(b) A single thermodynamic p-V cycle

Fig. 1: General schemes of the Wankel expander system