Demonstration of Sensor Monitoring of Lubricants

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Abstract

Due to the spread of carbon neutral, the effective use of lubricant has been drawing attention. Since the main component of lubricant is petroleum-derived hydrocarbon oil, reducing the amount used by 1 kg will reduce CO2 by approximately 3 kg. The value of CO2 reduction is very important. In order to reduce the amount of lubricant used, there is a movement to reduce the frequency of lubricant exchange or continue to use lubricant without exchanging it. However, it is known that lubricant-induced mechanical failures occur. For this reason, equipment condition monitoring using oil sensors has been spread. The color of the lubricant, also called machine blood, indicates the condition of the machine. The oil sensor measures contamination, which has a fatal effect on machine failure, and oxidation degradation, which is related to the performance of lubricant and the machine failure. Contamination includes water and wear debris, and oxidative degradation includes consumption of additives and oxidation of base oil. By digitizing the hue of wind turbine gear oil through color diagnosis using an oil sensor, the oil contamination and degradation is identified. Additives in the gear oil were quantified by liquid chromatography-mass spectrometry, and it was found that the color change of gear oil was highly correlated with the depletion of the extreme pressure additive. It is known that the depletion of the extreme pressure additive is correlated with the useful life of the gear oil. Using the technique, the remaining life diagnosis of the gear oil was shown. Demonstration in the gearbox with the oil sensor was succeeded by avoidance of the effects of air bubbles in the gear oil.

1. Introduction

1.1. Current status of renewable energy toward Net Zero

The world is moving towards green innovation. In May 2021, the International Energy Agency (IEA) announced the IEA Roadmap (Net Zero by 2050: A Roadmap for the Global Energy Sector). This report sets out the actions needed to reach net zero by 2050 in the global energy sector. It states that the fossil fuel ratio will drop to 20% and renewable energy will account for 60%. In order to achieve carbon neutrality, the spread of wind power, especially offshore wind power, which can be procured in a stable and large amount regardless of the time of day or night, is progressing. A report published by GWEC in 2021 shows technologies that contribute to net zero. Among these, there are many technologies that require lubricants as the GWEC reported in 2021 (Table 1). For example, onshore and offshore wind power generation in the electric power sector, electrification, hydrogen and e-fuel, and CCUS in the industrial sector, electric vehicles and biofuels in the transportation sector, and renewable energy air conditioning and electrification in the building sector.

By adopting oil condition monitoring, it is possible to reduce the amount of lubricant used and the amount of waste. By reducing the amount of lubricant used by 1 kg, CO2 can be reduced by approximately 3 kg.

Table 1 Technologies for Net Zero

Sector	Technologies
Power	Onshore wind, Offshore wind, Solar PV, Green power trading, Smart grids and demand side response
Industry	Electrification , Green hydrogen and e-fuels, CCUS
Transport	Evs, FVEVs, Biofuels
Buildings	Renewable heating, Electrification

1.2. Cost reduction of wind power generation

There are two ways to reduce wind power generation costs. One is simply the mass production effect. The other is cost reduction due to the increase in power generation output due to the increase in size of wind turbines and the extension of towers. The rated output of a wind turbine increases in proportion to the square of the blade length. In addition, the taller the tower, the more it can receive strong and steady winds from above, increasing the amount of power generated.

If the amount of power generated per wind turbine increases, the number of required wind turbines will decrease, and the construction cost for installation will decrease, leading to lower power generation costs.
There is a limit to the size of onshore wind turbines, as large parts such as blades and towers must be transported by land during construction. On the other hand, competition for larger offshore wind turbines is intensifying because large parts can be transported by ship. Recently, 15MW class wind turbines has been developed, with a nacelle height of about 200 m and a rotor diameter of about 200 m.

1.3. Issues of lubricant maintenance for wind turbines

Of the life cycle cost (LCC) of a wind turbine, 1/5 to 1/3 is O & M cost, and more than half of O & M cost is maintenance cost. For this reason, in wind power generation, LCC is more important than capital expenditure (CAPEX) as Colonado reported in 2016. Due to the increase in size of wind turbines, the size and price of gearboxes are increasing, and the importance of maintenance has been further increasing. The role of the gearbox is to increase the low speed rotation of the blade (10 to 30 rpm) to 1,200 to 1,800 rpm, which can generate electricity.

Hundreds, or over one thousand of liters of lubricant is used in the gearbox. The hub height of the recent wind turbine is 100 m or more. Since the lubricant for the geabox uses a high-viscosity product of VG320, its exchange work is so harsh. There are two ways to exchange the lubricant of the gearbox, one is to raise and lower the oil cans with a winch, and the other is to change it from the ground using a pump. The later is a method that is popular in Europe and the US. Lubricant replacement has many problems such as being affected by the weather, taking time, oil leakage and dropping of cans, and long downtime of the wind turbine and reduction of power generation. It is desired to extend the oil exchange cycle of the gearbox.

Lubricant diagnosis is a technology that quantifies and diagnoses contamination and degradation of lubricant, but it also contributes to decarbonization by optimizing the exchange cycle as aforementioned..

2. DIAGNOSIS OF GEARBOX LUBRICANT BY COLOR

2.1. How to diagnose gearbox lubricant by color

Lubricants are known to change color after use. As a conventional method, there is a simple colorimetric method (visual inspection) of ASTM, and when the hue becomes 2.5 or more darker than the hue defined as the ASTM number, it is diagnosed as the oxidative degradation limit of the lubricating oil.

In order to diagnose the contamination and degradation of the lubricant, the apparent color of the gearbox oil is digitized by expressing it in RGB color coordinates, and the brightness index A (root of sum of squares of R, G, B) and index B of distance from the neutral (color on the gray scale) are used. From the map of the two indicators of the degree of index B, we tried to extract a sample of abnormal contamination and a sample whose degradation progressed, and exchange is recommended. This is because when contaminated, that is, when solid fine particles, wear particle, or water having a saturation concentration or higher is mixed, the apparent color becomes dark because the light transmittance decreases regardless of the wavelength of visible light. That is, both index A and index B decrease. Under normal degradation, the color of the gearbox changes from almost colorless to yellow and then reddish brown. That is, the index A decreases, but the index B increases because the color becomes darker. Based on this principle, as shown in Fig. 1, the degradation progress and contamination of the gearbox are based on the maps of index A and index B obtained from the color coordinates of the oil used in the wind turbine gearbox and the oxidation test sample. It became clear that the sample can be detected.

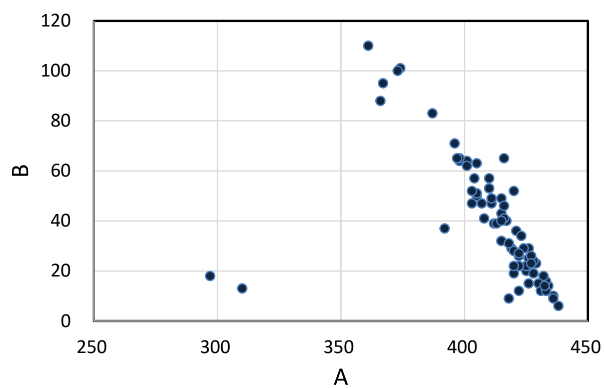

Fig. 1 Example of gearbox lubricant diagnosis based on color of lubricant.

2.2. Correlation between lubricant color index and EP additive concentration

Concentration of the phosphore based EP (extreme pressure) additive in the gearbox lubricant was determined by liquid chromatography-mass spectrometory. Fig. 2 shows correlation between the concentration of phosphorus-based EP additive in the oxidation test samples (model samples in which only degradation is progressed) with no abnormal contamination and the color index A. The phosphorus-based EP additive concentration was expressed as a relative value with the value of the new oil as 1. Index A is also expressed as a relative value with the value of new oil as 1. It became clear that the index A and the phosphorus-based EP additive concentration have a high correlation, which means that the residual EP additive concentration can be estimated by the color diagnosis of the gearbox lubricant..

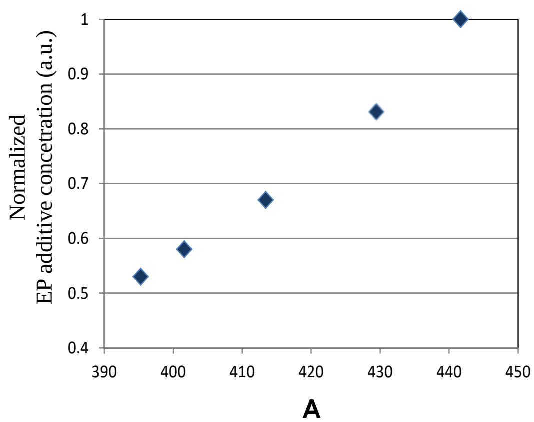

Fig. 2 Correlation between color index A and EP additive concentration in lubricant.

3. DEMONSTRATION OF GEARBOX LUBRICANT MONITORING OF WIND TURBINES

How to install the sensor and where to install it are issues for monitoring gearbox oil using the oil sensor. Especially in the case of retrofitting, there are many restrictions. The other is the effect of air bubbles in the lubricant that occur during operation of the gearbox. Gearbox lubricant has high viscosity, and once bubbles are generated, they are difficult to disappear.

Gearbox lubricant measurements were carried out using color sensors in gearboxes with three different structures.

The lubricants used were Mobilgear XMP SHC 320 and Mobil SHC Gear 320 WT obtained from Exxonmobil. Both contain defoamers. The drain ports of the oil stations were used to install the sensors. This has the advantage that it does not require pipe replacement work and can be done immediately. Disadvantages include difficulty in adjusting the sensor position.

3.1. Demonstration in the gearboxes of 5MW wind turbines

Demonstration was performed with gearboxes having two different structures. Continuous measurement was performed in the completed commercial wind turbine, and oil degradation could be evaluated using the data obtained when the gearbox stopped irregularly. In this wind turbine, color sensor measurement was difficult due to air bubbles during operation of the gearbox. Mobilgear XMP SHC 320 was used in the completed wind turbine.

On the other hand, the color sensor measurement was performed in another type of wind turbine. Mobil SHC Gear 320 WT was used in the experiment. This gearbox has a structure that makes it difficult for air bubbles to form when the oil flows vigorously under high load, so color sensor measurements were able to be performed with almost no effect from air bubbles even during operation. Fig. 3 shows the results of measurement of the lubricant with the color sensor under the conditions for increased load. When the load started to rise, the signal strength decreased due to bubble generation. As the load increased further, the signal strength increased. This means that bubbles have decreased under high load conditions, probably due to the gearbox structure.

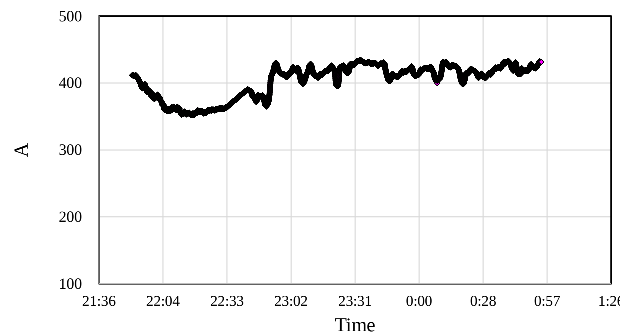

Fig. 3 Results of measurement of gearbox lubricant with the color sensor under different load condition.

4. CONCLUSION

Due to the increase in size of wind turbines and the spread of offshore wind turbines, the diagnosis of lubricant for gearboxes will become more important in the future. In addition to the conventional lubricant sampling and analysis during periodic inspections, remote monitoring using oil sensors will become widespread, and the optimization of the lubricant exchange cycle (mainly extension of the exchange cycle) will progress. As effects, it is expected to contribute to decarbonization by reducing maintenance costs, reducing wind turbine LCC by extending the life of the wind turbine, and reducing CO_2 emissions. Demonstration of gearbox lubricant monitoring of a wind turbine was successfully performed using the color sensor.

REFERENCES

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Kyoko Kojima, Ph. D. Dr. Kojima is currently the leader of oil condition monitoring research at Hitachi, Ltd. in Tokyo, Japan. She studied organic chemistry at Keio University in Japan. She also got a PhD in engineering from Keio

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