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Evaluation of Reliability of Large Hybrid Curvic Gear Using Thermography

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서모그래피 기법을 적용한 하이브리드 대형 커빅기어 신뢰성 평가

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ABSTRACT

Stabilizing the operation of dual fuel diesel engines is very important. The shipbuilding industry is rapidly growing, but gear components requiring reliability are still imported from other countries. The reasoning for this is three-fold. Firstly, it is compulsory that all ships must use devices that meet the performance standards specified in the Safety of Life at Sea (SOLAS) and the convention of MARine POLlution (MAPOL) to prevent pollution caused by ships. Secondly, most ships must comply with the ship classifications specified by ship owners. Therefore, it is specified that key engine gear components must be inspected and authorized for the quality and performance specified by the Ship Register Authority. Thirdly, it is essential that devices (engine gear) for human safety in ships comply with quality standards specified in the regulations and rules by the government. The Ship Register Authority's strict quality standards and approval requirements contribute to the reduction of motivation towards new investment and technology development by device component manufacturers. Therefore, this study aims to develop a method for using infrared thermography to examine gear reliability in order to ensure gear component reliability and national competitiveness in the global market.

Keywords : Thermography(열화상), Large Hybrid Gear(대형 하이브리드 기어), Curvic Gear(CUVIC 기어), Nondestructive Reliability Evaluation(비파괴신뢰성평가)

1. Introduction

Gears have been one of representative mechanical components along with bearings and screws since the beginning of the industrial society, and played a key role for a long time. Even today in 21st century, gears ensure power transmission and are efficient in operation. Therefore, they are classified into gears for small watches, turbine speed reduction gears for ships of hundreds of thousands of kW, speed reducers for

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cars and planes, differential gears, and gears for wind turbines in terms of their use, and there are various gear types available depending on their use.

Gears developed to meet their purpose have been developed to implement multiple motions, and studied to have various shapes. The aforementioned gears of multiple motions, special motions and shapes are called a hybrid gear which has been studied by researchers and in the academic world.

The large special gears as a hybrid gear are imported from other countries because they require high machining precision. This is a main reason for high development and production costs for large machine tools, large ships and wind turbines which require large hybrid gears.

It is important to stabilize the operation of dual fuel diesel engines in the shipbuilding industry rapidly growing and gear components requiring reliability are still imported from other countries. The reason is as follows.

Firstly, it is compulsory that all ships shall use devices with the performance specified in the SOLAS (Safety of Life at Sea) and the convention of MAPOL (MARine POLlution) to prevent pollution caused by ships.

Secondly, most ships shall comply with the ship classification specified by ship owners. Therefore, it is specified that key engine gear components shall be inspected and authorized for the quality and performance thereof specified by the Ship Register Authority.

Thirdly, it is essential that devices (engine gear) for human safety in ships comply with quality standards specified in the regulations and rules by the government. Strict quality standards and approval requirements by the Ship Register Authority are factors that contribute to lowering the desire for new investment and technology development by device component manufacturers.

Fourthly, shipbuilding devices (engine gear) depend largely on buyer’s reputation.

In the end, supporting the shipbuilding device (engine gear) industry is the field requiring advanced technology development and experience for a long time, and a basis for ensuring national competitiveness.

Small damages occurring in the gear operation stage may cause critical machine failures and mechanical defects may also lead serious accidents. Therefore, periodical gear inspection and soundness evaluation are very important. Gear defects can be inspected in many ways. Ultrasonic testing currently applied includes Manual Ultrasonic Testing, Phased Array Ultrasonic Testing (PAUT), and Noncontact Ultrasonic Testing. However, the methods currently applied are limited in terms of the scope of testing, and sometimes do not detect defects for some gear shapes.

The infrared thermal image testing is suggested to tackle the aforementioned disadvantage. The IR (infrared) thermal image testing is a method for sensing IR energy radiated from a tested object by means of an IR measurement instrument, and analyzing the temperature distribution of the object by means of thermal imaging created by mapping the signal as images to examine the inside of the object. IR thermal imaging nondestructive testing is classified into the passive method and the active method. While the passive method is a general measurement method for detecting infrared energy radiated naturally from a measured object, the active method is a method for supplying controllable energy independent of the unique IR volume of the examined object, measuring and analyzing the IR energy radiated by the examined object.

This study aims to conduct reliability evaluation through the IRT technique by using thermography to hybrid curvic gears.

2. Infrared Thermal Image Testing

2.1 Passive Method for Testing Infrared Thermal Image

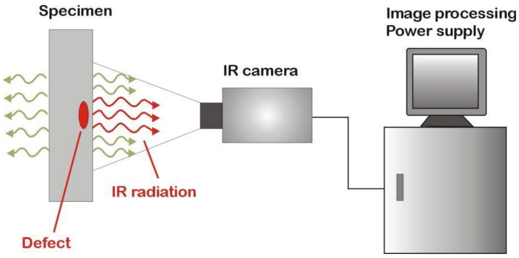


Fig. 1 Passive method (jenoptik ag)

The passive method is shown in Fig. 1 and for detecting IR energy radiated naturally from a measured object which is not heated or cooled. The passive thermal image method is applied generally to evaluation and monitors in industrial process and the step of drawing based on temperature patterns.

In the passive method, temperature before inspection is constant depending on the environment to detect defects. Therefore, it is essential to heat or cool the specimen in order to provide a recordable temperature in the spots with defects. This method is for measuring and analyzing IR energy radiated by the specimen through interaction with uncontrollable energy (sun) to sense and image the unique IR volume radiated by the specimen, and can be used for all objects radiating IR. Moreover, the passive method is the most essential method for examining the unique state of an object, and is rather one of macroscopic measurement methods than methods requiring quantitative microscopic precision of a measured object.

2.2 Active Infrared Thermal Image Testing

The active method is shown in Fig. 2, different from the passive method which depends on the unique IR volume of a specimen, and for emitting controllable energy to measure and analyze IR energy radiated by the specimen as a reaction to the energy. With the active method, it is possible to obtain desired precise results by controlling the effect depending on radiation from object surface, ambient temperature, measuring angles, wind speed, distance and shapes. The active method is classified into photo-infrared, vibration, microwave, ultrasound, and eddy current methods depending on the type of incident energy, and into methods depending on control methods.

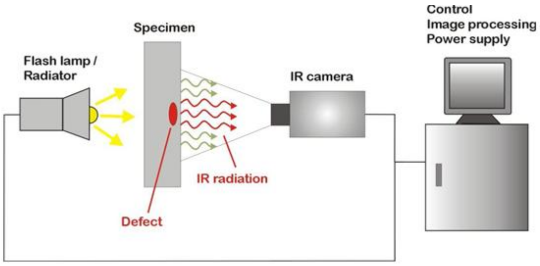


Fig. 2 Active method (jenoptik ag)

The aforementioned testing methods contribute to implementing more precise result values obtained from specimens. Furthermore, another method available is the methods for applying current or easily finding defective spots through current ON/OFF. The active method is for highlighting micro-defects (cracks, etc.) on the measured object surface or internal defects (internal cracks or voids=gaps) by applying heat from the outside as a temperature distribution to detect the defects where no heat is applied to the measured object to have no temperature distribution or there is very negligible temperature differences.

3. Soundness Evaluation of IRT Method

3.1 Components of Experiment Equipment

The IR thermal imaging camera FLIR T640 used in this study is a portable camera very mobile. This camera can be connected to high-resolution large touch screens, high-temperature resolution rotary-type lenses, view finders, Wi-Fi and Bluetooths, USBs, etc. It has a maximum IR resolution of (640×480) pixels, measured temperature range between −40℃ and 2,00

0℃, and sensitivity between 30℃ and 0.035℃. The camera is embedded with a visual camera of 1~8× continuous digital zoom, continuous automatic focusing and passive focusing, and 5-mega pixels to save thermal images/visual images concurrently. This camera can insert thermal images into visual images (PIP) and synthesize them. Furthermore, this camera can record and stream captured images by connecting a USB to user's PC. The camera can be used for a given time by means of two Li-Ion batteries without connection to any external power supply, and connected to other measuring instruments by means of a Bluetooth to improve measurement accuracy and reliability.

Moreover, it is essential that the camera has a thermocouple and IR software. Fig. 3 shows configuration of experiment equipment, and Fig. 4 shows a specimen.

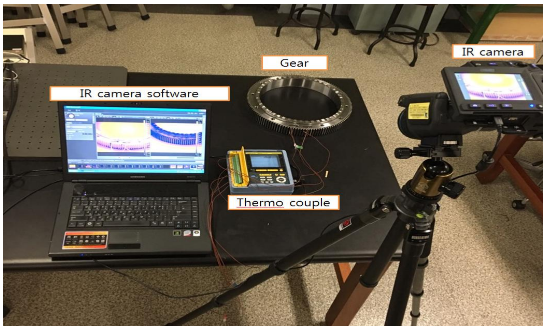


Fig. 3 Configuration of halogen lamp experiment equipment

Fig. 4 Normal specimen and specimen with artificial defects

3.2 Experiment and Consideration

This study was designed to evaluate IR thermal image reliability by using thermography, and used a hybrid curvic gear made of SCM420.

For the experiment, artificial defects were created on the gear teeth through wire cutting. One of the specimens with artificial defects was cooled to be below zero degree by means of a quick cooler, and the other specimen was cooled to be above zero degree. Fig. 5 shows a photograph showing the specimen captured with a thermal imaging camera and cooled to be above zero degree. Fig. 6 shows a photograph showing the specimen cooled to be below zero degree.

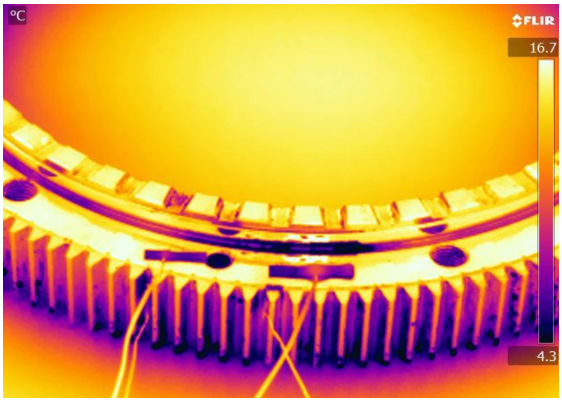


Fig. 5 Specimen cooled to be above zero degree

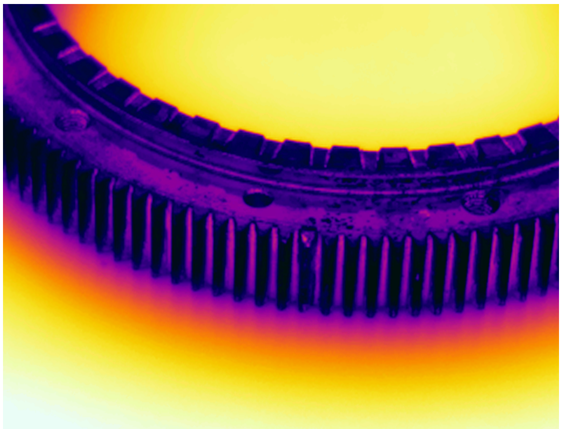


Fig. 6 Specimen cooled to be below zero degree

In this study, the contact area of the hybrid gear is divided into 5 spots with and without defects in order to create accurate temperature data. The result measured with the IR thermal imaging camera shows that Spot 2 with defects was at lower temperature than the surrounding area, and Spots 1, 3, 4 and 5 normal and without defects were at higher temperature than the Spot with defects. Fig. 7 shows a photograph showing the specimen captured with a thermal imaging camera and cooled to be above zero spots degree. Fig. 8 shows a photograph showing the specimen cooled to be below zero spots degree.

The image was captured at room temperature for 30 minutes to save and compare the values. Spot 1 which is the gear tooth end with defects was at 14.7℃; Spot 2 with artificial defects was at 5.9℃; Spot 3 which is a gear body was at 14℃; and Spots 4 and 5 normal and without defects were at 14.8℃ and 15.2℃, respectively.

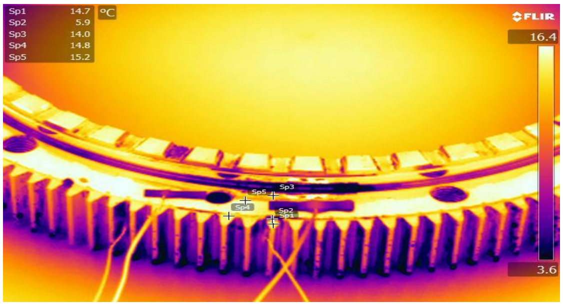


Fig. 7 Thermal image of specimen spots cooled above zero degree

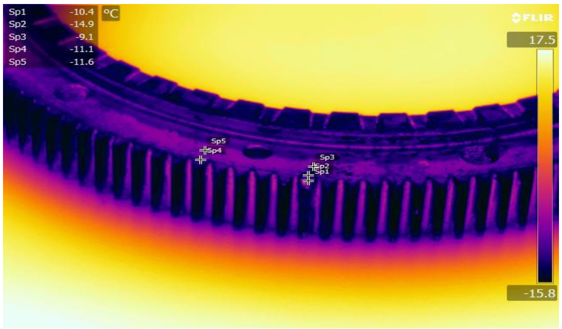
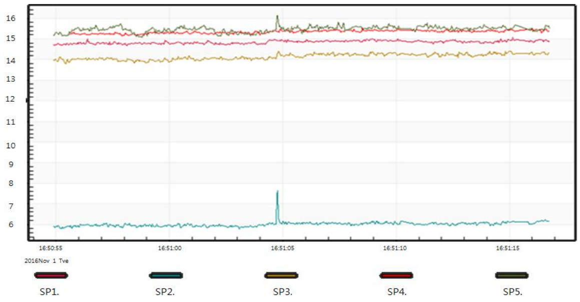


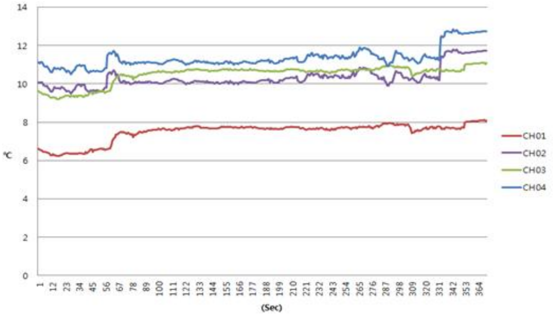
Fig. 8 Thermal image of specimen cooled to be below zero degree

In the method described above, the images were captured at room temperature for 30 minutes to save and compare the values. The result showed that Spot 1 which is a gear-tooth end with defects showed the highest temperature rise from −11.5℃ to −9.5℃; Spot 2 with artificial defects showed a temperature rise from −14.9℃ to −10.5℃; Spot 3 which is a gear body showed a temperature rise from −9.5℃ to −8.5℃; and Spots 4 and 5 normal and without defects showed temperature changes from −11.1℃ and −11.6℃ to −8.5℃ and −8.7℃, respectively.

Fig. 9 illustrates the result of this study. For this study, the hybrid gear was divided into 5 spots with and without artificial defects to create accurate temperature data about defects by measuring and analyzing temperature. Moreover, a thermocouple was used to measure accurate temperature to have the result about temperature changes. It was observed that Spot 2 with artificial defects showed the highest temperature rise to 5.9℃ in the experiment after cooling and by applying thermography. Temperature rises were observed at Spot 1 which is a gear-tooth end and with artificial defects showed temperature rise to 14.7℃; Spot 3 which is a gear body and with defects showed the highest temperature rise to 14℃; and Spots 4 and 5 without defects showed the highest temperature rise to 14.8℃ and 15.2℃, respectively. It was observed that the temperature difference between spots with and without defects was approximately 8℃.



(a) Thermal camera temperature graph



(b) Thermocouple measurement temperature graph

Fig. 9 Temperature graph for spots of the specimen cooled above zero degree

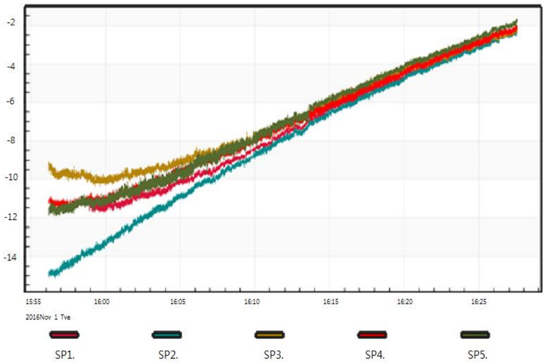


Fig. 10 Temperature graph for spots of the specimen cooled below zero degree

Fig. 10 Temperature graph for spots of the specimen cooled below zero The result is as follows

It was observed that Spot 2 with artificial defects and cooled below zero degree showed the highest temperature rise to −10.5℃. Spot 1 which is the gear-tooth end with artificial defects showed temperature rise to −9.5℃; Spot 3 which is a gear body and with defects showed the highest temperature rise to −9.5℃; Spots 4 and 5 without defects showed the highest temperature rise to −8.5℃ and −8.7℃, respectively. It was observed that the temperature difference between spots with and without defects was approximately 2℃.

4. Conclusion

An FEM analysis was conducted to minimize force displacement occurring when the hybrid curvic gear rotates, and detect the stressed area concentrated on the hybrid gear in consideration of the control performance of the hybrid curvic gear. This aimed to determine the possibility of crack occurrence. The resulting cracks approximately 8mm in length were found. On the basis of the FEM analysis result, a specimen was produced. Thermography after cooling the specimen showed a temperature difference of approximately 2℃ to 8℃. Hot spots were found in the spots with defects. The result of this study is applicable to industrial sites to improve gear reliability and thus ensure competitiveness.

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