A New Oil Debris Sensor for Online Condition Monitoring of Wind Turbine Gearboxes

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1. Introduction

Online Condition Monitoring (CM) is a key technology for the Operation and Maintenance (O&M) of wind turbines. Lubricating oil is the blood of the wind turbine gearbox. Metal debris in lubricating oil contains abundant information regarding the ageing and wear/damage of mechanical transmission systems. The health condition of the wind turbine gearboxes can be indicated by the quantity and size of the metal abrasive particles, which may provide very early warnings of faults/failures and benefit the condition based maintenance of the system [1]. Fig. 1 illustrates the lubrication-oil circulating system of the gearbox used in Multi-MW Wind Energy Conversion System (WECS). The step-up gearbox consists of one stage planetary gear and two stage parallel shaft gears. The oil debris sensor (ODS) can be implemented in the primary oil channel (as shown in Fig .1) or bypass oil channel which is in parallel with the primary channel for the online condition monitoring.

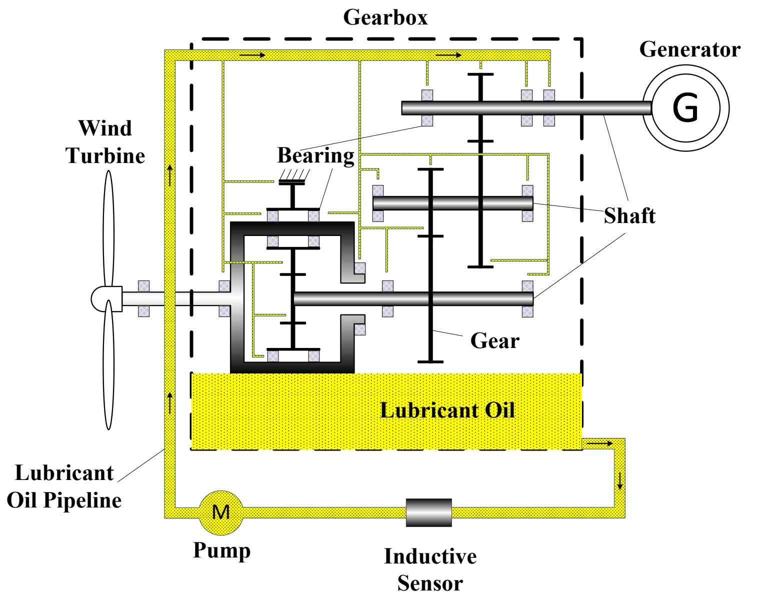


Fig. 1. The lubricating system of the gearbox used in wind energy conversion system.

Previous works on ODS have been done under the assumption that the magnetic field in the oil tube through which the particles pass is uniform. However, solenoid or planar coils which are used in references [2-5] around the tube cannot provide uniform magnetic field, which may result in error output of the sensor. Hence, a new inductive sensor which uses Helmholtz coils to generate a uniform magnetic field for metal particle detection is proposed in this paper.

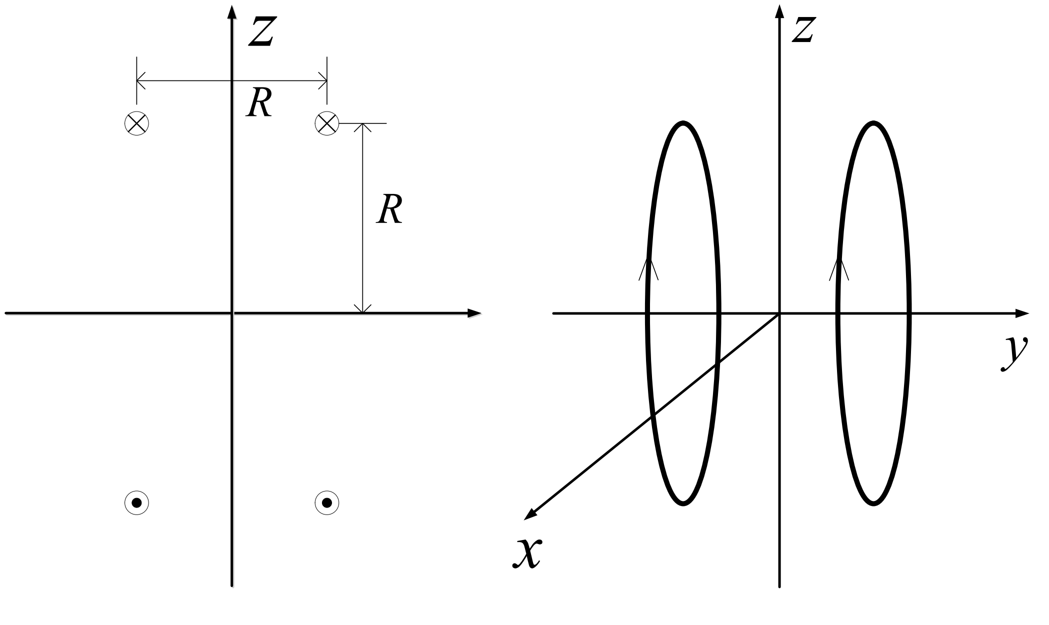
2. Approach

The homogeneity of the magnetic field of the proposed Helmholtz ODS is analyzed theoretically, then the performance of the new ODS is simulated and verified by using the Finite Element Modelling.

3. Main body of abstract

3.1 Homogeneity of the magnetic field of the proposed Helmholtz ODS

The geometry of Helmholtz coils is shown in Fig. 2. The Helmholtz coil pair consists of two identical circular coils which are put in parallel coaxially. The distance of the coils is the radius of the coil. The magnetic flux density can be obtained via equations (1)-(3) by using Biot-Savart law. The 5% homogeneity area of magnetic field is shown in



(a) (b)

Fig. 2. The geometry of Helmholtz coils.

$$B_x = \int dB_x = \int_0^{2\pi} \frac{\mu_0 I}{4\pi} \cdot \left(\frac{R\cos\theta\left(z_0 - R/2\right)}{r_1^3} + \frac{R\cos\theta\left(z_0 + R/2\right)}{r_2^3} \right) d\theta \quad (1)$$

$$B_y = \int dB_y = \int_0^{2\pi} \frac{\mu_0 I}{4\pi} \cdot \left(\frac{R\sin\theta\left(z_0 - R/2\right)}{r_1^3} + \frac{R\sin\theta\left(z_0 + R/2\right)}{r_2^3} \right) d\theta \quad (2)$$

$$B_z = \int dB_z = \int_0^{2\pi} \frac{\mu_0 I}{4\pi} \cdot \left(\frac{R\left(R - y_0\sin\theta\right)}{r_1^3} + \frac{R\left(R - y_0\sin\theta\right)}{r_2^3} \right) d\theta \quad (3)$$

Where,

$$r_1 = \sqrt{\left[R\cos\theta\right]^2 + \left[y_0 - R\sin\theta\right]^2 + \left(z_0 - R/2\right)^2}$$

$$r_2 = \sqrt{\left[R\cos\theta\right]^2 + \left[y_0 - R\sin\theta\right]^2 + \left(z_0 + R/2\right)^2}$$

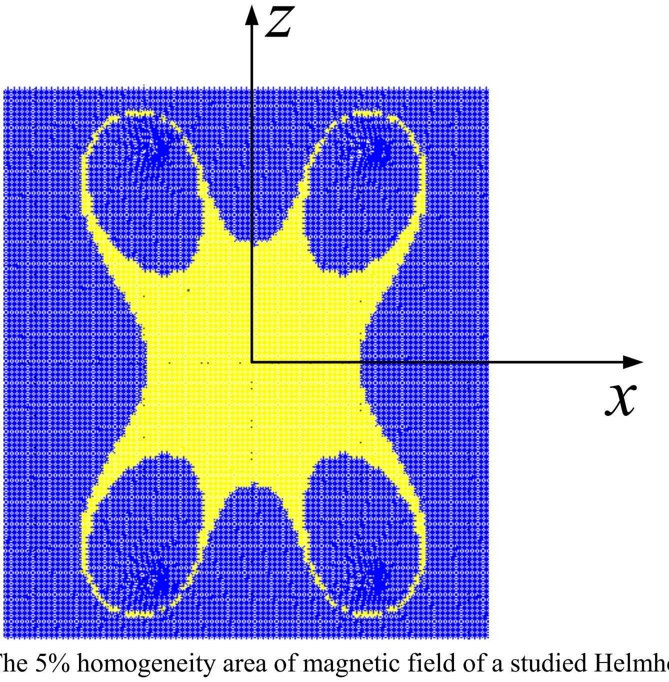


Fig. 3. The 5% homogeneity area of magnetic field of a studied Helmholtz-coils.

3.2 Simulation and result analysis

TABLE I
PARAMETERS OF THE STUDIED HELMHOLTZ COIL OIL DEBRIS SENSOR

Parameter	**Value**
Excitation frequency	2MHz
Coil diameter	1mm
Copper particle diameter	200 µm
Ferro particle diameter	100 µm
Excitation current density	$6.83 \times 10^6 \mathrm{A}/m^2$
Nominal inductance	7.1795nH

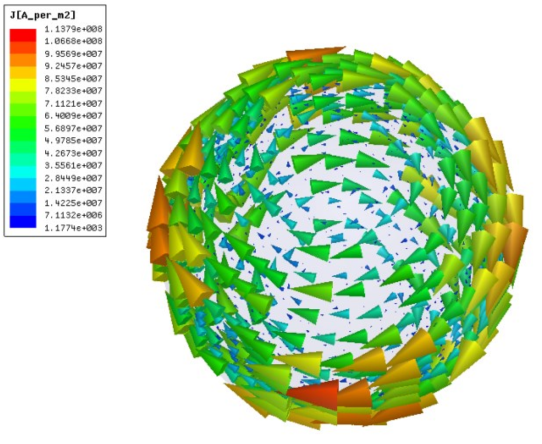


Fig. 4. The eddy current of the Cu particle (diameter 200 µm) under the alternating magnetic field

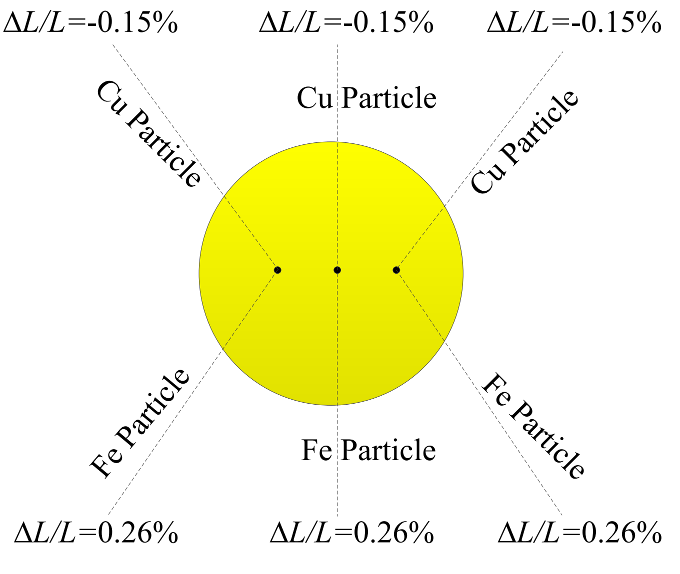


Fig. 5. Relative inductance variation of Helmholtz-coil ODS at different locations in the cross section of the oil tube.

The ODS model is developed in FEM software. The materials of the ferromagnetic and non-ferromagnetic particles used in this study are iron and copper, respectively. The particles pass through the sensor along the positive direction of y axis from different locations in xz plane. Three locations are studied in this paper, namely r/R =0, r/R =0.5, $r/R = -0.5$, where r is the perpendicular distance from the point to y axis, R is the radius of the saddle coils. The parameters of the studied oil debris sensor are shown in Table I. Fig. 4 demonstrates the eddy current distribution of the Cu particle.

In Fig. 5, the relative inductance variations of saddle coils $\Delta L/L$ at different locations in the cross section of the oil tube for Cu particle are all -0.15%, while for Fe particle, the relative inductance variations are all 0.26%, which verify the theoretical analysis of the proposed inductive sensor.

4. Conclusion

An improved inductive sensor probe is proposed in this paper for the online health monitoring of wind turbine gearbox. The magnetic field homogeneity as well as the performance of the proposed Helmholtz-coil probe are analyzed and verified by finite element analysis. Future work will be the experimental verification of the proposed Helmholtz coil probe.

5. Learning objectives

To improve the performance of the oil debris sensor

To detect the incipient faults of gearboxes

To prolong the lifetime of gearboxes

To benefit the condition based maintenance of gearboxes

To enhance the reliability of wind turbines

To reduce the O&M cost of wind turbines

References

[1] J. Edmonds, M. S. Resner, and K. Shkarlet, "Detection of precursor wear debris in lubrication systems," in *Proc. IEEE Aerospace Conference*. Mar. 2000, pp. 73–77.

[2] I. M. Flanagan, J. R. Jordan and H. W. Whittington, "An inductive method for estimating the composition and size of metal particles," *Measurement Science and Technology*, vol.1, no. 5, pp. 381-384, May 1990.

[3] L. Du and J. Zhe, "A high throughput inductive pulse sensor for online oil debris monitoring," *Tribology International*, vol. 44, no. 2, pp. 175–179, Feb. 2011.

[4] L. Du, X. L. Zhu, Y. Han, L. Zhao, and J. Zhe, "Improving sensitivity of an inductive pulse sensor for detection of metallic wear debris in lubricants using parallel LC resonance method," *Measurement Science and Technology*, vol. 24, no. 7, pp. 1–10, Jul. 2013.

[5] B. Liu, F. Zhang, Y. Wu, and D. Sheng, "Research on the Detection of Metal Debris with Microplane Inductance Sensor," *Advances in Mechnical Engineering*, vol. 2013, pp. 484710, 2013.