PROFILE DESIGN AND VOLUMETRIC EFFICIENY ANALYSIS OF GEROTOR PUMPS FOR AWD VEHICLES

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Abstract- This paper presents a newly designed profile (K-floid) for a gerotor pump, which is applied for transmission lubricating system of All Wheel Drive vehicles. Nowadays gerotor pumps are increasingly widely applied on lubricating system due to their compact size and low cost. However, volumetric efficiency is an important specification for gerotor pump application. Volumetric efficiency of the newly designed profile is compared with those of the conventional trochoidal profile and the combined trochoidal profile via CFD simulation. Simulation results indicate that the proposed K-floid profile can achieve higher volumetric efficiency than other profiles.

Index terms- Gerotor pump, Profile design, K-floid, Volumetric efficiency, All Wheel Drive (AWD), Electric Oil Pump (EOP).

I. NOMENCLATURE

e	eccentricity
r_{be}	radius of base circle of epitrocloid
r_{bh}	radius of base circle of hypotrocloid
r_e	radius of rolling circle of epitrocloid
r_h	radius of rolling circle of hypotrocloid
R_1	radius of pitch circle of inner rotor
R_2	radius of pitch circle of outer rotor
x_{in-e}	x-coordinate of epitrocloid of inner rotor
x_{in-h}	x-coordinate of hypotrocloid of inner rotor
y_{in-e}	y-coordinate of epitrocloid of inner rotor
y_{in-h}	y-coordinate of hypotrocloid of inner rotor
Z_1	lobe number of inner rotor
Z_2	lobe number of outer rotor
β	parameter of epitrocloid or hypotrocloid

II. INTRODUCTION

Gerotor oil pumps are a type of positive displacement internal gear pumps. Compared with external gear pumps, they keep lots of advantages, such as less components, simple structure, compact size, low noise, low ripple of flow rate and low cost[1]. Thus they are widely used in applications of lubricating system of on-road or off-road engines. Especially they are applied as oil pumps such as for transmissions of All Wheel Drive (AWD), Electric Oil Pump (EOP) for hybrid vehicles and so on.
The main components of a gerotor pump include an inner rotor, an outer rotor, and a housing in which inlet (suction) and outlet (delivery) ports are machined. The inner rotor is placed inside the outer rotor and it positions itself at a fixed eccentricity from the outer rotor center[2]. The inner rotor is driven by input torque, generally generated by a motor or engine, and the outer rotor rotates with it since they contact each other at less several points of their geometrical profiles. Thus the profiles of the inner and outer rotors are a pair of conjugate curves[3].
It is well known that the volumetric efficiency of a gerotor pump rapidly decreases as increasing of outlet pressure due to internal leakage, which occupies about 40% of entire energy loss of a transmission. Obviously, profiles of the inner and outer rotors are crucial to volumetric efficiency of the gerotor pump. There are some references about profile generation of gerotor pumps[2-7]. Based on profile generation, some researches about performance analysis, such flow/pressure ripple, calculation of flow rate, and noise level and so on, have been done by using CFD modeling[4][8][9], AMESim[7], or experiment[10]. However, there are seldom references about how profile of gerotor pump affects on volumetric efficiency. Therefore the paper focuses on volumetric efficiency for various profiles of a gerotor pump. A newly designed profile of the gerotor pump, with other two different ones based on previous research, is proposed in the paper. And then flow rates of the gerotor pump with these three profiles are calculated via simulation of commercial CFD software. Thus volumetric efficiency can be compared through simulation results.

III. DESIGN OF DIFFERENT PROFILES OF A GEROTOR PUMP

Three types of profiles: trochoid, combined trochoid, and K-floid, will be discussed in this section.

- DESIGN OF TROCHOIDAL PROFILE

The trochoidal profile, which refers to any of the cycloid including the curtate cycloid and the prolate cycloid, is widely used for gerotor pumps[2, 5-7]. It is not difficult to generate the trochoidal profile of inner and outer rotors according to the reference [2], shown as in Fig. 1, in which the lobe number of the inner rotor is Z_1=10.

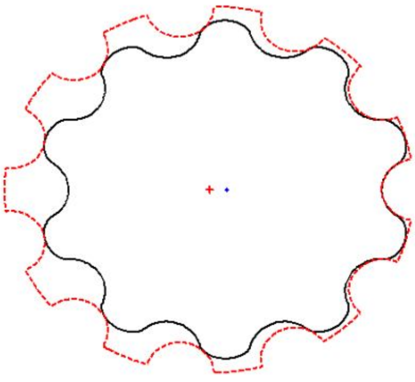


Figure 1: Trochoidal profile

- DESIGN OF COMBINED TROCHOIDAL PROFILE

Reference [3] shows how to design combined trochoidal profile of the inner rotor for the gerotor pump. The profile of the inner rotor is composed of a segment of hypotrochoidal curve and a segment of epitrochoidal curve. One important thing is that the base circles of the hypotrochoidal curve and the epitrochoidal curve are same one, i.e. the pitch circle of the inner rotor, whose radius is R_1. Thus the parametric equations of the hypotrochoidal and epitrochoidal curves are expressed by Eqs. (1)~(3), where β is parameter[3].

$$\begin{cases} x_{in\_h} = (r_{bh} - r_h)\cos\beta + r_h \cos(\frac{r_{bh} - r_h}{r_h}\beta) + e \\ y_{in\_h} = (r_{bh} - r_h)\sin\beta - r_h \sin(\frac{r_{bh} - r_h}{r_h}\beta) \end{cases} \quad (1)$$

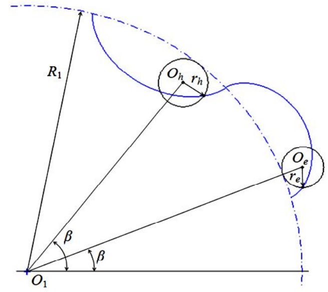
$$\begin{cases} x_{in\_e} = (r_{be} + r_e)\cos\beta - r_e \cos(\frac{r_{be} + r_e}{r_e}\beta) + e \\ y_{in\_e} = (r_{be} + r_e)\sin\beta - r_e \sin(\frac{r_{be} + r_e}{r_e}\beta) \end{cases} \quad (2)$$

$$r_{bh} = r_{be} = R_1 \quad (3)$$

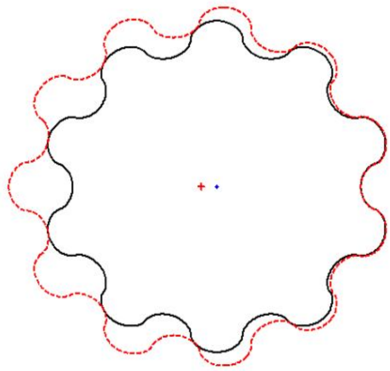
Fig. 2(a) illustrates the combined trochoidal profile of the inner rotor and the outer rotor profile is able to be obtained by means of conjugate relation of the inner and outer rotors mentioned in reference[3]. The profile of inner and outer rotors are shown in Fig. 2(b).

- DESIGN OF K-FLOID PROFILE

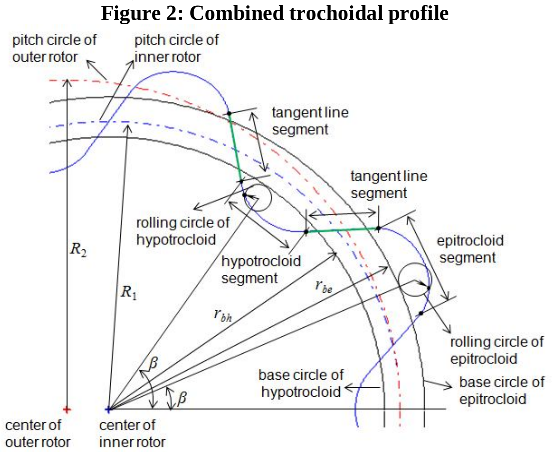
As stated in last section, the base circles of the hypotrochoidal and the epitrochoidal curves have the same radius, equal to radius of the pitch circle of the inner rotor, in design of combined trochoidal profile. In design of K-floid profile, the base circles of the hypotrochoidal curve and the epitrochoidal curve are not same any more. Particularly, the radius of base circle of the hypotrochoidal curve is less than that of the epitrochoidal curve. Moreover a common tangent line (in green color) is utilized to connect the hypotrochoidal and epitrochoidal curves. This profile, including hypotrochoidal and epitrochoidal curves as well as a common tangent line between them, is named as K-floid profile. Fig. 3(a) illustrates each segment of K-floid profile and meaning of each component. Fig. 3(b) illustrates the inner rotor profile and the conjugate profile of the outer.



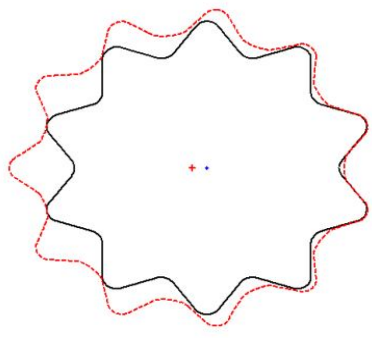
(a) A lobe of combined hypotrochoidal and epitrochoidal profile



(b) Profile of inner and outer rotors
Figure 2: Combined trochoidal profile



(a) Components of K-floid profile and their meaning



(b) Profile of inner and outer rotors
Figure 3: K-floid profile

IV. CFD ANALYSIS AND DISSCUSION

The generated coordinates of the inner and outer rotors are utilized to construct the flow field model of the gerotor pump. And then flow rate and volumetric efficiency for different profiles are obtained via CFD simulation software, PumpLinx.

- MODELING FOR CFD SIMULATION

Dimension of the inlet and outlet ports can be determined based on the designed profiles of the inner and outer rotors and the contact points between them, shown as in Fig. 4.

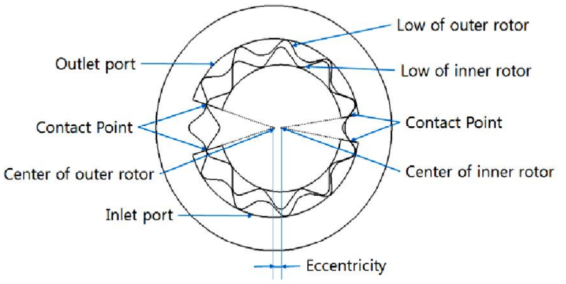
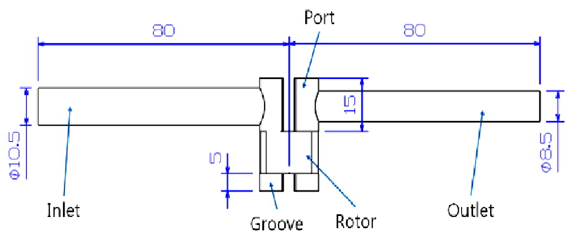
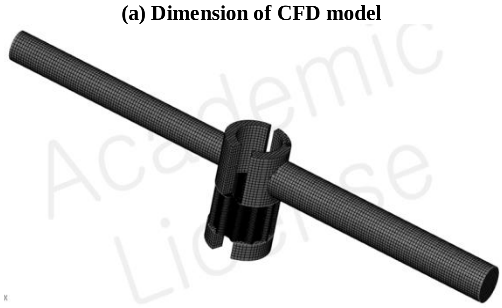


Figure 4: Port design of gerotor pump

The port shape should be also considered to perform CFD simulation. It is same for three types of profiles so as to fairly compare volumetric efficiency. As shown in Fig. 5(a), the diameter of the inlet port is greater than that of the outlet port in order to prevent cavitation in the inlet port. And the meshed CFD model is given in Fig. 5(b).



(a) Dimension of CFD model

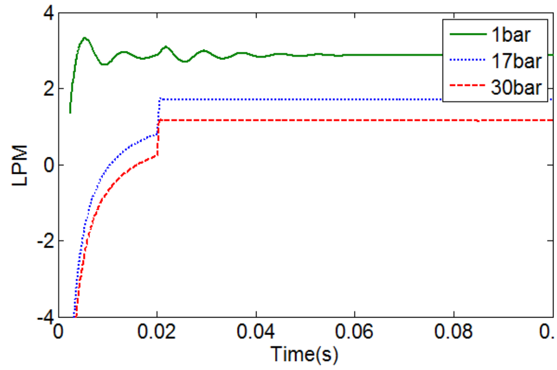


(b) Meshed CFD model
Figure 5: CFD model of gerotor pump

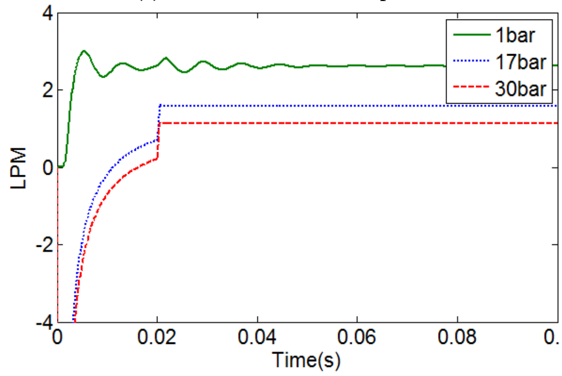
CFD simulation conditions are set as cavitation and turbulence model, and oil density: 800kg/m^3, oil saturation pressure: 400Pa, oil operating temperature: 300K, inlet pressure: 0bar, outlet pressure: 1bar, 17bar, and 30bar, respectively, pump rotary velocity: 3000rmp.

- SIMULATION RESULTS AND DISSCUSSION

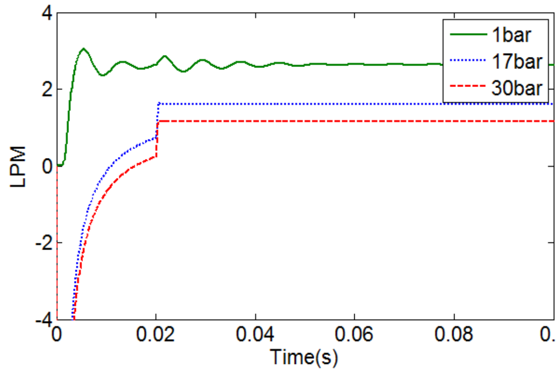
Flow rates of three designed profiles of gerotor pump are obtained by simulation as shown in Fig. 6. It can be seen from simulation results that it takes more than 0.02 second to establish pressure to resist outlet pressure, and then flow rates keep constant valves.



(a) Flow rate of trochoidal profile



(b) Flow rate of combined trochoidal profile



(c) Flow rate of K-floid profile
Figure 6: Flow rate of different profile designs

In order to compare volumetric efficiency the theoretic displacements of three profiles are calculated based on coordinates of the inner and outer rotors, and they are 0.985cc/rev, 0.896cc/rev, and 0.898cc/rev, respectively. Accordingly, volumetric efficiencies can be obtained through simulation results, summarized in Table1. It can be clearly seen that volumetric efficiencies greatly reduce with increasing of outlet pressure in that internal leakage becomes more serious as pressure increasing. Meanwhile volumetric efficiencies gradually increase by order of trochoid, combined trochoid, and K-floid no matter how much the outlet pressure is, which indicates that the proposed K-floid profile design is superior to other two profiles in the view point of volumetric efficiency.

Table 1 Comparison of volumetric efficiency for different profiles and outlet pressure

Profile type	Trochoid	Combined trochoid	K-floid
Theoretic displacement (cc/rev)	0.985	0.896	0.898
LPM (3000rpm)	2.96	2.69	2.69
Outlet pressure	Volumetric efficiency (%)		
1bar	96.9	97.1	97.7
17bar	57.4	58.8	59.5
30bar	38.8	41.8	42.6

CONCLUSION

In order to improve volumetric efficiency of gerotor pumps for AWD vehicles, a K-floid profile, i.e. combination of hypotrochoidal segment, tangent line segment, and epitrochoidal segment, is designed in the paper. And then simulation has done to compare its volumetric efficiency to those of conventional trochoidal profile and the combined trochoidal profile via CFD software. Simulation results show that the proposed K-floid profile has higher volumetric efficiency superior to other profiles.

ACKNOWLEDGEMENT

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