FUEL, LUBRICANT AND GREASE

1 Introduction

After fluctuating quite a bit during the previous three years, the price of crude remained relatively steady in 2017. The price of West Texas Intermediate (WTI), a grade of crude oil used as a benchmark for oil pricing due to its large volume of trade and many market participants, had declined dramatically by the end of 2015, but started rising gradually after an agreement to reduce production was signed in November 2016. However, the increased development and production of shale oil in the U.S. that accompanied the rise in crude oil prices in general curbed a significant rise in price, which reached about $50 US dollars per barrel at the beginning of 2017[1]. After that, it hovered around $45 per barrel until June and then rose to around $55 per barrel in July. It then gradually declined from the middle of September, dropping back to around $45 per barrel in January 2018. The fluctuations in price over the entire course of 2017 therefore remained within a range of $15 dollars per barrel.

The amount of crude oil imported into Japan in 2017 was 187.64 million kL, a decrease of 2.6% from the previous year, and the amount of crude oil processed in Japan was 186.79 million kL, a decrease of 2.3% from the previous year. Both of these statistics are currently trending downward[2].

Figure 1 shows the change in the amount of demand for petroleum products in Japan[3], with the total amount of fuel oil in 2017 estimated at 169.77 million kL (a 1.0% decrease from the previous year). Broken down by oil type, gasoline accounted for 51.11 million kL (a decrease of 2.2% from the previous year), diesel oil accounted for 33.38 million kL (a decrease of 0.1% from the previous year), and A class heavy oil accounted for 11.36 million kL (a decrease of 5.1% from the previous year), reflecting a lower demand than in the previous fiscal year in all categories. Moving forward, the overall demand for fuel oil is predicted to decrease by 1.5% on average per year (excluding C class heavy oil for generating electric power) from 2017 to 2021. By type of fuel oil, demand for gasoline is predicted to decline by 2.2% due to the popularization of environmentally-friendly vehicles and advances in low-fuel consumption technologies, while demand for diesel fuel is expected to remain flat.

2 Fuels

2. 1. Fuel Trends

The Second Notice of the Act on Sophisticated Methods of Energy Supply Structures announced in 2014 required Japanese oil companies to increase the installation ratio of their residual oil processing equipment for the purpose of promoting the effective use of fossil fuels. Each company had achieved this goal by 2017 by disposing of their atmospheric distillation equipment and reducing their nominal capacity. The average installation ratio of residual oil processing equipment at the target refineries in Japan improved from about 45% to about 50% as a result. In contrast, the effective utilization of heavy oil cracking equipment (e.g., improving the capacity utilization rate, greater cooperation between refineries, and boosting the capacity) falls short compared to the highly competitive refineries in other countries.

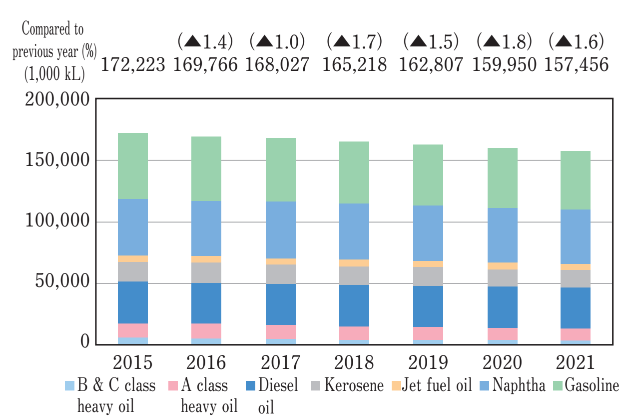

Fig. 1 Demand for Petroleum Products

Copyright© 2018 Society of Automotive Engineers of Japan, Inc. All rights reserved

Therefore, in the Third Notice announced in October 2017, Japanese refineries were requested to improve the processing rate of residual oil by 2021[4].

The Act on Sophisticated Methods of Energy Supply Structures also specifies target values for the introduction of bioethanol into the Japanese market to promote energy security and reduce CO_2 emissions[5]. Steady progress has been made and interim target values have been achieved since the initial introduction of bioethanol in 2011, with the target of supplying 500,000 kL of bioethanol (in terms of its crude oil equivalent) to the Japanese market anticipated to be cleared in fiscal 2017. In addition, it was decided to set the target values for 2018 and the following five years at the same level as in 2017. Although Japan is presently achieving the targets set for bioethanol in its marketplace, issues such as the reliance on imports from Brazil for the majority of that fuel and its higher price than gasoline need to be addressed. There is a growing need to develop technologies to allow Japan to increase its volume of domestically-produced biofuel while also taking the avoidance of competition with food sources and further reductions in CO_2 emissions into account. Research is therefore focusing on the breeding of Botryococcus to develop a biofuel production technology that uses algae as its base material[6].

At the same time, the International Maritime Organization (IMO) has decided to reduce the upper limit of allowable sulfur content in the C class heavy oil used for marine fuel from the current 3.5% down to 0.5% by the year 2020[7]. Figure 2 shows the details of this change in the regulations, the purpose of which is to reduce the amount of sulfur oxide (SOx) and particulate matter (PM) in exhaust emissions. Given that petroleum products are a joint product from crude oil, this new marine fuel regulation may eventually have some influence on the properties of automotive gasoline and diesel fuel.

In response to the increasing use of base materials from cracked petroleum products such as those mentioned previously, the petroleum industry and automotive industry in Japan conducted a joint research project called JATOP III (Japan Auto-Oil Program III) over the course of three years from 2015 to 2017. This research project used actual vehicles and on-bench engine testing to look into solutions to the various technical issues for gasoline and diesel vehicles identified during the previous JATOP II research project[8].

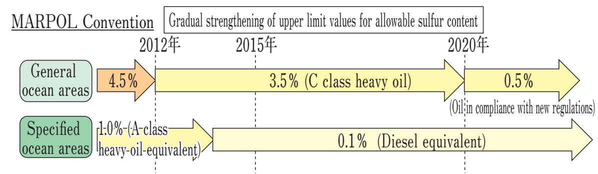

Fig. 2 Marine Fuel Sulfur Regulations

2. 2. Gasoline for Automobiles

The increasing use of cracked gasoline has also increased the proportion of olefin and heavy aromatics content in that fuel. The previously mentioned JATOP III research project examined the influence that this content had on deposits and automotive emissions[9]. As a result of testing using actual vehicles, the researchers concluded that even an olefin content increase of 30% of volume posed no concern about negative impacts on the exhaust emissions, deposits, and fuel economy. Increases in heavy aromatics content also increased the number of fine particles (PN). However, a higher olefin content decreases the total aromatics content, and the possibility of relying on this property to suppress the amount of increase in the PN was considered. In addition, it was also concluded that even a significant olefin content increase reaching 40% of volume, still presented no concern about negative impacts on exhaust emissions and deposits, as long as the heavy aromatics content did not increase.

Research into the fundamental characteristics of fuels, such as the ignition delay, laminar burning velocity, and knocking of gasoline, continues to be pursued and numerous research reports have been published[10-12]. One characteristic example of this research is a report that closely examined the properties of fuel[12] in an effort to realize a super-lean burning fuel[13], which is a goal of the Strategic Innovation Promotion Program (SIP) led by the Cabinet Office of the Japanese government. Since raising combustion speed is necessary to realize a super-lean burning fuel, this research focused on the differences in the molecular structures of fuels and investigated their on combustion speed and the lean limit. The results of practical testing using actual equipment confirmed that mixing chemical species said to have a high burning rate into the fuel expanded the lean limit and also improved the thermal efficiency. This led to the conclusion that realizing a super-lean burning fuel might be possible by combining this improved fuel with technology that increases the tumble ratio in the engine. There was also a study that evaluated the influence of fuel composition on

Copyright© 2018 Society of Automotive Engineers of Japan, Inc. All rights reserved

the knocking that occurs in a super-lean burn environment[10]. The results of practical testing using actual equipment confirmed that n-heptane promotes spontaneous ignition of unburnt gas, while toluene acts as a suppressant.

Many other reports on gasoline fuels focused on fuel deposits, and especially the generation of intake valve deposits (IVD). One study investigated the relationship between fuel composition and the amount of accumulated IVD, reporting that the amount of IVD does not increase if oxidation stability is maintained, even if the olefin content increases. Results also showed that an increase in the proportion of a polycyclic aromatic with a high boiling point and the ability to stay on the valve for a long time also increases the weight of the IVD[14]. Furthermore, the addition of methylaniline, a highly polar aromatic, to fuels has been reported to not only promote the formation of deposits, but also to form a highly polar network structure and increase the Young's modulus, which indicates the hardness of the deposit[15].

2. 3. Diesel Fuel for Automobiles

The previously mentioned JATOP III research project also examined diesel fuels. One study found that distillation and lightening while maintaining a constant cetane number was an effective fuel-side measure against increasing the load on the diesel particulate filter (DPF), even when the aromatics content rose due to an increase in the amount of cracked base material blended into the fuel[16]. At the same time, this study also reported that equipping diesel vehicles with a urea selective catalytic reduction (SCR) aftertreatment system not only reduced the nitrogen oxides (NOx), but also provided an effective vehicle-side countermeasure against the increasing load on the DPF.

Rising expectations on reducing the burden on the environment will make it even more important to improve the fuel efficiency of diesel vehicles. One of the factors that decreases the fuel efficiency performance of diesel vehicles is the accumulation of deposits on the fuel injector nozzles, which is well known to affect engine performance in various ways[17](18). Research on the accumulation of nozzle deposits has also been conducted outside the JATOP project in, for example, a study that examined the nozzle deposit formation mechanism in diesel engines[19]. The resulting report explained how a detailed investigation was conducted to determine the influence of fuel composition and temperature within the injection holes on the formation of deposits through actual engine tests, detailed analyses of the deposits, the numerical calculation of the flow within the nozzle holes, and standalone laboratory testing. To achieve this, zinc was added to the test fuel oil to promote the formation of deposits and the distribution of deposit formations within the nozzle holes was tracked, allowing the researchers to not only infer the mechanism behind deposit formation, but also propose a nozzle shape that should suppress the accumulation of such deposits.

Research into the mechanism of deposit formation is not limited to Japan, and is also being actively carried out on diesel fuel with added fatty acid methyl ester (FAME), a blend that is seeing increased use and serves as base material in regions such as Europe, North America, and Southeast Asia and is a strong potential candidate fuel for use outside of Japan[20]. This study used biodiesel with a 20% of volume palm oil-derived FAME mixture as the base fuel, adding Zinc at 2 parts per million (ppm) to promote deposit formation and surmise the underlying mechanism. The study also compared the different engine test results based on whether detergent additives were present, and discussed the influence of deposit accumulation on engine performance.

3 Lubricants

3. 1. Gasoline Engine Oil

3. 1. 1. Regulatory Trends

The delay in developing the test methods for GF-6, the next generation of the International Lubricants Standardization and Approval Committee (ILSAC) gasoline engine oil standard has made it probable that it will not come into effect until 2019 or later.

One of the focal points of GF-6 is the introduction of a test to evaluate the ability to prevent low speed pre-ignition (LSPI). However, following automotive industry demand prompted by its concern that the delay in GF-6 coming into effect will push back the introduction of engine oils compliant with the LSPI requirements, it was decided to introduce the API SN PLUS standard (scheduled for 2018), which is the API SN standard supplemented with the LSPI prevention performance evaluation test (Sequence IX)[21].

The Japanese Automotive Standards Organization (JASO) is considering the establishment of an engine oil standard for oils with lower viscosity than 0W-16 that would cover oils up to 0W-8. The standardization of the

Copyright© 2018 Society of Automotive Engineers of Japan, Inc. All rights reserved

fuel efficiency evaluation test for this low viscosity engine oil by April 2019 is under assessment[22].

3. 1. 2. Technological Trends

Improving automobile fuel economy is a technical issue that cannot be ignored since it represents a measure against global warming. Consequently, downsizing, direct fuel injection, and supercharging are being combined to advance fuel-efficient engine technologies. This process led to identifying the LSPI phenomenon as a problem, and discussions about its causes and possible solutions have been going on for a long time, and the SN PLUS standard going into effect is expected to accelerate the market penetration of engine oils designed to prevent LSPI[23].

At the same time, the installation of a gasoline particulate filter (GPF) in gasoline engines may become necessary to comply with the PM and PN regulations for direct injection gasoline engines made even stricter under the EURO 6c emissions regulations. Verifying the influence of ash originating from the engine oil on GPF clogging showed that it had less effect on GPF clogging than in a diesel engine DPF[24], and that some level of ash accumulation in the filter is actually necessary for the filter to effectively remove soot from the exhaust[25]. However, the required level of ash in the gasoline engine oil still calls for a more detailed examination.

3. 2. Diesel Engine Oil

3. 2. 1. Regulatory Trends

Japan, the U.S., and Europe are acting independently with respect to diesel engine oil regulations. In Japan, JASO M355 was revised in June 2017. In addition, JASO DH-2F, an engine oil standard that assigns fuel efficiency requirements to the existing DH-2 standards, and JASO DL-0 for passenger car diesel engines that do not meet the Euro 4 emissions regulations (sulfur content < 500 ppm) were established[26].

The DH-2F engine oil standard assigns fuel efficiency requirements that were not specified in JASO DH-1 and DH-2. In North America and Europe, high temperature, high shear (HTHS) viscosity at 150° C is used to specify the fuel efficiency performance of engine oils, whereas the JASO standards use an engine test to evaluate fuel efficiency performance. In the newly established N04C fuel efficiency test, the standard values for the required fuel efficiency improvement rates compared to the reference oil (BBL1 and DH-2 equivalent SAE 30) are an improvement rate of 3.7% or more for new oil and a total improvement rate of 6.8% or more for new and degraded oil (oil obtained after 200 hours of use in the JASO M336 Detergency Test or JASO M354 Valve Train Wear Test) combined (JASO M362: 2017)[27].

The DL-0 standard, which covers regions such as Southeast Asia, where emissions regulations equivalent to Euro 4 and earlier have been established, was added to replace the API CF-4 standard that expired in 2008. The need to apply a standard that is equivalent to CF-4 to maintain engine oil quality in these markets led to the addition of JASO DL-0.

In the U.S. and Europe there were no major actions in regard to diesel engine oil standards in 2017, but oils compliant with the API CK-4, FA-4, and ACEA 2016 standards introduced in 2016 began to be disseminated in the market.

3. 2. 2. Technological Trends

Satisfying the latest strict fuel economy and emissions regulations requirements makes it crucial for diesel engine oils to provide excellent fuel efficiency characteristics without sacrificing their longstanding wear resistance, detergency and other engine protection properties. The use of additives containing boron in the diesel engine oil has been reported to improve piston detergency[28]. Research into dispersing agents with wear resistance properties and containing aromatic amines and molybdenum to provide both wear resistance and the ability to disperse soot has also been reported[29].

3. 3. Gear Oils

Lower viscosity and making other improvements mirroring those in engine oils, are being applied to other automotive gear oils, such as manual transmission oil and differential gear oil, in an effort to improve vehicle fuel efficiency. However, there are concerns that simply lowering oil viscosity may cause a decline in the fatigue prevention properties and wear resistance that naturally accompany a decrease in oil film thickness. In addition, in some mechanical elements, a smaller fluid lubrication area may actually worsen the fuel economy. Consequently, finding the right balance between fuel efficiency and reliability is an important aspect of automobile gear oil development.

In response to this issue, Kurihara and others have reported the results of their research into a fuel-efficient differential gear oil that achieves both fuel efficiency and reliability by improving oil film retention via a high viscosity base material and improving the friction reducing

Copyright© 2018 Society of Automotive Engineers of Japan, Inc. All rights reserved

effect of the boundary lubrication zone by applying a molybdenum-based friction modifier[30].

In addition, Maruyama and others have proposed an in-laboratory screening method that to evaluate reliability during gear development using a small, four-cylinder testing machine to determine the fatigue life and amount of wear on actual gears[31]. Furthermore, Kamei and others used a taper roller bearing test to simulate the scuffing phenomenon of the surface of an actual bearing race and reported that bearing scuffing was caused by a tribochemical reaction involving the oil, the powder produced by abrasion, and the newly formed metal surface[32].

3.4. Grease

As global-scale measures to reduce vehicle CO_2 emissions continue to intensify, the active development and introduction of electric-powered vehicles such as hybrids (HEVs) and fully electric vehicles (EVs) is being pursued in parallel to efforts aimed at decreasing the fuel consumption of gasoline and diesel engines.

This has increased the demand for reduced friction and improved transmission efficiency in automotive parts, and consequently raised the level of performance required of the grease used on these parts.

For example, the grease used on the bearing of various types of electric motors must be able to cope with the rise in temperature that accompanies their smaller sizes and higher outputs (temperature suppression and long service life), while also possessing excellent quietness under low torque conditions. One grease that meets these requirements is a urea grease using linear aliphatic amines as raw material. The low modulus of elasticity of the thickener and the narrow fluctuation range of the oil film thickness were reported to provide both low torque characteristics and quietness[33].

In electric power steering, the transmission mechanism and parts differ depending on the steering mechanism (e.g., column assist or rack assist EPS)[34] and therefore have very different required specifications from those for the grease used on the bearing of electric motors. Nevertheless, quietness is already a general requirement for almost all automotive parts, and the demand for stable operating characteristics and low torque is expected to grow even stronger. Furthermore, the ball joints used for steering tie rod ends are a kind of sliding bearing[35], and the grease for these parts has properties that are quite different from the grease used for general rolling bearings. While a stable film thickness and low torque can be realized by balancing the contradictory forces of adhesiveness and fluidity, demand to further lower of the torque for these parts is likely to intensify.

The development of stable, high-efficiency grease with little friction fluctuation, as well as research into the relationship between grease flow behavior and bearing torque are still being carried out, even in the case of grease used for the hub bearing unit and constant velocity joints (CVJs), which, among power transmission parts, have a low torque loss rate of 1% or less. It has been demonstrated that optimizing grease flow characteristics can contribute to lower torque[37], creating expectations for even further technical development.

References

(1) Petroleum Association of Japan: Petroleum Industry Today 2017, http://www.paj.gr.jp/statis/data/data/2017_data.pdf (in Japanese)

(2) Ministry of Economy, Trade and Industry: Report (Resources and Energy Statistics (Petroleum)) Time-series Table, December, http://www.meti.go.jp/statistics/tyo/sekiyuka/pdf/se201712kakji.pdf (in Japanese)

(3) Sekiyu Tsushin: "Material for Petroleum", 2017, p. 20-38 (in Japanese)

(4) Ministry of Economy, Trade and Industry: Method to Sophisticate Energy Supply Structure, http://www.meti.go.jp/committee/kenkyukai/energy_environment/sekiyu_seisei/pdf/006_05_00.pdf (in Japanese)

(5) Ministry of Economy, Trade and Industry: Actions and Latest Trends regarding Introduction of Bioethanol, http://www.meti.go.jp/committee/kenkyukai/energy_environment/bio_nenryo/pdf/001_02_00.pdf (in Japanese)

(6) Satoko Touei: Technology Development of Biofuel Production using Algae, 2015 Petroleum Products Discussion Session, Proceedings, p. 64-67 (2015) (in Japanese)

(7) Ministry of Land, Infrastructure, Transport and Tourism, Introduction of Discussion Results regarding Strengthening of Concentration of Sulfur in Marine Fuel Oil in MEPC70, http://classnk-rd.com/pdf/katsudou201702_A.pdf (in Japanese)

(8) Takashi Tatsumi, Summary of JATOP II and Expectations, http://www.pecj.or.jp/japanese/jcap/

Copyright© 2018 Society of Automotive Engineers of Japan, Inc. All rights reserved

jatop2/pdf/index_jatop2_5-2.pdf (in Japanese)
(9) Takashi Kaneko: WG Report of Diesel Cars, Japan Auto-Oil Program III, Conference Materials, p. 55-71 (2018) (in Japanese)
(10) Yasunobu Goto: Effect of Fuel Composition on Knocking of Lean Burn SI Engine, Society of Automotive Engineers of Japan, Inc., 2017 Annual Congress Spring, Proceedings, p. 1045-1049, 20175189 (2017) (in Japanese)
(11) S. Ratnak, et al.: Experiments and Simulations of a Lean-Boost Spark Ignition Engine for Thermal Efficiency Improvement, JSAE 20159711/SAE2015-32-0711 (2015)
(12) Nozomi Yokoo: Research of Fuel Molecular Structure to Achieve Improvement of Heat Efficiency of Engine, Society of Automotive Engineers of Japan, Inc., 2017 Annual Congress Autumn, Proceedings, p. 1677-1682, 20176313 (2017) (in Japanese)
(13) Norimasa Iida: Engine Development Promoted by Industry, Government, and Schools, SIP "Innovative Combustion Technology" Research Status of Gasoline Combustion Team- Super Lean Burn Research Development for High Efficient Gasoline Engine-, Society of Automotive Engineers of Japan, Inc., Vol. 70, No. 9, p. 18-24, 20164409 (2016) (in Japanese)
(14) G. Sandro, et al.: An Intake Valve Deposit (IVD) Engine Test Development to Investigate Deposit Build-up Mechanism Using a Real Engine, AE 2017-01-2291 (2017)
(15) Yosinori Nakayama: Curing Mechanism of Gasoline Deposit due to Addition of Aromatic Elements, Society of Automotive Engineers of Japan, Inc., 2017 Annual Congress Autumn, Proceedings, p. 1665-1670, 20176311 (2017) (in Japanese)
(16) Mamoru Nomura: WG Report of Diesel Cars, Japan Auto-Oil Program III, Conference Materials, p. 35-51 (2018) (in Japanese)
(17) T. Akio, et al.：Inner Diesel Injector Deposit Formation Mechanism, SAE-2013-01-266 (2013)
(18) Takashi Kaneko: WG Report of Diesel Cars, Japan Auto-Oil Program Conference, Session II, Part 1 (3) (2010) (in Japanese)
(19) Masasato Ikemoto: Deposition Mechanism of Injection Hole in Fuel Injection System of Diesel Engine, PETROTECH, Vol. 35, No. 11, p. 781-786 (2012) (in Japanese)
(20) L. Liang, et al.: Discussion of Deposition Mechanism in Diesel Engine Nozzle when High Concentration Bioethanol Fuel is Used, Society of Automotive Engineers of Japan, Inc., Symposium for "Vision regarding Fuel in the Future to Achieve Low Emission and High Efficiency", No. 15-17 (2018) (in Japanese)
(21) API SN with SN Plus, http://www.api.org/~/media/Files/Certification/Engine-Oil-Diesel/Publications/17thed1509addendum7rev021218.pdf
(22) Kazuo Yamamori, Toyoharu Kaneko, Satoshi Hirano: Lubricating Oil Technology, Standard Trends of Automotive Gasoline Engine Oil and Technology of Low Fuel Consumption, The Tribology, No. 364, December (in Japanese)
(23) H. Liu, J. Jin, H. Li, K. Yamamori, et al.: 0W-16 Fuel Economy Gasoline Engine Oil Compatible with Low Speed Pre-Ignition Performance, SAE Technical Paper, 2017-01-2346
(24) R. Bernardoff, B. Hennebert, T. Delvigne, O. Courtois, et al.: A Study of Ash Accumulation in the After-treatment System of a Gasoline Direct Injection Engine Equipped with a Gasoline Particulate Filter, SAE Technical Paper 2017-01-0879
(25) L. Rubino, D. Thier, T. Schumann, S. Guettler, et al.: Fundamental Study of GPF Performance on Soot and Ash Accumulation over Artemis Urban and Motorway Cycles - Comparison of Engine Bench Results with GPF Durability Study on Road, SAE Technical Paper 2017-24-0127
(26) Automotive Diesel Engine Oil Standard (JASO M 355:2017) Application Manual http://www.jalos.or.jp/onfile/pdf/DH_E1706.pdf
(27) K. Hashimoto, et al.: The Development of Fuel Economy Test Method for Heavy Duty Diesel Engine Oil (The First HD Engine Test Method and the New JASO DH-2F Category), SAE Technical Paper, 2017-01-0884
(28) Ueda, et al.: Effect of Agent to Improve Viscosity Index of Polymethacrylate in Diesel Engine Oil on Cleanliness of Piston Underside, Tribology Conference 2017, Spring, Tokyo, Proceedings, 397-398 (in Japanese)
(29) Guo Peng, et al.: Study of an Antiwear Soot Dispersant, Runhua Yumifeng, 42, 133-135, 101, 2017
(30) Kurihara, et al.: Development of Differential Gear

Copyright© 2018 Society of Automotive Engineers of Japan, Inc. All rights reserved

Oil with Low Fuel Consumption, Society of Automotive Engineers of Japan, Inc., Vol. 71, No. 9, p. 75-80 (2017) (in Japanese)

(31) Maruyama, et al.: Sliding of Tribology Surface-Rolling Conditions and Relation between Gear Wear and Fatigue, Tribology Conference 2017, Spring, Tokyo, Proceedings, 213-214 (2017) (in Japanese)

(32) Kamei, et al.: Development and investigation of lubricant degradation test using tapered roller bearing, World Tribology Congress 2017

(33) Tsuda, et al.: Research of Grease Achieving Quietness in Low Torque, Tribology Conference 2017, Autumn, Takamatsu, Proceedings, C15 (2017) (in Japanese)

(34) Matsuoka: Development and Future Outlook of Steering Systems, JTEKT ENGINEERING JOURNAL, No. 1013 (2016) http://eb-cat.ds-navi.co.jp/enu/jtekt/tech/ej/img/no1013e/1013e_03.pdf

(35) Sasaki, et al.: Effect of Oil Separation Characteristic of Grease on Lubricating Conditions in Reciprocating Dynamic Friction of Low Amplitude, Tribology Conference 2017, Autumn, Takamatsu, Proceedings, F28 (2017) (in Japanese)

(36) Fujio: Next-generation High Efficiency Fixed Type Constant Velocity Joint "CFJ", NTN TECHNICAL REVIEW, No. 81 (2013) https://www.ntn.co.jp/japan/products/review/pdf/NTN_TR81_P064.pdf (in Japanese)

(37) Sotoo: Technologies of grease lubrication which contribute to the reduction of rolling bearing torque, Tribologist. 63. No. 2, p 69-74 (2017) (in Japanese)

Copyright© 2018 Society of Automotive Engineers of Japan, Inc. All rights reserved