Proposal for Evaluation Criteria for Checking Deterioration of Lubricating Grease Used on Trains

Sumiko HIBINO  Junichi SUZUMURA  Sadayuki KIKAWA  
Lubricating Materials Laboratory, Materials Technology Division 
Yasutomo SONE  
Materials Technology Division 

Running gear maintenance is indispensable for maintaining the safe operation of railway vehicles. The lubricant used on bearings is therefore regularly replaced in axle boxes and traction motors, to maintain performance. Lubricant deterioration depends on the service conditions in which it is used, therefore it was necessary to determine a set of criteria to evaluate its state. A series of criteria were formulated in the 1980’s based on the correlation between analysis data and the process of deterioration of lubricating grease as it is used, and have been widely used until today as a guide for replacing grease. This paper therefore revises the criteria in the light of current running conditions.

Keywords: grease, deterioration, replacement period, maintenance, criteria

1. Introduction

Lubricating grease and oil used on railway vehicles gradually lose their lubricant properties through degradation. It is therefore necessary to replace lubricants before they become completely ineffective to maintain relevant components and equipment in good working condition. In another aspect, the prediction of the progress in degradation is difficult because it is changeable depending on the driving condition of the vehicle, so it is not easy to determine the effective timing of replacement. Therefore, by the former Japanese National Railways, from the empirical knowledge of degradation analysis of lubricants, the “management reference items” as the indexes for monitoring the degraded state of lubricants and “the replacement threshold values” as the criteria of the degradation degree for judgement of lubricants replacement were set from the past degradation data of lubricants used in vehicles in service.

The judgment of the degraded state of lubricants using this replacement threshold value is implemented in such a manner as to evaluate the degradation state of the lubricant and judge the necessity for replacement by extracting a target lubricant from equipment, finding analytical values of management reference items and comparing them with the replacement threshold values.

The replacement threshold values of the lubricating grease has been used widely as a basis of the check and judgement of the grade of the usage state of grease, and the decision of the renewal cycle of grease (the frequency) and the elongation of its service duration.

In recent years, because there have appeared cases in which evaluation by the conventional replacement threshold value is difficult to apply due to the introduction of new brand grease which indicates a different degradation tendency and the changes in driving conditions, etc., a revision of the replacement threshold values has become necessary to reflect current driving conditions. So the new replacement threshold value of each management reference item as well as the analysis method suitable for it was considered.

2. Review process for the grease replacement threshold values

2.1 Original replacement threshold values and the corresponding key standard values

The 7 key standard values used to assess railway vehicle grease are: penetration (consistency, the relative hardness of the grease), metallic residue (iron and copper content), acid number, dropping point (dropping temperature by heating), the oil separation rate (lost percentage of base oil relative to initial state) and water content [1]. The conventional grease replacement threshold values corresponding to the respective management reference items are indicated in Table 1. Grease is kept in a semi-solid state by adding a thickening agent to the base oil. The penetration, dropping point and oil separation rate are specific to grease.

The conventional replacement threshold values were first described in full in [2] in 1980. In addition to these 7 items, the antioxidant agent consumption rate among the additives was also considered. The scope of grease replacement threshold values is stated to be:

Table 1 Conventional replacement threshold values for grease [1]

| Management reference items | Replacement threshold values |
|---------------------------|-----------------------------|
|                           | Axle journal bearing        |
|                           | Traction motor bearing      |
| Cone penetration (Consistency) | 100-400 | 150-350 |
| Iron content, %           | ≤ 1.0%                      |
| Copper content, %          | ≤ 0.3%                      |
| Acid number, % (Converted to oleic acid) | ≤ 5.0% | ≤ 5.0% |
| Dropping point variation, °C | ± 20°C                      |
| Oil separation rate, %     | ≤ 30.0%                     |
| Water content, %           | ≤ 5.0%                      |
2.2 Problems with evaluation using conventional replacement threshold values

Of the management reference items indicated in Table 1, the iron content, dropping point and oil separation rate became difficult to evaluate using the conventional replacement threshold values as described below:

(1) Deterioration in lubricant properties due to grease degradation or contamination from extraneous substances can accelerate wear in the raceway and at the rolling contact surface of rolling elements in the bearing. Iron content was therefore used as an indicator of the level of wear inside the bearing, but a mixture of grease and abrasion powder from fretting which occurs at the contact surface between the inner ring and the backing ring (Fig. 1) of the axle bearing can lead to a false reading which exceeds the replacement threshold value, which means that on occasion wear inside the bearing cannot be estimated correctly.

(2) The dropping point is taken as an index of the heat resistance of the grease, and, it’s the temperature at which liquefied grease hangs down and falls when the grease is heated, and is the temperature at which metallic soap dissolves into the base oil in the case of metallic-soap thickened grease [3]. For grease thickened by lithium complex soap (hereinafter called lithium complex soap grease) used on trains, cases were found where only the dropping point fell below the replacement threshold value whilst the other values did not indicate deterioration, which triggered the need for this phenomenon to be investigated further.

(3) The oil separation rate can be calculated either using the method applied by RTRI or the method used by the Japanese Society of Tribologists (hereinafter called JAST), which means that a decision has to be made about which approach to use.

(4) Among the management reference items, several appeared to have more than one possible analytical method, producing different analytical values. Therefore, it will be necessary to set the replacement threshold values according to and associate them with designated analysis methods.

3. Revision of the replacement threshold values

The conventional standard replacement threshold values were established empirically using the collected grease analysis data from vehicles being used at the time they were set. Since then they have not been revised in the light of changing driving conditions and performances of grease.

As preparation for revision, used grease samples were extracted for analysis from vehicles currently operated by JR, to investigate their state of deterioration. The greases analyzed in this investigation are indicated in Table 2.

Grease was extracted from axe bearings (analyses were conducted on grease from the inboard of double row bearings) and traction motor bearings (gear side: Cylindrical roller bearings and opposite side: deep groove ball bearings).

Grease was extracted from selected vehicles that had distinctive running conditions, i.e. running long distances every day, running in snowy regions, passing through mainly mountainous regions or running on lines close to the coast, etc. In addition, for each of the grease brands used, priority was given to selecting vehicles that had severe operating conditions, such as vehicles that had run a long distance since the last grease renewal, and vehicles having a large axle load due to the motive power unit. Vehicles with traction motors in operation that had been re-greased in the interim, however, were excluded.

This investigation was performed exclusively on vehicles using currently available grease brands, whereas further work will be required in order to update these results using synthetic oil grease (grease made of synthetic oil as base oil) which is expected to come into use, and show a different deterioration pattern to other conventional mineral oil greases (grease made of refined crude oil as base oil).

| Table 2  | Surveyed grease brand (Mineral oil based grease) [1] |
|----------|-----------------------------------------------------|
| Notation | Type of thickener                                   |
|          | Worked penetration (25℃)                           |
|          | Dropping point (℃)                                 |
| When used on axle journal bearings                |                                                 |
| J-A      | Lithium calcium complex soap                        | 294 | 177 |
| J-B      | Lithium complex soap                               | 297 | 177 |
| J-C      | Lithium soap                                       | 280 | 186 |
| J-D      | Natrium soap                                       | 232 | 212 |
| When used on traction motor bearings              |                                                 |
| T-A      | Lithium complex soap                               | 280 | ≥ 260 |
| T-B      | Lithium complex soap                               | 278 | 212 |
| T-C      | Lithium soap                                       | 280 | 186 |
| T-D      | Urea                                               | 279 | 280 |

3.1 Iron content

3.1.1 Axle bearing grease

The iron content levels in axle bearing grease extracted from an actual vehicle are indicated in Fig. 2. The level...
of iron found in axle bearings through analysis is sometimes high because of abrasion powder getting mixed into grease from fretting between the inner ring and the backing ring as described in Fig. 1. Grease with an auburn appearance is a clear sign that abrasion powder from fretting has contaminat-ed the grease. The problem is therefore, from the values ob-tained through analysis, how to estimate the iron content from wear, as opposed to iron in the grease from another source.

The influence of fretting wear on a machine could there-fore be considered to be “degradation of a lubricant by abra-sion powder getting mixed” [3]. Metal powder from wear is generally harder than the base metal due hardening through abrasion. However, since the wear powder particles from fretting are small, and there is some adhesion between min-ute oxidation powder particles and metal powder between the contact surfaces, close metallic contact is diffused [4], which has the effect of both accelerating and reducing wear.

Consequently, it is not clear what kind of influence fretting wear powder has on bearing lubrication. A test was therefore performed to evaluate the service life of the lubricant, using iron oxide to imitate the very small grains of fretting wear powder (ferric oxide: representa-tive particle diameter about 0.5 μm) which was mixed into the grease. Results of the test showed no clear difference be-tween the case where about 1% of the iron, that is, the replacement threshold value, was mixed into the axle bear-ing grease and the case where no iron was mixed. This outcome indicates that fretting wear powder has a slower impact on the lubricant than abrasion powder which is usually assumed to be mixed into the grease in use.

However, as mentioned above, it is not possible to distin-guish the source of iron residue in the grease between fretting wear powder from outside and abrasion powder gener-ated inside the bearing, therefore, the replacement threshold value for iron in axle bearing grease was not changed and grease refilling is recommended as before when the analysis value exceeds the replacement threshold value. As such, the obvious presence of fretting wear powder in the axle bearing grease is not enough to establish wear inside the axle bear-ing, therefore the evaluation of the state of health of grease should not be based only the state of the grease, but also on the state of wear of the bearing. When it is clear that fretting wear powder has been mixed into the bearing, it is rec-ommended to take measures to prevent it.

3.2 Oil separation rate

3.2.1 Traction motor bearing grease

Data from analyses of grease extracted from traction motor bearings on actual vehicles were conducted for each brand of grease. The greases (grease T-A and T-C) are indicated in Fig. 3(a), and show similar tendencies in terms of the relationship between oil separation rate and iron content. Both greases T-A and T-C were found to have more iron resi-due when the oil separation rate exceeded about 6%. This is interpreted as being the result of wear generated by a fall in the release of oil to the area to be lubricated. This clear cor-relation was not observed with any other grease.

Based on these results and taking into consideration the replacement threshold value 0.5% of iron in traction motor bearings, the oil separation rate of 6%, beyond which an in-crease in iron is observed in grease, could be applied as the standard value for evaluating oil seepage. Other data how-ever showed that iron in grease did not increase even when the oil separation rate exceeded 6%, which suggests a great-er variation in data regarding degree of wear progression. Aside from this, in practice oil separation rates are kept below or equal to 15% for traction motor bearings, which means that the conventional replacement threshold value of 30% is too high to be the standard. The oil separation rate of 15% could therefore be used as the new standard, since no problems have been found in bearings, even at this rate, evi-denced by data in Fig. 3(a) collected from vehicles in opera-tion which had been returned to the maintenance plant and re-greased without any problems being found.

Consequently, the former value (6%) may be thought of as a “precursor value” whereas 15% would be the “recommended replacement value.” Since the conventional replacement threshold value is equivalent to the recommended replace-ment value, the replacement threshold value for oil separation was changed to 15% from the conventional 30% considering actual deterioration, whereas the 6% found to trigger an in-crease in iron was prescribed as the precursor value.

3.2.2 Axle bearing grease

Figure 3(b) illustrates the relationship between iron content and the oil separation rate in axle bearing grease. The values obtained through analysis for grease which clearly contained fretting wear powder were excluded. The correlation between iron content and the oil separation rate found in traction motor bearing grease was not seen in axle bearing grease. This could be explained by the greater amount of grease used on axle bearings than on traction mo-tor bearings. The maximum rate of oil separation was about 8% which is lower than that in traction motor bearings.

Applying the same logic as with the traction motor bearings, the replacement threshold value for the axle bearings should therefore be 8%. However, there is insuf-ficient evidence to suggest that the lubricant properties of the grease are compromised when the oil separation rate exceeds that value. Accordingly, the replacement threshold value of the traction motor bearing can be applied because, in the case of the traction motor bearing, the amount of grease is small, with the result that the degree of deterio-ration of the grease seems to be better reflected than in the
churning in the roller bearings and grease itself can become mixed in. This makes interpreting results difficult: it is not possible to be sure what the calculated numerical output value represents since it was obtained on the premise that only the oil release was variable and the volume of thickener was invariable.

The RTRI formula however, estimates ‘oil consumed’ in the grease which occurs through bleeding. In general, when the content of oil in grease falls below 40-60%, oil is no longer released from the thickener, marking the end of the grease’s serviceable life as a lubricant [6]. While about 20-25% of the base oil is trapped in the thickener because of intermolecular force with the thickener and rarely contributes to lubrication, the remaining base oil resides in the gaps of a network structure by capillary action, and it is thought that it is released and contributes to lubrication naturally [6]. Thus, the rate at which oil content is consumed is an important factor in deciding whether a grease is still in good enough condition to be kept in use.

The RTRI formula is therefore more appropriate for calculating the deterioration rate, using the new standard values.

The two methods differ because of the difference in approach and ultimate purpose of the resulting calculation.

Nevertheless, given the ambiguity that arises from having two calculation methods for evaluating different aspects given the same name, the expression used until now for the RTRI calculation method has been changed to the “decreasing rate in oil content.”

For the analysis, the Membrane filter filtration method replaces the conventional Soxhlet extraction method.

| Table 3 | Formulae for Oil separation rate and oil separation content |
|---------|-----------------------------------------------------------|
| (a) Oil separation rate (RTRI formula) | \( \frac{B_u - B}{B_u} \times 100 \% \) |
| (b) Oil separation content (JAST formula) | \( \frac{T - T_c}{T_c} \times 100 \% \) |

\( B_u \) — Oil rate of new grease, \( B \) — Oil rate of used grease, \( T_c \) — Thickener rate of new grease, \( T \) — Thickener rate of used grease

3.3 Dropping point

The dropping point (hereinafter called DP) is an index of heat resistance, however, a lower dropping point in the grease used does not pose any particular problem when there is a sufficient margin between the lower DP and operating temperatures. Consequently, the influence of a lower DP on lubrication performance and life span of a lubricant are still unclear, which has made it difficult to fully understand and manage any problems.

Given this background, when there was insufficient grease to be collected for analysis, priority was given to other management reference items, other than DP, for testing and decision making.

Over the past few years, lithium complex soap grease has become widely used for traction motor bearings. It is produced to have a DP “over 260°C” . In practice, this grease has been found to have a DP that can vary depending on batch, between 260- 290°C. This means that it is impossible to know the DP of each batch exactly, which makes checking the state of deterioration of the grease accord-
complex soap has an undeniable impact on its serviceable
DP cannot be expected to always behave in the same man
falls according to the mechanism described above, it can
mum operating temperature of 150
thought to be appropriate because the grease has a maxi
usual degradation range is ensured, as has been proven in
practice in actual vehicles in operation. Accordingly, the
replacement threshold value was set at 215℃ based on the DP
of lithium soap grease (about 190-215℃).

The management standard value, i.e. 215℃ can be thought to be appropriate because the grease has a maxi
imum operating temperature of 150℃, which is generally about 70% of the maximum permissible DP to ensure per
formance (215℃ × 0.7 = 150.5℃). However, even if the DP falls according to the mechanism described above, it can be thought that the thickener deteriorates and at the same time partly loses its thickening function. Consequently, the thickener’s capacity to hold oil weakens and the oil re
lease tendency changes. As a result, the grease with lower DP cannot be expected to always behave in the same manner as lithium soap greases.

The variation in the performance and alteration of complex soap has an undeniable impact on its serviceable life. As such, based on the required DP of 260℃ for lithium
complex soap grease and the conventional replacement threshold value, minimum temperature-fall limit (fall of 20℃), the precursor temperature gives 240℃. When grease loses oil content, there is a possibility that DP rises, but this can be cross-checked with any other reference items (oil separation rate or metal content). For greases with thickeners other than the lithium complex soap, replacement threshold value was not modified. The dropping point test method (JIS K 2220.8.4:2013) was not changed either.

4. Next generation replacement threshold values

The replacement threshold values were revised as shown in Table 4, in the light of the considerations described above. Currently, the management reference items first focus on natural deterioration of the grease itself, followed by deterioration due to contamination from the outside. From now on, new replacement threshold values will also be used as a means to evaluate the state of health of grease, determine grease replacement cycles and whether grease maintenance intervals should be extended. The revised contents are summarized below.

1) Oil separation rate

This was renamed “decreasing rate in oil content”. The replacement threshold value is changed to 15% from the conventional 30%, taking actual degraded state into consideration. The second change was to the precursor value, which was set at 6% which is the rate at which iron content starts to increase. The Membrane filter filtration analysis method replaced the conventional Soxhlet extraction method.

2) Dropping point

A new replacement threshold value was set at 215℃ for lithium complex soap grease alone. 240℃ was set as the precursor value based on the required DP of 260℃ for lithium complex soap grease performance. The replacement threshold value was not changed for greases with other thickeners. The dropping point test method was not changed (JIS K 2220.8.4:2013) either.

3) Iron content

The replacement threshold value and grease refilling recommendations for when values obtained through analysis exceeded the replacement threshold values were not modified. For situations where axle bearing grease obviously contained fretting wear powder, it was determined that the evaluation of the state of health of grease should not be based solely on the analytical data of the grease but be confirmed by checking the state of wear of the bearings. No change was made to the method to be used for analysis (X-ray fluorescence analysis method).

5. Conclusions

Replacement threshold values have for many years been central to the management of grease used on railway vehicles. In order to ensure that evaluation methods are kept up to date and remain reliable in the face of new demands, situations encountered today where grease deteriorates were investigated in the light of basic data obtained from laboratory tests, and then the conventional replacement
threshold values were revised. A maximum amount of operational data was collected in order to propose new standard values, however, since these values are by definition common standards, certain margins had to be introduced to cater for the heterogeneity in operational conditions and rolling stock. As such, these new values will have to be monitored continuously in the light of actual analytical data as it is collected to ensure their validity. Furthermore, future technological improvements in railway vehicles, including new greases and evolving driving conditions will make it necessary for the values to be updated regularly over time.

References

[1] Suzuki, M., “The liquid tribology materials,” RRR, Vol. 57, No. 3, pp. 8–9, 2000 (in Japanese).
[2] Suzuki, Y., “Degradation judgment of used grease,” Journal of Railway Engineering Research, No. 37–2, pp. 89–94, 1980 (in Japanese).
[3] Japanese Society of Tribologists, Tribology Handbook (1st Edition), Yokendo Ltd., Tokyo, Japan, p. 712, 2001 (in Japanese).
[4] Shima, M. and Jibiki, T., “Fretting wear,” Journal of Japanese Society of Tribologists, Vol. 53, No. 7, pp. 462–468, 2008 (in Japanese).
[5] Suzuki, Y., “The soap in the use lithium grease, the piece for the wear metal, lubrication and by an atomic absorption way,” Journal of Japan Society of Lubrication Engineers, Vol. 14, No. 9, pp. 479–484, 1969 (in Japanese).
[6] Komatsuzaki, S., “Degradation of grease, the prevention countermeasure,” Mechanical research work, Vol. 28, No. 8, pp. 951–957, 1976 (in Japanese).
[7] Japanese Society of Tribologists, Junkatsu Handbook, Revise version, Yokendo, p. 356, 1987 (in Japanese).

Authors

Sumiko HIBINO
Senior Researcher, Lubricating Materials Laboratory, Materials Technology Division Research Areas: Grease, Tribology

Junichi SUZUMURA
Senior Researcher, Lubricating Materials Laboratory, Materials Technology Division Research Areas: Lubricants, Deterioration Analysis on Lubricants

Sadayuki KIKAWA
Assistant Senior Researcher, Lubricating Materials Laboratory, Materials Technology Division Research Areas: Lubricants, Deterioration Analysis on Lubricants

Yasutomo SONE, Dr. Eng.
Director, Materials Technology Division Research Areas: Chemistry for Lubricants

Table 4 Revised replacement threshold values for grease (Revised parts are shaded)

| Management reference items | Replacement threshold values | Methods of analyses |
|----------------------------|-----------------------------|---------------------|
|                            | Axle journal bearing        |                     |
| Cone penetration           | 100 - 400                   |                     |
| (Consistency)              | (25℃・Unworked)              |                     |
|                            | 150 - 350                   |                     |
|                            | (25℃・Unworked)              |                     |
|                            | Axle journal: ④ penetration |                     |
|                            | Traction motor: Spread meter|                     |
|                            |                             | Axle: 1/4 penetration |
|                            |                             | Traction: Spread meter |
|                            |                             |                     |
|                            | 5.0% or below               |                     |
|                            | Determination by infrared spectroscopy with model substance of Oleic acid |
|                            |                             |                     |
| Decreasing rate in oil content ① | 15.0% or below ② (Precursor value: 60.0%) | Membrane filter filtration method ⑤ |
|                            |                             |                     |
| Dropping point             | Lithium complex soap grease: 215℃ or over (Precursor value: 240℃) | Dropping point test method ④ |
|                            | Others: variation within ± 20℃ |                     |
| Iron content               | 1.0% or below ③ | X-ray fluorescence analysis method |
|                            | 0.5% or below ⑤ |                     |
| Copper content             | 0.3% or below ⑥ |                     |
| Water content              | 5.0% or below ⑦ | Karl Fischer moisture meter ⑧ |

① The name for the RTRI calculation method “oil separation rate” was changed to “decreasing rate in oil content.”
② Calculated as a percentage: amount of lost oil to the amount of oil content in the original grease.
③ When fretting abrasion powder has clearly been mixed into the axle bearing grease, judgement should be made with confirmation of the state of wear of the bearings not only by the threshold value, which should be taken only for decision to replace the grease.
④ Complies with JIS K2220
⑤ This can be derived and confirmed through the conventional Soxhlet extraction method as required.
⑥ Complies with JIS K2275