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Kinematic modeling, analysis and test on a quiet spherical pump

Dong Guan [a,b,*], Jiu Hui Wu [a,**], Li Jing [a], Harry H. Hilton [b], Kuan Lu [a]

[a] School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, China
[b] Department of Aerospace Engineering, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, 104 S. Wright St., Urbana, IL 61801, USA

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ABSTRACT

In this paper, design and modeling of a novel spherical pump are undertaken. Both sound and vibration properties of the pump are studied experimentally. The working mechanism of the pump is analyzed firstly, and then structural design and kinematic theory are modeled by using two different coordinate systems. Nonlinear kinematic constraint equations are developed using a generalized computational method for spatial kinematic analysis. These equations are solved to yield the displacement, angular velocity and acceleration properties of motion parts with different structural parameters. Sound and vibration characteristics of the spherical pump and traditional solenoid pumps are studied experimentally at different rotating speeds of 1000, 1500, 2000, 2500 and 3000 rev/min. Results indicate that sound pressure levels of the proposed spherical are reduced to 40.7 dB(A), which are 11.1 dB(A) lower than the traditional solenoid pump's 51.8 dB(A) at the rated operating conditions. The sound spectra are analyzed in detail in order to investigate the causes, which are structural pattern and working mechanisms. The proposed spherical pump has many advantages and can be utilized as a substitute for other pumps in some special fields, such as hospital facilities and household appliances.

1. Introduction

Due to their compact and lightweight structure [1–5], solenoid pumps are widely used in flow injection analysis (FIA) of systems [6,7], automotive and robot industries [1] etc. Generally, the solenoid pump is composed of an electric coil, springs and a plunger, etc. A magnetic force will generate by the electric coil when the current passed through it, and the generated magnetic force and springs will make the plunger move backward and forward to pull and push the fluid. Weeks [6] replaced the conventional peristaltic pump by using a solenoid pump in a FIA system, which was tested by a simple nitrite analysis. The results indicated that the solenoid pump can produce an acceptable performance in a typical FIA system. The characteristics of solenoid pumps as a function of flow rate and flow resistance were systematically studied by Horstkotte and his colleagues [8]. Systems versatility, transportability and pressure robustness were improved by using a new, economic and miniature control unit.

* Corresponding authors at: School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, China.
** Corresponding author.
E-mail addresses: guandong029@gmail.com (D. Guan), ejhwu@mail.xjtu.edu.cn (J.H. Wu).

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Nomenclature

FIA	flow injection analysis
R	piston radius
SPL	sound pressure level
α	piston angle
ϕ	angular displacement of piston and central pin
ϕ'	angular displacement of rotary disk in plane $x'Oy'$
θ	angular displacement of shaft
ω_ϕ	angular velocity of piston
a_ϕ	angular acceleration of piston

Although the solenoid pump is one of the simplest pumps and has very few moving parts, it also has many drawbacks. Considerable vibration and noise are generated when the plunger moves forward and backward rapidly. Kim [1] conducted the structural and vibration analyses in the design of a new solenoid pump to avoid resonance effects on the key parts of the pump. However, the vibration and sound are mainly caused by the inertial force of the plunger and it is difficult to reduce the pump noise levels drastically due to its fast axial reciprocating motion.

In 1885, Heenan [9] proposed a tower spherical engine which is quite similar with the spherical pump. But the spherical engine is complex than spherical pump and has one more moving parts. This will increase the cost and decrease the reliability inevitably. The objective of this paper is to study the spherical pump theoretically and experimentally, including its novel working mechanism, kinematic principles and sound performance. Similar to the solenoid pump, the spherical pump [10,11] consists of only few moving parts and much more compact. In addition, it has lower sound pressure levels than the solenoid pump, and these advantages make it more suitable for hospital, household appliances and aerospace applications.

The organization of the paper is as follows: The structure and working process of the spherical pump and kinematic analysis of the pump are presented in Section 2. The experimental devices which are utilized to test noise levels of both the spherical pump and solenoid pumps are presented in Section 3. Testing results and discussions are presented in Section 4. Finally, Conclusions are given in Section 5.

2. Structure and working mechanism of the spherical pump

1-piston; 2-cylinder cover; 3-passage; 4-working chamber V1; 5-connection screw; 6-shaft; 7-shaft bracket; 8-rotary disc; 9-cylinder body; 10-central pin; 11-working chamber V2; 12/13-inlet/exhaust passage;.

As shown in Fig. 1(a) and (b), the spherical pump includes only three rotary parts, which are the shaft 6, the rotary disc 8 and the piston 1, respectively. The bottom of the rotary disc inserts into the shaft, while the top of the rotary disc connects with the piston by a central pin 10. Piston and the cylinder cover are connected by a hinge as shown in Fig. 1. In addition, the axis of the piston has an angle α relative to the vertical direction and it is called the piston angle. Generally, piston diameter ranges from 10 to 55 mm due to authors design experience. Another one of the important design parameter is piston angle, which ranges from 0° to 30° due to the past design and manufacture experience [11]. On the one hand, spherical pump displacement is drastically affected by the piston radius because of the spherical shape piston. And volume of working

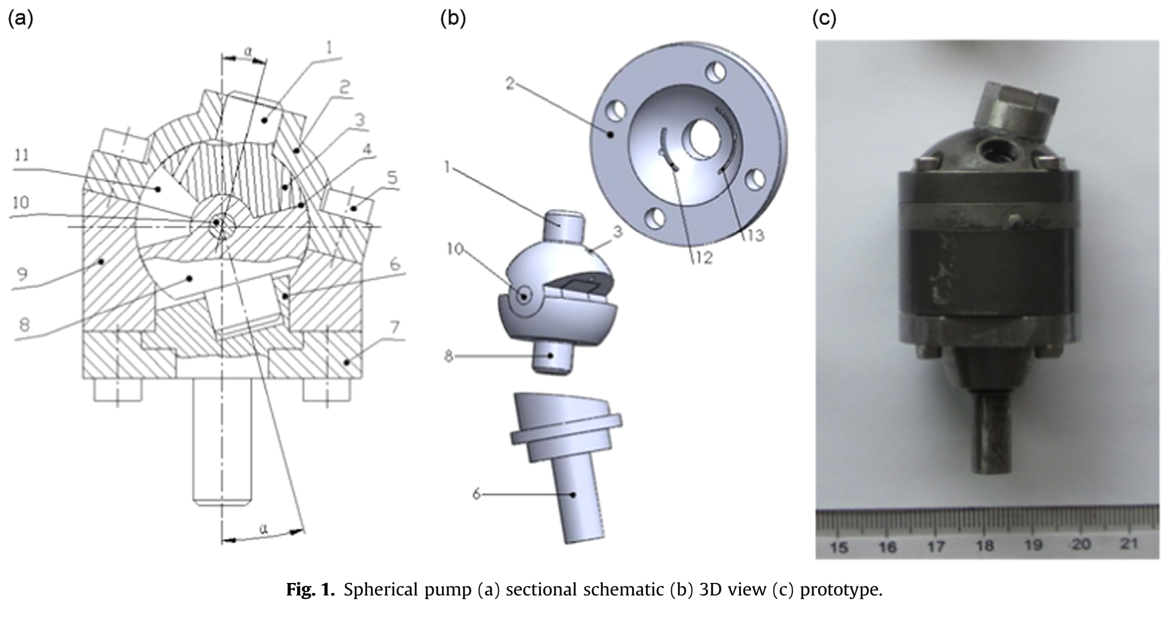

Fig. 1. Spherical pump (a) sectional schematic (b) 3D view (c) prototype.