Development of High Efficiency Internal Gear Pump Rotor “Geocloid Rotor”

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Internal gear pump rotors are powder metallurgy parts widely used for oil pumps of automobile engines, automatic transmissions (ATs), and continuously variable transmissions (CVTs). In the recent development of energy-efficient, environmental-friendly automobiles, oil pump rotors are required to reduce their size while maintaining sufficient discharge volume. To meet the requirements, we have developed a highly efficient oil pump rotor with a new tooth profile “Geocloid.” The Geocloid tooth height is designed to be higher than those of conventional rotors to provide higher mechanical efficiency, while allows the reduction in size of rotor without sacrificing the discharge volume. In 2011, Geocloid rotors started to be used in the automotive transmission oil pumps of hybrid vehicles.

Keywords: automobile, oil pump, internal gear pump rotor

1. Introduction

Internal gear pump rotors made by powder metallurgy (P/M) are widely used as key elements of automotive oil pumps. In typical applications they lubricate the engine, generate hydraulic pressure in automatic transmissions (ATs) and continuously variable transmissions (CVTs), and feed fuel to diesel engines. Recent paradigm shifts in the automotive industry have spurred the use of P/M internal gear pump rotors in additional applications, such as lubrication of hybrid vehicles (HVs) transmissions.

Energy loss attributable to oil pumps accounts for approximately 10% of the total engine energy loss in the case of an engine lubrication oil pump, 20% to 30% in the case of an oil pump for AT, and 5% to 10% in the case of oil pumps for HV. The intensifying fuel economy competition resulting from exhaust gas regulations that will take effect in 2012, and fuel economy regulations that will take effect in 2015,have led to growing demand for oil pumps that can reduce energy loss.

Sumitomo Electric Industries, Ltd. has led the development and commercialization of “Parachoid” and “Megafloid” rotors featuring our proprietary tooth profiles for improved oil pump efficiency. In response to strong demand for even greater oil pump efficiency with respect to, among other aspects, loss reduction, we have developed an oil pump rotor with new teeth profile (“Geocloid” rotor), which has a distinct advantage of size reduction, and have succeeded in mass-producing it for transmission lubrication applications in HV.

2. Approach to Developing High-Efficiency Pump Rotors

2-1 Internal gear pump mechanism

Figure 1 shows the structure and mechanism of an internal gear pump. The inner and outer rotors are set eccentrically within a case. The outer rotor has one more tooth than the inner rotor. The tooth faces of the outer and inner rotors create closed spaces (chambers). When the inner rotor is driven and rotates, the outer rotor, meshing with the inner rotor, is also driven and rotates in the same direction. The volume of each chamber gradually increases with rotation, and after reaching its maximum, gradually decreases. This process occurs repeatedly. As the chamber volume increases, the pump draws oil via the suction port. When chamber volume reaches maximum, the chamber is temporarily separated from both the suction and discharge ports. The pump discharges oil via the discharge port as the volume becomes smaller. This is the mechanism of oil pump operation.

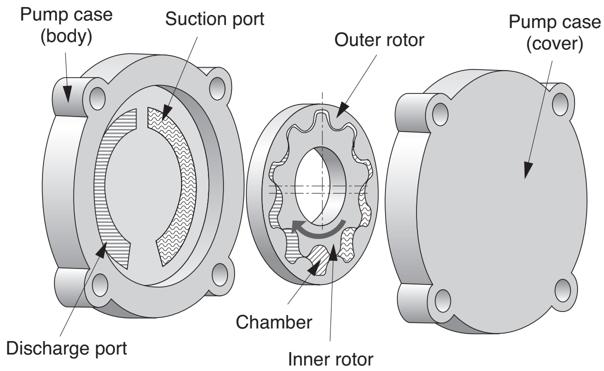


Fig. 1. Structure of oil pump with internal gear pump rotors

2-2 Improving pump efficiency

Oil pump efficiency is expressed as the product of volumetric efficiency and mechanical efficiency.

Pump efficiency (%) = Volumetric efficiency x Mechanical efficiency x 100

Volumetric efficiency (%) = Actual discharge volume/Theoretical displacement x 100

Mechanical efficiency (%) = (Theoretical displacement x Discharge pressure)/(2π x Drive torque) x 100

In these equations, the theoretical displacement is a fixed quantity dependent on the product of the aforementioned maximum chamber volume and the number of inner rotor teeth. Important factors in improving pump efficiency are an increased actual discharge volume and reduced drive torque. Drive torque is determined on the basis of actual oil discharge work and the sum of losses induced during rotor rotation by frictional resistance at each sliding portion. Reducing this friction loss is one way to reduce drive torque. Since the actual work is proportional to the discharge pressure, the lower the oil pump discharge pressure setting, the greater the proportion of friction loss to drive torque.

Figure 2 shows an example theoretical calculation of drive torque versus rotor size (outside diameter of outer rotor), performed under a specific set of pump conditions. Given the same theoretical displacement, drive torque decreases as outer rotor outside diameter decreases. **Figure 3** shows a breakdown of friction loss attributable to different sections. These data shows that reduction in rotor radial size is most effective for drive torque reduction.

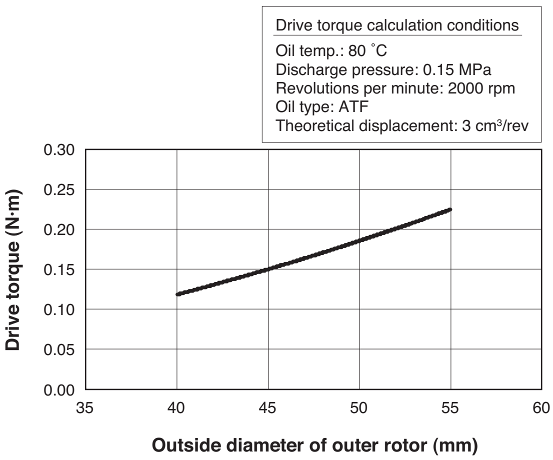


Fig. 2. The relationship between rotor size and drive torque

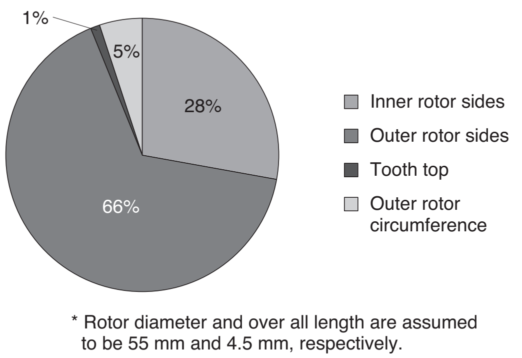


Fig. 3. Breakdown of friction loss in rotor portions

2-3 Challenge to reduce the rotor diameter

Rotor diameter is chosen according to the inner rotor tooth profile, which is designed on the basis of pump specification requirements including discharge volume, driveshaft diameter and number of teeth. Top and root diameter of the inner rotor is designed according to the inside diameter (= driveshaft diameter), oil sealing width [= (root diameter – inside diameter)/2] and tooth height [= (top diameter – root diameter)/2], as shown in **Fig. 4**. The oil sealing thickness is designed to ensure satisfactory part strength and sealing performance against oil leaks from the chamber to the driveshaft area, and tooth height is designed to meet the applicable discharge volume requirement. As previously stated, theoretical displacement is determined by the product of the maximum chamber volume and the number of inner rotor teeth. Accordingly, greater tooth height increases maximum chamber volume and theoretical displacement.

The conventional design of inner rotor tooth profile based on a trochoidal or cycloidal curve is subject to have parameter limits. In such a design, therefore, it may be necessary to provide more than necessary sealing thickness (= sealing width) to meet the respective pump specification requirements. In other words, the problem is a larger diameter of rotor than desired. As an example of conventional tooth profile, **Fig. 5** shows how to create an inner rotor tooth profile based on a cycloidal curve. Cycloidal tooth profiles are described by a point on a circle that is rolling without slipping along a base circle. Base circle diameter, and consequently, rotor size, are uniquely chosen on the basis of the selected theoretical displacement and number of teeth.

Sumitomo Electric met the challenge by developing and mass- producing the Megafloid rotor, combining cycloid and involute curves that improved tooth profile design flexibility. Moreover, in a positive response to strong demand for reduced rotor driving torque, we have developed a tooth profile curve (Geocloid) that provides greater design flexibility so as to further reduce rotor size.

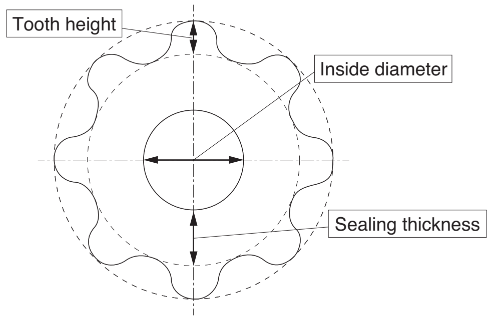


Fig. 4. Inner rotor structural features

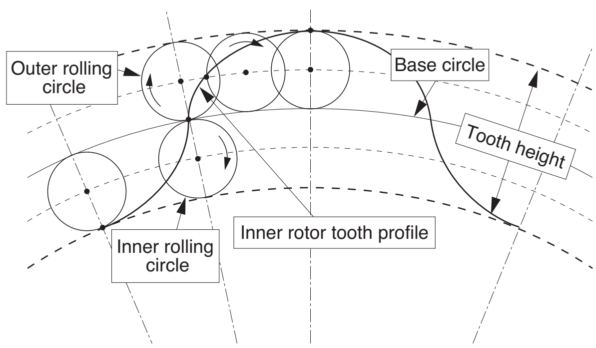


Fig. 5. Outline of inner rotor profile based on cycloidal curve

2-4 Design concept and advantages of newly developed Geocloid rotor

Figure 6 shows the outline of inner rotor profile of Geocloid rotor.

The improved design flexibility of the Geocloid rotor is achieved by maneuvering the center position of a profile generating circle in a desired manner and adopting the curve described by a point on the profile generating circle as a tooth profile. **Figure 7** shows the advantages of the Geocloid rotor.

[1] Enables small-diameter design, reducing thickness (= sealing width).

[2] Enables rotors of same size to vary in number of teeth.

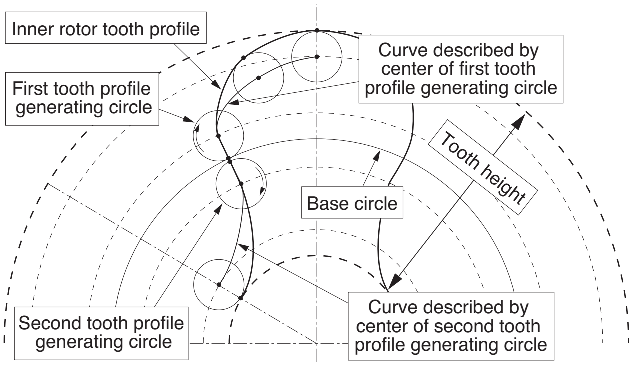


Fig. 6. Outline of inner rotor tooth profile of Geocloid rotor

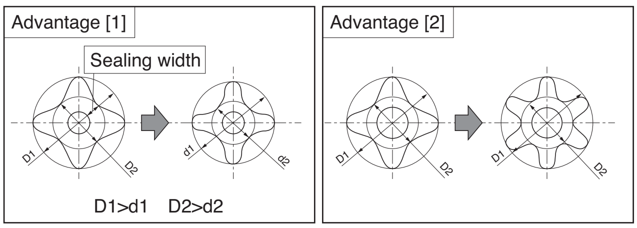


Fig. 7. Advantages of Geocloid rotor

Figure 8 shows an example of advantage 1. This example achieves an 11% diameter reduction from Sumitomo Electric's rotor with the conventional tooth profile.

Figure 9 shows the design concept of an outer rotor, which is represented by a group of envelope curves of the inner rotor. This Sumitomo Electric proprietary design method (registered utility model no. HEI06-039109) has optimized the clearance between inner and outer rotor teeth to achieve [1] high volumetric efficiency and [2] rotation assurance.

Design conditions

Numbers of teeth: 8/9 (inner/outer) Rotor over all length: 5.5 mm Theoretical displacement: 3 cm^3/rev

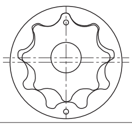
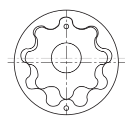
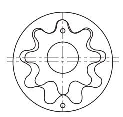
Tooth profile	Parachoid rotor	Megafloid rotor	Geocloid rotor
Rotor shape			
Size (ratio)	ø54.6mm (100)	ø52mm (95)	ø48.6mm (89)
Tooth height (ratio)	4.6mm (100)	4.8mm (105)	5.5mm (120)

Fig. 8. Example of downsized Geocloid rotor

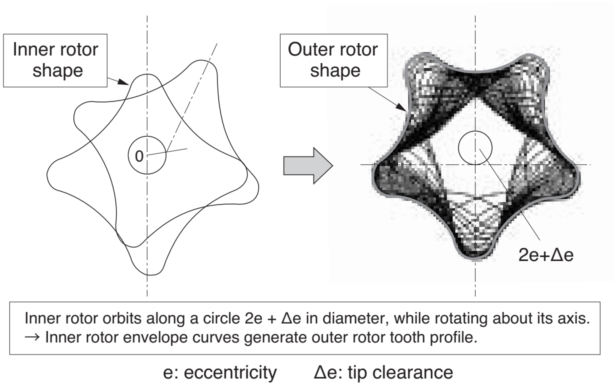


Fig. 9. Outer rotor profile generation using envelope curves

3. Geocloid Rotor Pump Performance

3-1 Performance test 1

Geocloid and Parachoid rotors, designed with the same numbers of teeth, were used for comparative pump performance testing. **Table 1** shows design specifications and test conditions. **Photo 1** shows test equipment. **Figure 10** shows discharge volume and volumetric efficiency test results; **Fig. 11** shows drive torque test results.

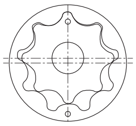
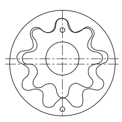
The test results reveal that the Geocloid rotor, while retaining high volumetric efficiency similar to that of the Parachoid rotor, reduces drive torque as a result of downsizing.

3-2 Performance test 2

Geocloid and Megafloid rotors designed in the same size were used for comparative testing of pump performance under high discharge pressure. **Table 2** shows design specifications and test conditions. **Figure 12** shows discharge volume and volumetric efficiency test results. **Figure 13** compares pulsation of discharge pressures.

These test results reveal that under high discharge pressure (1.0 MPa), the Geocloid rotor reduces pulsation as a result of the increased number of teeth, while achieving the same level of discharge performance as the Megafloid rotor.

Table 1. Performance test 1 specifications and conditions

Tooth profile		Parachoid rotor		Geocloid rotor	
Clearance specs.		MIN	MAX	MIN	MAX
Rotor specs.	Number of teeth (inner/outer)	8/9		8/9	
	Over all length	5.5mm		5.5mm	
	Outside diameter of outer rotor	ø54.6mm		ø48.6mm	
	Theoretical displacement	3cm³/rev		3cm³/rev	
	Tooth profile				
Clearance	Side clearance	MIN	MAX	MIN	MAX
	Body clearance				
	Tip clearance				
Test conditions	Oil type	ATF			
	Oil temp.	50, 120˚C			
	Discharge pressure	0.05MPa			
	Revolutions per minute	1000~6000rpm			

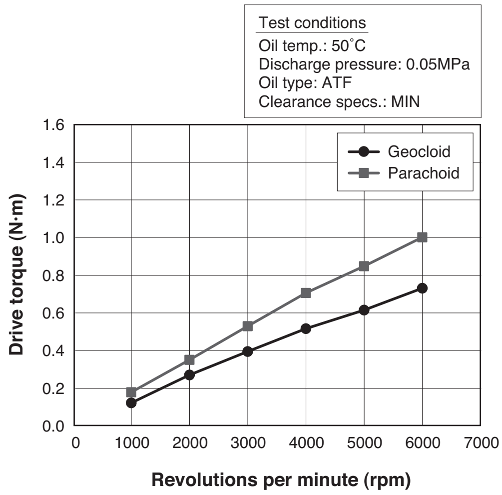


Fig. 11. Drive torque

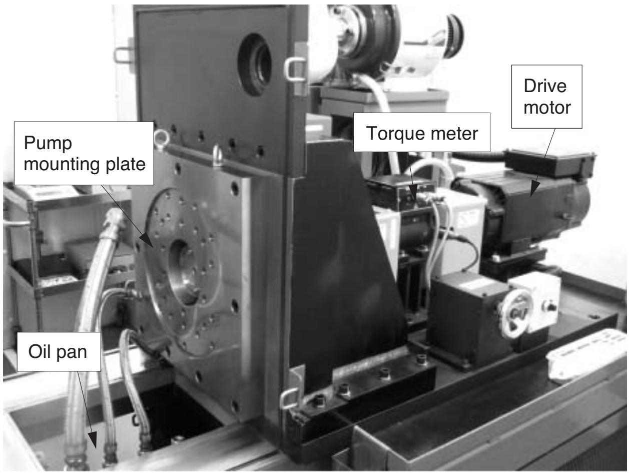
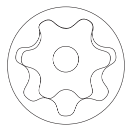
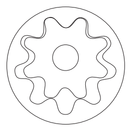


Photo 1. Test equipment

Table 2. Performance test 2 specifications and conditions

Tooth profile		Megafloid rotor	Geocloid rotor
Rotor specs.	Number of teeth (inner/outer)	6/7	8/9
	Over all length	15mm	15mm
	Outside diameter of outer rotor	ø60mm	ø60mm
	Theoretical displacement	12cm³/rev	12cm³/rev
	Tooth profile		
Clearance	Side clearance	NOM	NOM
	Body clearance		
	Tip clearance		
Test conditions	Oil type	ATF	
	Oil temp.	80˚C	
	Discharge pressure	1.0MPa	
	Revolutions per minute	500~6000rpm	

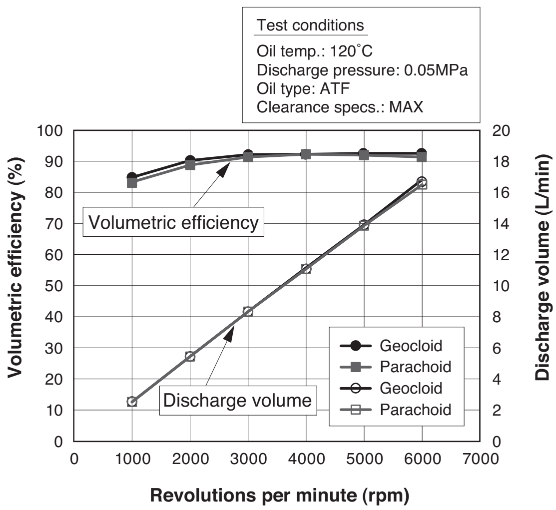


Fig. 10. Discharge volume and volumetric efficiency

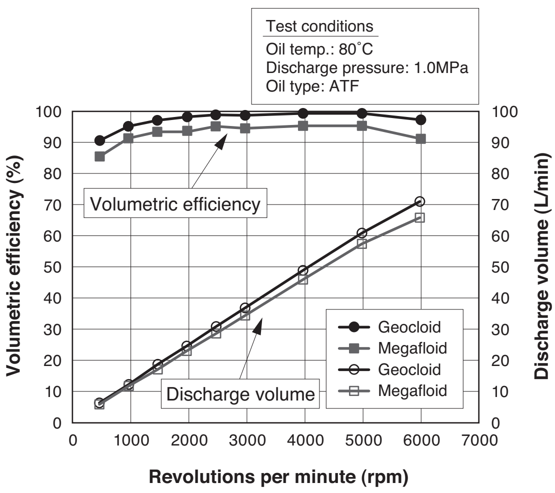


Fig. 12. Discharge volume and volumetric efficiency

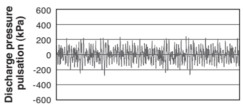
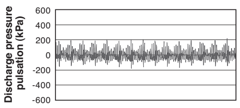
	Megafloid rotor	Geocloid rotor
80°C 1MPa 3000rpm		

Fig. 13. Pulsation of discharge pressures (peak-to-peak values)

4. Conclusion

An innovative oil pump rotor (Geocloid rotor) has been developed, which reduces energy loss in oil pumps. We produced the Geocloid rotor in lubrication pumps for HV transmissions in 2011, and intend to explore other applications in the future. We have also begun work on developing a next-generation tooth profile as an improvement on the performance of the Geocloid rotor, and will meet the challenges in the automobile industry of lower fuel consumption and higher performance.

* Geocloid, Parachoid and Megafloid are trademarks or registered trademarks of Sumitomo Electric Industries, Ltd.

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