Applied Thermal Engineering 141 (2018) 1020–1034

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

A review of scroll expander geometries and their performance

Simon Emhardt, Guohong Tian*, John Chew

Department of Mechanical Engineering Sciences, University of Surrey, Guildford, Surrey GU2 7XH, UK

HIGHLIGHTS

- R&D stages of different scroll expander geometries were identified.
- The performance of scroll expander with a constant wall thickness was investigated.
- The use of unconventional scroll profiles and their effects on performance was discussed.
- Scroll expanders with variable wall thickness scrolls should be further developed.

ARTICLE INFO

Keywords:
Organic Rankine cycle
Scroll expander
Built-in volume ratio
Pressure ratio
Variable wall thickness design

ABSTRACT

Scroll expanders are currently attracting interest for integration in small scale organic Rankine cycle (ORC) waste heat recovery applications and have been subject to significant research over the last two decades. The most common geometrical design uses a scroll profile generated by the involute of a circle with a constant wall thickness. A major disadvantage of this approach is that the increase of the geometric expansion ratio is constrained, since it is accompanied with a large increase in the scroll profile length and is associated with a decreased efficiency. In this paper, the published literature related to scroll expander geometry is reviewed. Investigations regarding the influence of varying scroll geometrical parameters on the performance of scroll expanders with a constant wall thickness are first examined. The use of variable wall thicknesses and their effects on the performance are then considered. Finally, the impact of scroll expander geometries using unconventional scroll profiles and scroll tip shape variations on the performance is discussed and summarised. The major conclusion to be drawn from this review is that scroll expanders with variable wall thickness scrolls should be further designed and developed. It is possible to increase the geometric expansion ratio without increasing the length of the scroll profiles. CFD simulations are a promising tool to illustrate and understand the non-uniform and asymmetric inner flow and temperature fields. The related benefits could lead to scroll devices with variable wall thickness not only improving the performance of organic Rankine cycle (ORC) systems but also opening a broad new field of applications such as refrigeration cycles and other power cycles where a high pressure ratio is preferred.

1. Introduction

Electrical power can be generated in a regenerative manner from middle to low grade waste heat with the help of organic Rankine cycle (ORC) technology. Such systems can be operated by energy lost from sources such as internal combustion engine exhaust gases [1,2], biomass combustion [3,4], industrial waste heat [5,6], solar thermal energy [7,8] and geothermal heat [9,10]. The choice of the expansion machine is of key importance to ORC performance.

There are two categories of suitable expansion machines for ORC-based systems. These are the velocity type including axial and radial-inflow turbines, and positive displacement devices, such as screw expanders, reciprocating piston expanders, rotary vane expanders and scroll expanders [11]. Compared to the competitors, scroll expanders may have positive properties such as high efficiency, high pressure ratio, relatively low flow rate, low level of noise and vibration due to fewer moving parts and the symmetric working chamber layout, and much lower rotational speed. Furthermore the ease and low cost of manufacture, lack of valves, tolerance to two-phase flows, and high reliability make them suitable for applications in small or micro ORC systems in the output power range from several hundred watts up to 10 kW [10–14]. In contrast low capacity and lubrication needs may disadvantage scroll expanders for larger systems [14]. The pressure ratio is also too low for some applications. Some authors defined the

---

* Corresponding author at: Department of Mechanical Engineering Sciences, University of Surrey, 388 Stag Hill, Guildford, Surrey GU2 7XH, UK.
E-mail address: g.tian@surrey.ac.uk (G. Tian).

https://doi.org/10.1016/j.applthermaleng.2018.06.045
Received 16 February 2018; Received in revised form 7 June 2018; Accepted 14 June 2018

Nomenclature

a	base circle radius (mm)
A/C	Air Conditioning
CAE	Computer-Aided Engineering
CFD	Computational Fluid Dynamics
CO2	Carbon Dioxide
COP	Coefficient of Performance
FEM	Finite element method
h	Scroll profile height (mm)
L	Tangential distance between inner and outer involute (mm)
LFEC	Liquid Flooded Ericsson Cycle
NH_3	Ammonia
ORC	Organic Rankine cycle
P	Power output (W)
PMP	Perfect Meshing Profile
PR	Pressure ratio (–)
p-V	Pressure-Volume
$\dot{Q}$	Heat transfer rate (W)
R22	Chlorodifluoromethane
R123	2,2-Dichloro-1,1,1-trifluoroethane
R134a	1,1,1,2-Tetrafluoroethane
R245fa	1,1,1,3,3-Pentafluoropropane
RE	Reverse Engineering
r_o	orbiting radius of the moving scroll (mm)
r_v	built-in volume ratio (–)
rpm	revolutions per minute (rad/s)
t	scroll wall thickness (mm)
$\dot{W}$	Power (W)
x	x-coordinate
y	y-coordinate

Greek letters

α_i	initial angle of the inner involute (rad)
α_o	initial angle of the outer involute (rad)
θ	Orbiting angle (rad)
φ_e	involute ending angle (rad)
φ_i	inner involute angle (rad)
φ_o	outer involute angle (rad)
η_{cycle}	cycle efficiency (%)
η_{mech}	mechanical efficiency (%)
η_s	isentropic efficiency (%)
η_{vol}	volumetric efficiency (%)

Subscripts

i	inner involute
o	outer involute
s	isentropic
mech	mechanical
vol	volumetric

imposed pressure ratio between scroll expander inlet and outlet as the expansion ratio. It has been renamed into pressure ratio in this paper in order to avoid any misunderstanding.

The principle of a scroll expander is illustrated in Fig. 1. This shows two interleaving scrolls. As one scroll orbits, a volume of air initially trapped in a volume at the centre of the device expands and moves radially outwards as the movement proceeds. This is shown by the time sequence for an anticlockwise orbiting movement. A clockwise orbiting movement would produce the reverse effect with the device operating as a compressor.

To date, in most of the published research on scroll expanders, off-the-shelf scroll compressors have been modified and driven in the opposite direction as expanders [16–25]. The main reason for this approach is to reduce cost. Song et al. [26] divided scroll compressors into different types, namely hermetic refrigeration scroll compressors, semi-hermetic automotive A/C compressors, open-drive automotive A/C compressors and open-drive scroll air compressors. Hence, the conversion to expanders is dependent on the scroll compressor type. Moreover, scroll machines can be categorised into kinematically constrained and compliant scroll devices. The clearance gap between the orbiting and fixed scroll in a kinematically constrained scroll design is fixed to a small value permanently during the operation. In a compliant scroll design, movement of the fixed scroll in the axial direction and the orbiting scroll in the radial direction is possible. This allows the device to deal with liquid flashing and to ride over debris [27]. Whereas researchers place greater emphasis on basic and fundamental research, a few companies such as OBRIST Engineering [28], Exoés [29], Air Squared, Inc. [30], Eneftech Innovation [31] and ECR International [32] aim to implement commercial solutions of scroll expander on the market.

Scroll expanders have a certain tolerance to liquid droplets. Hence, the potential working fluids can be slightly wet at the expander outlet. Bao and Zhao (2013) [14] provided a thorough and comprehensive review about a wide range of suitable working fluids including the impact of their physical and thermodynamic properties on the ORC system performance. Apart from the scroll expander classification, Song et al. (2015) [26] also covered a huge number of references in their literature review regarding the thermodynamic analysis of scroll machines and the prediction of occurring mechanisms inside the scroll volumes by means of experimental studies, theoretical modelling and CFD simulations. Recently, the CFD technology began making inroads into the scroll machine development [33–42]. It can be a promising technology to further optimise the scroll expander geometry and improve the thermodynamic performance due to the opportunity to more easily depict the asymmetric inner flow and temperature field compared to experimental investigations.

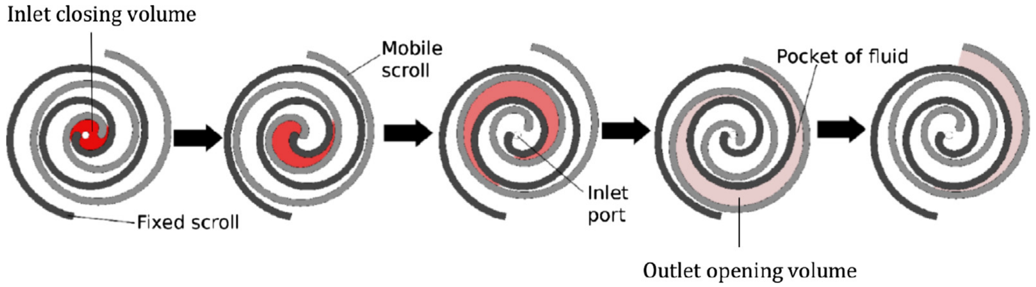

Fig. 1. The principle of a scroll expander [15].