Mechanical Systems and Signal Processing 109 (2018) 352–378

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Analysis of continuous-contact helical gear pumps through numerical modeling and experimental validation

Xinran Zhao *, Andrea Vacca

School of Mechanical Engineering, Purdue University, Lafayette, IN 47907, United States

ARTICLE INFO

Article history:
Received 8 November 2017
Received in revised form 31 January 2018
Accepted 25 February 2018

Keywords:
External gear pumps
Helical gear pumps
Continuous-contact gear pumps
Kinematic flow ripple
Pump modeling
Pump noise
Experimental validation

ABSTRACT

External gear pumps are one of the most commonly used types of positive displacement machines in high pressure hydraulic control systems, fuel-injection and fuel transport systems. Despite many merits of the traditional external gear pump design with involute teeth, the significant flow non-uniformity intrinsic of such design is considered to be a detrimental aspect, since it causes undesired noise emissions and mechanical vibrations. A disruptive concept of continuous-contact helical gear pumps (CCHGP) was proposed and successfully commercialized in the recent past. Such concept was proven to have clear advantages in terms of noise emissions. However, a clear interpretation of the displacing action and the transient features of the delivery flow was never addressed in past literature. This paper addresses this gap by first discussing the family of gear profiles suitable for implementing the CCHGP design. Subsequently, an analysis on the kinematic flow ripple is given, showing how such design concept can reduce or even eliminate the kinematic flow pulsations. The paper also presents a numerical approach for modelling the operation of CCHGPs, starting from the modeling of the geometric features necessary for a fluid dynamic analysis based on a lumped parameter approach. For model validation purposes, a commercial CCHGP was tested at the authors' research center, and the simulation results were compared against the experiments, to show the level of accuracy of the model, as well as it potentials for future design studies.

1. Introduction

Among the existing designs for positive displacement pumps, external gear pumps are very successful in applications that include hydraulic control systems, fuel injection, automotive lubrication and transmission systems, high pressure washings and fluid transport systems. The main advantages of such design are the low manufacturing cost, the compact package, the capabilities of operating at high pressure, for a high range of fluid viscosity and with high tolerance to fluid contamination and cavitation.

In common with other positive displacement pumps, traditional external gear pumps based on involute teeth are commonly characterized by a significant non-uniformity of the outlet flow. This is a detrimental feature, being at the basis of fluid-borne noise generation as well as of vibrations induced into the overall system connected to the pump. The origin of the flow non-uniformity is typically described through a kinematic analysis of the displacing action realized by the pump. Analyses of the kinematic flow for various pump designs can be found in Ivantysyn and Ivantysynova [1]; and particularly for

* Corresponding author.
E-mail address: zhao596@purdue.edu (X. Zhao).

https://doi.org/10.1016/j.ymssp.2018.02.043

Nomenclature

Latin symbols

A	area [mm^2]
A_{tip}	radial gap opening area [mm^2]
a	distance between center of the circular-arc and the gear center [mm]
b	width of the leakage gap [mm]
C	radial clearance of the journal bearing [mm]
CR	contact ratio [–]
CCHGP	Continuous-Contact Helical Gear Pump
c_q	discharge coefficient [–]
c_{qmax}	maximum discharge coefficient [–]
DC	Displacement chamber
D_h	hydraulic diameter [mm]
EGP	External gear pump
e	eccentricity of gear shaft in the journal bearing [mm]
H	whole depth of gear [mm]
h_{tip}	height of tooth-tip gap [mm]
h	height of the leakage gap [mm]
i	center distance [mm]
K	bulk modulus [bar]
L	length of the leakage gap [mm]
m	module of gear [mm]
N	number of teeth [–]
p	pressure [bar]
Q	volumetric flowrate [L/min]
r	pitch circle radius [mm]
r_a	addendum circle radius [mm]
r_b	base circle radius [mm]
r_r	root circle radius [mm]
TS	Tooth space
u	fluid velocity [m/s]
u_s	shearing velocity of the solid wall [m/s]
V	volume [mm^3]
Z'	axial position of the sealing surface [mm]
z	axial position [mm]

Greek symbols

α	pressure angle [rad]
β	helical angle on the pitch circle [rad]
β_a	helical angle on the addendum circle [rad]
γ	base pitch [mm]
Θ	total helix rotation angle [rad]
θ	gear profile parameter [rad]
λ	predictor for Reynolds number [–]
μ	dynamic viscosity [Pa·s]
ν	kinematic viscosity [m^2/s]
ρ	density [kg/m^3]
ρ_r	radius of circular-arc [mm]
ϕ	profile/gear rotation angle [rad]
ϕ_{ref}	reference profile rotation angle (intermediate cross-section) [rad]
ψ	angle shift between force direction and eccentricity direction [rad]
ω	angular velocity [rad/s]

Subscript

a	addendum
crit	critical
d	driver gear
i	index of displacement chambers or connections
in	inlet