Design concept and technical verification of low viscosity reducer oil

Kazunori ISHIGAMI* Gou KATOU* Makoto MAEDA**
Ryo SASAKI*** Hitoshi KOMATSUBARA***

Abstract

The development of electric vehicles (EVs) is accelerating in response to the urgent need to curb CO_2 emissions and combat global warming. However, increasing battery capacity to ensure a sufficient driving range significantly increases manufacturing costs. This study aims to reduce the necessary battery capacity by lowering electric power consumption in EVs. To achieve this, a low-viscosity oil for reduction gears was developed, and its performance was evaluated. Specifically, the study focused on friction (agitation resistance) in the reduction gears, designed low-viscosity oil to reduce power consumption, and verified its performance through in-life tests. The results confirmed that the developed low-viscosity oil significantly reduced friction in the reduction gears compared to conventional oil, leading to lower power consumption. This low-viscosity oil effectively improves the electric power efficiency of EVs and is expected to contribute to reducing battery costs.

1. Introduction

In recent years, as global regulations on CO_2 emissions have tightened to combat climate change, the automotive industry has accelerated electrification. Alongside traditional internal combustion engine vehicles, automakers and suppliers are focusing their efforts on developing and promoting hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs). However, a significant challenge to the widespread adoption of BEVs is the limited driving range. Extending the range requires increasing battery capacity, which significantly raises costs. Therefore, improving energy efficiency (hereafter referred to as ʻenergy savingʼ) is a critical solution to this issue.

Additionally, to meet the demand for smaller, more powerful EVs, drive systems that combine small-diameter, high-revolution motors with high reduction-ratio gears are becoming mainstream[1]. With the adoption of such high-power-density motors, addressing motor heat generation has become a new technological challenge, and motor-oil cooling systems are gaining attention as an effective solution.

This study focuses on reducing torque loss (friction reduction) in reduction gears to lower electric power consumption in EVs. As part of this effort, a low-viscosity reducer oil suitable for motor oil cooling was developed. This paper presents the design concept and verification results of the new oil.

2. Development aims and objectives

The aim was to create the lowest viscosity oil among all the benchmark oils in order to reduce electricity consumption, while also achieving better performance than conventional oils (ATF) in terms of friction characteristics during sliding, fatigue prevention of metal parts, and anti-seizing performance.

*Hardware System Development Department **Innovative Technology Development Department ***ENEOS Corporation

The target viscosity was set to a kinematic viscosity of 11 mm^2/s or less at 40°C (Fig. 1) to meet the electricity consumption target of the vehicle and align with market benchmarks for reducer oils. Additionally, the oil was designed to ensure electrical insulation for motor oil cooling. The target electrical insulation property was set to exceed the volume resistivity of current motor cooling oils.

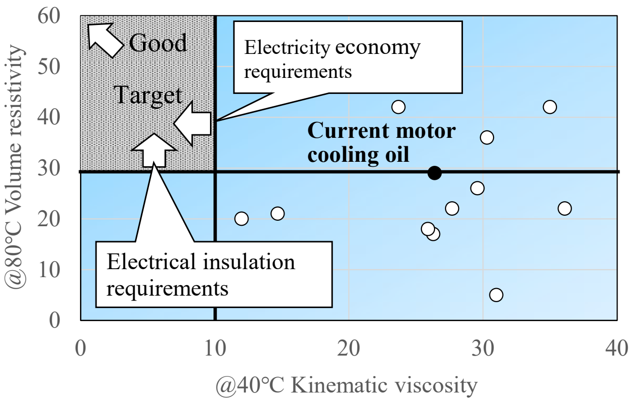


Fig. 1 Target value development oil

3. Issues with low viscosity

The Stribeck curve in Fig. 2 demonstrates that, in the fluid lubrication range, the low-viscosity ATF has a lower coefficient of friction compared to conventional oils. However, in the mixed lubrication range, the oil film becomes thinner, making metal contact more likely. This can lead to an increase in the coefficient of friction and a decrease in the anti-fatigue and anti-seizing performance of the metal.

Conventional low-viscosity technologies have prevented metal contact (improved extreme pressure) by blending highly viscous oil-film-forming polymers to ensure the formation of an oil film[2]. However, to achieve the target viscosity, these polymers, which have a thickening effect, were excluded from this development.

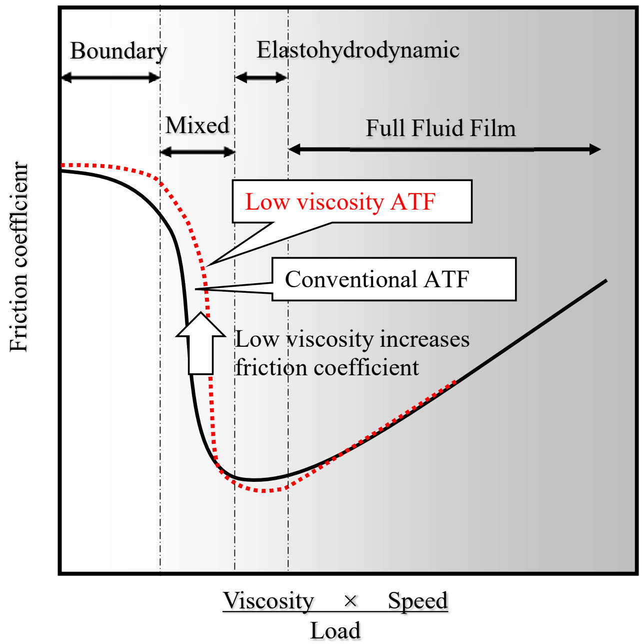


Fig. 2 Stribeck Curve

4. Design concept

To prevent metal contact in the mixed lubrication zone caused by low viscosity, extreme pressure needs to be enhanced by forming an additive film. This was achieved by utilizing the heat generated from the thinning oil film to rapidly form adsorption and reaction films on the sliding surfaces[3]. Two phosphorus-based additives with distinct properties were blended to quickly create protective films in the mixed lubrication zone.

5. Improvement of extreme-pressure performance

5.1 Blending of phosphorus additives

To mitigate rapid load fluctuations in reduction gears, preventing metal contact between the sliding parts by forming a protective film as early as possible in the mixed lubrication zone is crucial. A strategy was developed in which an adsorption-type phosphorus additive forms a film on the sliding surfaces under low surface pressure and low-speed conditions, while a chemical-reaction-type phosphorus additive creates a film under high surface pressure and high-speed conditions.

5.2 Revision of additive formulation

Considering the performance requirements[4] of the reducers outlined in Table 1, the additive formulation was revised from existing oils to ensure both extreme pressure and electrical insulation properties, while addressing the challenge of low viscosity. The revision aimed to eliminate unnecessary additives from the reducer oil to maximize the formation of a reactive film on the sliding surfaces. Specifically, dispersants and friction modifiers, which affected the friction characteristics of the wet clutches, were removed.

Table 1 Performance Required for e-Axle

Performance required for e-Axle (Reducer)	Performance required for Oil	Objectives of additive formulation optimization
Reduction of agitation resistance	Low viscosity	Elimination and reduction of dispersants with thickening effects, FM agents
Oil-cooling the motor	Electrical insulation	Elimination and reduction of conductive dispersants and FM agents
Gear durability	Wear resistance, Pitching resistance, Scuffing resistance	To maximize the effectiveness of the two phosphorus-based additives, the dispersant and FM agent that cause competitive adsorption reduced or eliminated

6. Verification results

The friction and anti-seizing performances of the developed oil were compared with those of the conventional oil and low-viscosity ATF. The results are discussed below.

6.1 Friction coefficient

Friction coefficient measurements were conducted under the mixed lubrication conditions specified in Table 2 using the mini traction machine (MTM) test. The results, shown in Fig. 3, indicate that the newly developed oil has a lower coefficient of friction compared to the low-viscosity ATF. These results validate the design concept, confirming that the adsorbed and chemically reacted phosphorus additives form adsorption and reaction films on the sliding surfaces, preventing metal contact and resulting in reduced friction.

Table 2 MTM test conditions

Surface pressure[GPa]	1.2(Load 60N)
Speed[mm/s]	10-3000
Oil temperature[°C]	40
Slip ratio[%]	50

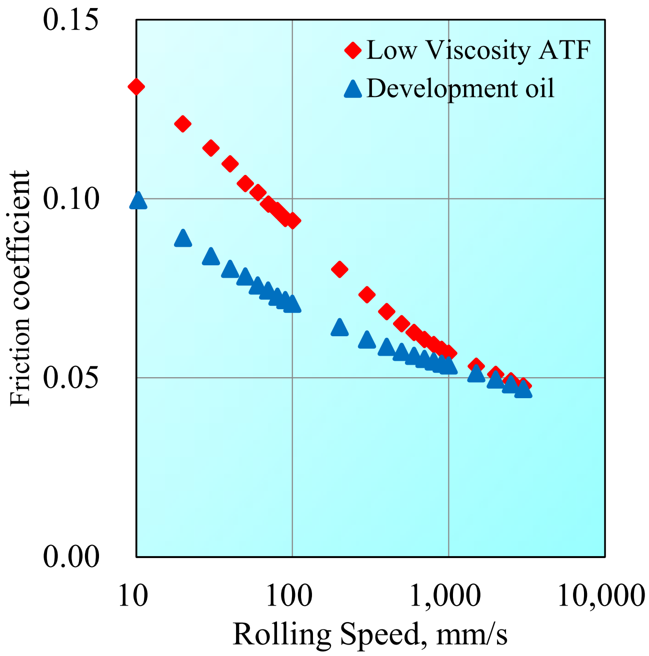


Fig. 3 MTM test

6.2 Anti-seizing performance

Figure 4 presents the evaluation results of the anti-seizing performance in a high-speed four-ball test. When the conventional ATF was replaced with low-viscosity ATF, the maximum non-seizing load decreased compared to the existing oil. However, the maximum non-seizing load of the newly developed oil was higher than that of the conventional ATF, as predicted by the design concept. These results validate the design concept, where the additive formulation was revised to form a reactive film on the sliding surface.

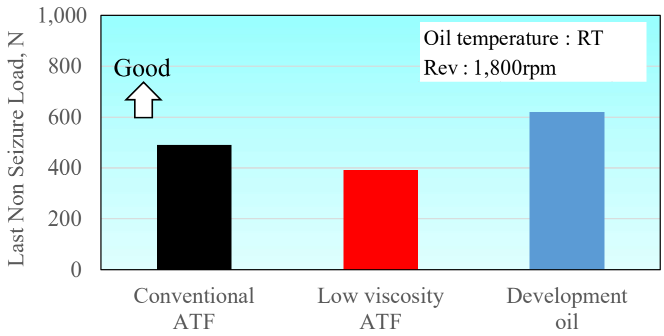


Fig. 4 High-speed 4-ball test

6.3 Assessment of seizure resistance under assumed conditions of actual gears

The anti-seizing performance of the developed oil was compared to that of the existing oil using high-peripheral-speed gears under test conditions simulating a poorly lubricated environment on the gear fracture surface and the running pattern of a vehicle (Fig. 5). The developed oil demonstrated superior resistance to seizure, with the rotational speed at which surface damage occurred being higher than that of the conventional ATF, particularly under conditions simulating BEV start-up running (high torque).

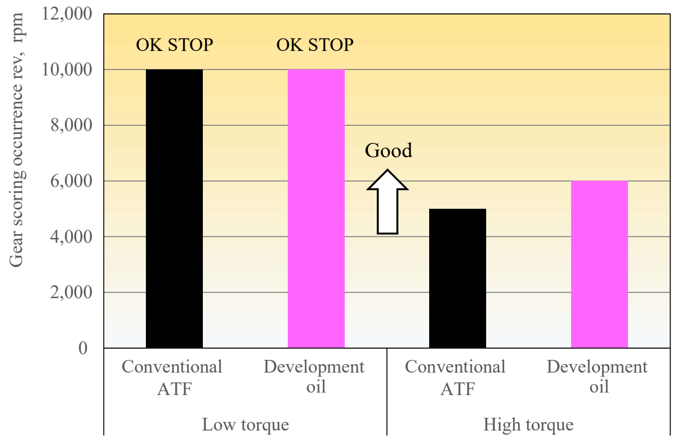


Fig. 5 High-speed gear seizure test

7. Summary

In this study, a reduction gear oil for electric vehicles was developed, yielding the following results:

The newly developed reduction gear oil demonstrated industry-leading low-viscosity characteristics while offering excellent friction properties, anti-fatigue performance, and anti-seizing performance during gear component sliding. Additionally, the oil provided the required electrical insulation for motor oil cooling.

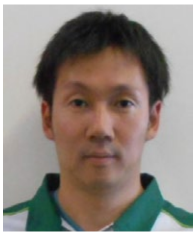
Performance evaluation tests confirmed that the newly developed oil improved energy efficiency by approximately 10% compared to conventional oils. This efficiency improvement is expected to directly contribute to extending the driving range of electric vehicles.

The findings from this study will help address technical challenges in the promotion of electric vehicles and will make a significant contribution to advancing lubricant design technology in the future.

8. References

1) Tsukagoshi, et al: Development of Synchronous 3-Pulse Control in High-RPM Motors for e-Axle, Journal of Society of Automotive Engineers of Japan, Vol. 53, No. 3, May 2022
2) Masuda: Development of ultra-low viscosity ATF, JXTG Technical Review, Vol. 61 (2019.7)
3) Ariyama, Komatsubara: Elucidation of Friction Reduction Mechanism of Low Viscosity Differential Gear Oil, Tribology Conference (Fall 2017)
4) Ishigami, Arakawa, Maeda: History and Latest Trends in Automotive Transmission Oils, Tribologists (2020)
5) Ishigami, Kato, Maeda: Design Concept of Low Viscosity Reduction Gear Oil and Its Verification, Proceedings of Tribology Conference 2024 Fall Nago, 2024, A32

■ Authors ■


Kazunori ISHIGAMI


Gou KATOU


Makoto MAEDA