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Research paper

Generation method for a novel Roots rotor profile to improve performance of dry multi-stage vacuum pumps

Yu-Ren Wu[a,*], Van-The Tran[a,b]

[a] Department of Mechanical Engineering, National Central University, 300, Jhongda Rd., Jungli City, Taoyuan, Taiwan 320, Republic of China

[b] Department of Mechanical Engineering, Hung Yen University of Technology and Education, 39A Rd., Hung Yen City, Viet Nam

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ABSTRACT

Multi-stage vacuum pumps are commonly used to increase pump efficiency, and several kinds of Roots rotor profiles have been proposed. However, the lack of design flexibility for rotor profiles means they may be unable to meet the requirements for different stages. This paper proposes a mathematical model and method to generate a novel rotor profile for multi-stage "IVEC" type Roots vacuum pumps. Two geometric performance indices, the area utilization ratio and the meshing gap area, are used to evaluate different types of rotor profiles. A practical experiment compares the performance of an existing benchmark vacuum pump to one with IVEC rotors. Numerical and experimental results demonstrate the superiority of the proposed IVEC Roots rotor profile.

1. Introduction

The rotor profile of a Roots rotor (lobe pump) is crucial to the performance of a vacuum pump since it permits the Roots rotors to remain meshed with each other. Roots pumps are used in wide range of domestic and industrial applications, such as food, medicine and biotechnology. They can work with various materials, from low viscosity fluids such as water to very high viscosity fluids such as oil, and even solids. Recently, several stages (multi-stage) on two rotor shafts with different rotor profiles and sizes for Roots vacuum pumps have been developed to achieve higher pumping speed and lower final pressure than single-stage Roots pumps. This paper proposes a new rotor profile design method based on a combination of different traditional curves, including circular arc, variable extended epicycloid, involute curve and their envelopes. This method allows better design flexibility, area utilization ratio and pump performance than traditional rotor profiles to meet the demand of dry multistage Roots vacuum pumps.

The profile design for Roots rotors of vacuum pumps has received much research attention. Litvin and Fuentes [1] proposed a geometric design for the profile of a rotor with two lobes using a single circular arc. A new rotor profile was then developed by combining circular arcs and a conjugated epicycloidal curve [2]. Fang [3] patented addendum and dedendum portions for the rotor profiles of a rotor by including four circular arcs to improve the area efficiency of a vacuum pump. Another rotor profile was developed with the combination of five circular arcs by Wang et al. [4]. Niimura et al. [5] patented an addendum rotor profile consisting of a circular arc and an involute to increase pump efficiency. More recently, an extended cycloid curve with a variable trochoid ratio was applied to improve pump performance by Hwang and Hsieh [6,7]. Kang

* Corresponding author.
E-mail address: yurenwu@ncu.edu.tw (Y.-R. Wu).

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Nomenclature

A_m	Meshing gap area
A_r	Cross section area of rotor
c	Half tooth backlash
d	Variable extension amount
E_c	Center distance between two rotors
f	Continuity or meshing condition
g_a	Top gap
l_p	Translation distance of rack
$\mathbf{M}$	Coordinate transformation matrix
$\mathbf{n}$	unit normal vector of rotor profile
N	Lobe number of rotor
r	Radius
$\mathbf{r}$	Position vector
s	Arc length of sealing line
S	Coordinate system
$\mathbf{t}$	Tangent vector
u	Profile parameter of hypothetic rack
u_b	Limit of profile parameter u

Subscripts

1	Rotor 1
2	Rotor 2
a	Outer circle of rotor
W_p	Pitch tooth thickness
α	Pitch pressure angle of involute
β	Angle of intersecting point of outer circles
δ	Normal gap
ΔE_c	Increment of center distance
ε	Variable extension exponent
ζ	Function of variable extension amount
η	Area utilization ratio
θ	Angular parameter of circular arc
θ_u	Half top angle
μ	Extension coefficient
ξ	Offset of rotation angle
ρ	Radius of circular arc of CIC rotor
τ	Angular parameter of pitch circle
τ_e	Angular parameter of rolling circle
τ_u	Upper limit of parameter τ
φ	Rotation angle of gear
ϕ	Rotation angle of rotor
e	Rolling circle
h	Pump chamber
sp	Singular point

et al. [8,9] proposed a dynamic mesh method to provide factors affecting the performance of lobe pumps and developed a new lobe pump rotor profile used circular and epicycloidal curves that significantly improves pump performance. A multi-stage Roots pump having with multiple teeth to reduce power consumption and simplify machining was patented by Imai et al. [10]. A stator housing a multistage rotor assembly has been included with a multistage vacuum pump with each stage having intermeshing Roots rotor components [11]. A method for improving pump performance in multistage Roots pumps by designs that achieve the greatest economy in outlet discharge enhancement was proposed.by Hsieh and Deng [12]. Yan et al. [13] presented two different rotor profiles and analyzed the performance of 2–3 lobe combinations of twin-screw pumps, one of which is more suitable for large-volume pumps and the other for high-pressure pumps. Hsieh [14] proposed a new elliptical roulette curve for rotors of lobe pumps that provides higher discharge efficiency and controls the level of vibration and noise. Yao et al. [15] proposed a novel three-lobe helical rotor with the cross section composed of a combination of concave and convex arcs and cycloidal curves for a Roots blower that creates greater air flow and reduces the peak blower pressure. A numerical method to evaluate meshing clearance between male and female rotors by using their discrete profile points was presented by Wu and Chi [16]. Zhang and Fong [17] proposed a novel tilt form grinding method to prevent the