

Development of a competitively priced lubrication system for JATCO's 1-axis e-Axle

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Summary

There are demands to reduce the size and cost of e-Axle systems used on electrified vehicles that have been spreading in recent years. A low-cost lubrication system with a simple structure and no oil pump has been built for JATCO's 1-axis e-Axle that uses a planetary gear set as the gearbox in order to downsize the system. Oil flow inside the unit was optimized to achieve both lubrication performance and excellent transmission efficiency.

1. Introduction

Advances are being made in downsizing and increasing the efficiency of e-Axle systems that integrate the drive motor, inverter and gearbox into one unit toward expanding the diffusion of electrified vehicles. Downsizing an e-Axle system produces many benefits with respect to improving vehicle packaging, including securing luggage space and interior roominess, obtaining space for mounting the battery pack, which has been increasing in volume in recent years, and providing collision safety space, among other things. The resulting improvement of mountability also reduces vehicle assembly costs. JATCO's 1-axis e-Axle uses a planetary gear set as the gearbox, which downsizes the unit by suppressing its height and longitudinal length compared with the previous 3-axis system.

This article describes the low-cost lubrication system adopted for the 1-axis e-Axle.

2. Structure of 1-axis e-Axle and lubrication system

2.1 Structure of 1-axis e-Axle

The structure of the 1-axis e-Axle is shown in Fig. 1. The 1-axis e-Axle uses a planetary gear set as the gearbox, with the motor rotating shaft and output shaft of the gearbox coaxially mounted. Lubrication oil is enclosed inside the gearbox, and oil seals are provided between the motor and the gearbox to prevent gearbox oil from penetrating into the motor chamber. The system is structured such that the output shaft passes through the hollow motor shaft. Because the interior of the hollow motor shaft is connected to the gearbox, a bearing and an oil seal are also positioned on the opposite side of the gearbox from the motor. This bearing is positioned on the left-hand (LH) side of the vehicle in the newly developed 1-axis e-Axle, so it is referred to here as the LH bearing. Lubrication is also provided to this LH bearing and oil seal that are located at some distance from the gearbox.

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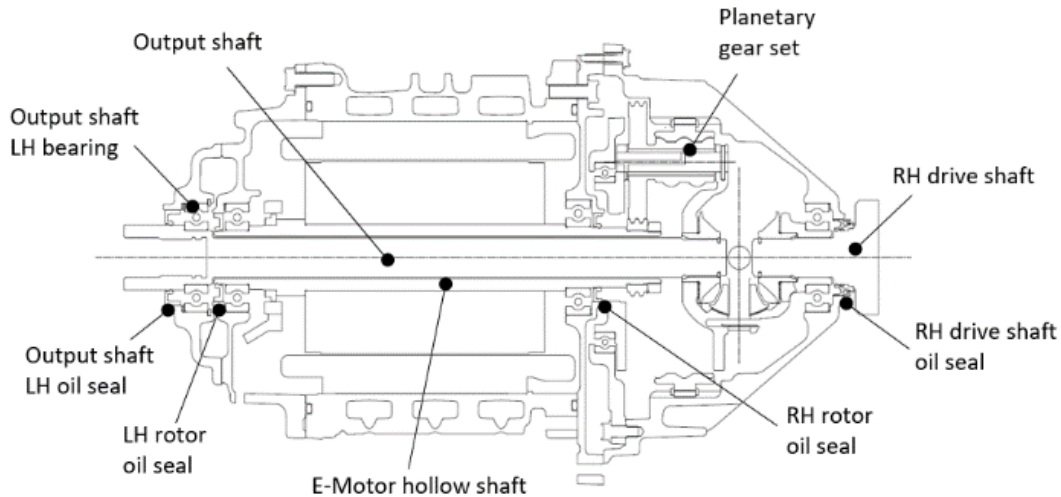


Fig. 1 1-axis e-Axle structure

2.2 Development concept of the lubrication system

The development concept of the lubrication system for the 1-axis e-Axle had the following three aims.

- (1) The lubrication system does not use an oil pump in order to reduce the cost and size, whereas a planetary gear set ordinarily has an oil pump to forcibly lubricate the interior of the shafts.
- (2) The lubrication system adopts an oil catch structure for circulating oil to lubricate the planetary gear set and the LH bearing.
- (3) Oil churning resistance is kept to a minimum, thus achieving high transmission efficiency combined with lubrication performance.

2.2.1 Lubrication system using an oil catch structure

Figure 2 shows the lubrication system incorporating the oil catch structure.

Oil splashed by the rotating planetary gears is captured by the oil catch positioned at the top of the case. Captured oil is distributed through oil holes in the e-Axle case to lubricate the planetary gear set and the LH bearing.

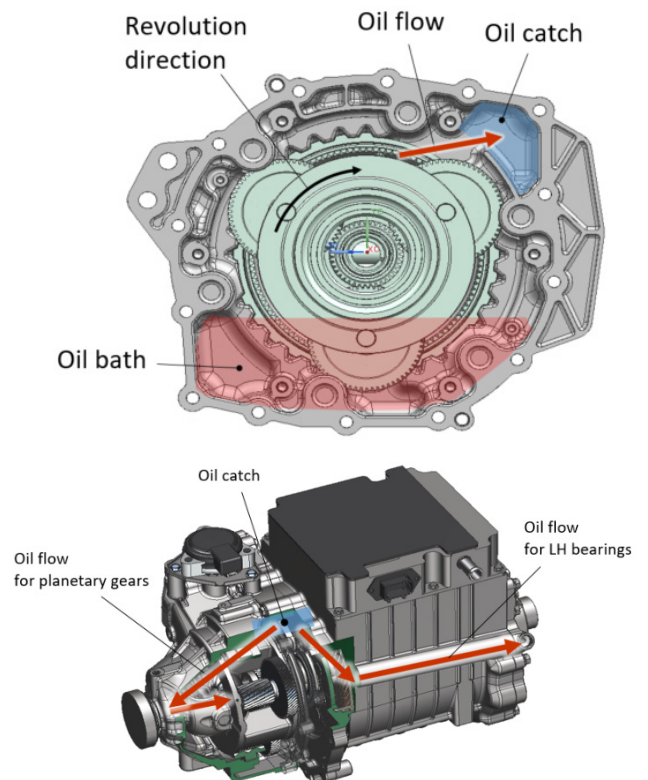


Fig. 2 Lubrication system for 1-axis e-Axle

2.2.2 Lubrication of the planetary gear set

The pinion gear of the planetary gear set revolves around the sun gear while rotating on its own axis. As shown in Fig. 3, the oil level is set so that the pinion gear is immersed in oil at low rotational speeds. Revolution of the immersed pinion gear churns oil toward the center of rotation of the planetary gears, thereby lubricating every part of the planetary gear set.

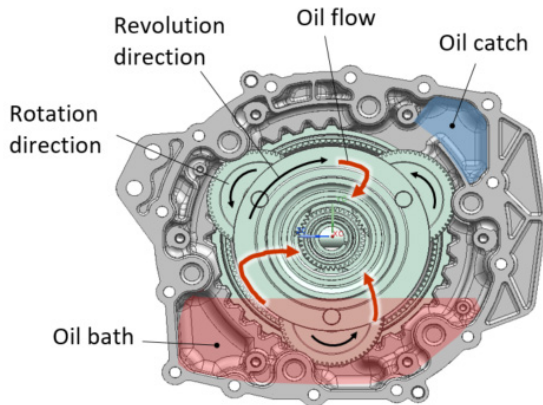


Fig. 3 Oil flow under low speed

As the rotational speed rises, centrifugal force reduces the amount of lubrication provided by churning caused by the pinion gear. However, because the quantity of oil splashed into the oil catch increases, oil captured by the oil catch is supplied through the case oil holes to the center of rotation of the planetary gears. As shown in Fig. 4, oil that reaches the center of planetary gear rotation is supplied to all parts of the planetary gear set by centrifugal force.

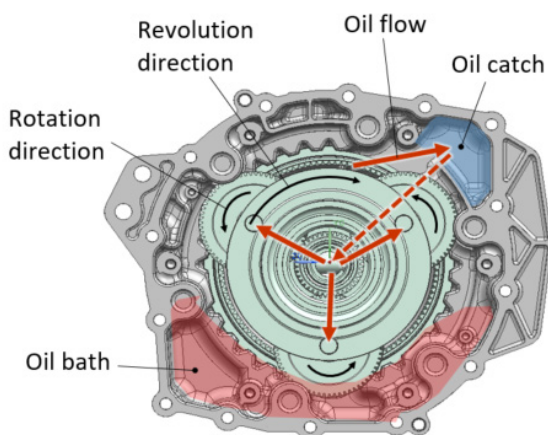


Fig. 4 Oil flow under high speed

2.2.3 Lubrication of LH bearing

The oil flow route to the LH bearing is shown in Fig. 5. As the rotational speed rises, lubrication oil from the oil catch reaches the LH bearing. However, there was concern that lubrication might be insufficient right after the start of rotation. To avoid that, the oil level on the LH bearing side is set higher than that on the gearbox side so that the lower half of the bearing is immersed in oil from a zero speed condition. Oil supplied from the oil catch is returned to the gearbox through the hollow rotating motor shaft, which provides a structure for circulating the oil.

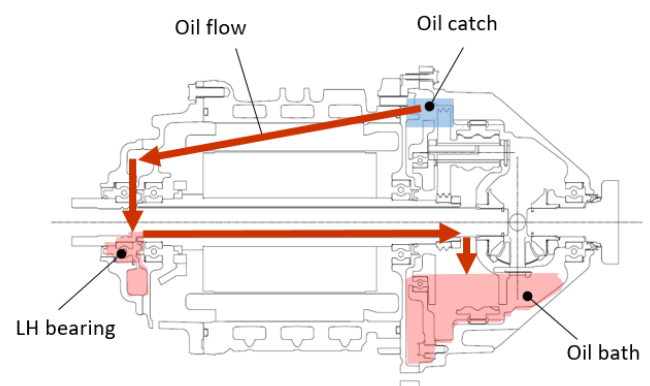


Fig. 5 Oil flow for LH bearing

3. Lubrication system issues and feasibility

3.1 Feasibility of lubrication system using the oil catch structure

To ensure the feasibility of the lubrication system using the oil catch structure, the oil catch had to be designed so that it could efficiently capture oil splashed by the rotating planetary gear set. Oil flow inside the gearbox was simulated using computational fluid dynamics simulation software. An oil flow visualization test was conducted to verify the validity of the simulation results. Figure 6 shows the oil flow simulation results, and Fig. 7 shows the appearance of the oil flow visualization test using a transparent resin case. The simulation results were validated experimentally using a test gear set, enabling the oil catch to be designed with the optimal geometry and optimally positioned.

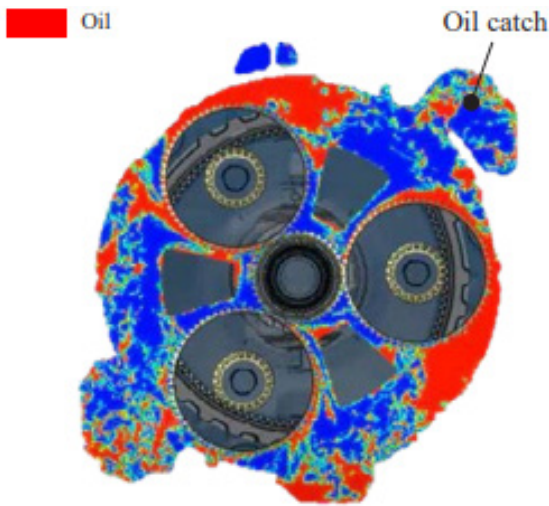


Fig. 6 Oil flow simulation

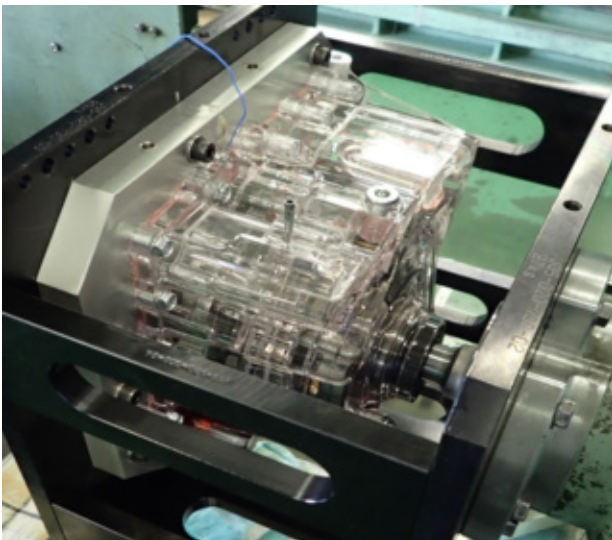


Fig. 7 Oil flow visualization test

3.2 Issues and feasibility of planetary gear set lubrication

As described in section 2.2.2, lubrication provided by pinion gear churning is dominant from a zero speed condition to the low-speed range, and oil catch lubrication is dominant in the medium- to high-speed ranges. The two lubrication methods have contradictory characteristics relative to their respective rotational speed. Accordingly, one issue was to ensure a stable supply of the lubrication volume required by the planetary gear set in all speed ranges.

The lubrication volume provided by pinion gear churning and that provided by oil catch lubrication were measured. Figure 8 presents the measured results that

validated the feasibility of these methods of lubricating the planetary gear set. The results confirmed that the combination of lubrication by pinion gear churning and oil catch lubrication stably supplied lubrication to the planetary gear set in all speed ranges.

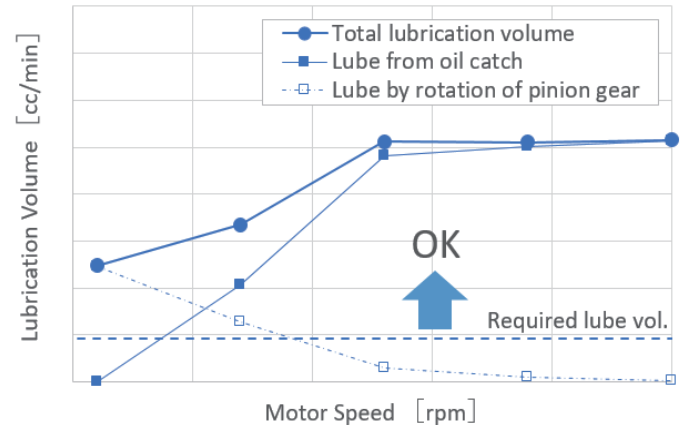


Fig. 8 Results of planetary gear lubrication volume measurement

3.3 Issues and feasibility of LH bearing lubrication

There was concern about an increase in oil churning resistance because the LH bearing would be immersed in oil from a zero speed condition, as mentioned in section 2.2.3. Therefore, oil churning resistance was reduced by actively retaining oil in the oil catch so as to lower the dynamic oil level on the gearbox side. The oil catch capacity was designed so as to ensure the desired lubrication performance and also reduce oil churning resistance by lowering the dynamic oil level.

The effect of retaining oil in the oil catch on lowering the oil level was validated by conducting a visualization test of the oil catch and by measuring the oil level in the gearbox. The transmission efficiency of the gearbox was also measured and was confirmed to be superior to that of the conventional 3-axis system.

Figure 9 shows the results of the oil level measurement. For comparison, the oil level was also measured for a unit with an ineffective oil catch. The visualization test results and the measured oil level results confirmed that the dynamic oil level was reduced as expected.

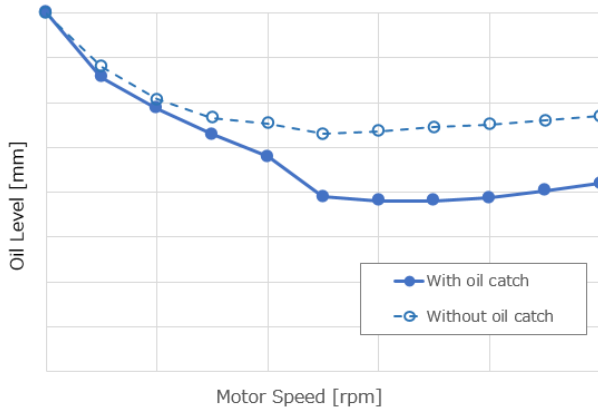


Fig. 9 Results of gearbox oil level measurement

Figure 10 compares the torque loss of the gearbox of the 1-axis e-Axle with that of the conventional 3-axis e-Axle. The torque loss of the 1-axis e-Axle has been reduced to approximately one-half that of the 3-axis unit. That reduction is attributed to the effect of reducing oil churning by lowering the oil level and the effect on reducing mechanical loss by the bearing structure of the 1-axis e-Axle which does not use tapered roller bearings.

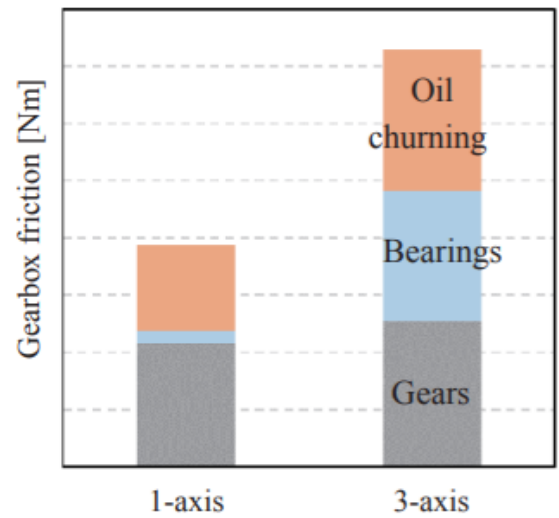


Fig. 10 Gearbox friction loss

4. Conclusion

A lubrication system with a simple structure was built for the 1-axis e-Axle by using a planetary gear set instead of adopting an oil pump. Oil flow inside the unit was optimized so as to both ensure lubrication performance and reduce churning resistance. That worked to achieve a low-cost, compact and high-efficiency 1-axis e-Axle system.

5. References

- (1) Hiroki UEHARA, Shota OIKAWA, Kazuhiko YOKOYAMA, “Compact and high-efficiency 1-axis e-Axle with a planetary gear set,” JATCO Technical Review, No. 21, pp. 77-80, 2022.

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