摩擦発電原理を用いたすべり軸受の摩耗センシング

Triboelectric nanogenerator-based wear detection sensor for a sliding bearing

東大・工（院）*楊　致遠　　中南大・理（非）高　莽　　大同メタル工業（正）城谷　友保
大同メタル工業（正）今村　信也　　都市大・工（正）崔　埈豪

Zhiyuan Yang*, Mang Gao**, Tomoyasu Shiroya***, Shinya Imamura***, Junho Choi****

*The University of Tokyo, **Central South University, ***DAIDO METAL CO., LTD

****Tokyo City University

With the quick advancement of triboelectric nanogenerators (TENG) [1,2], the self-power sensing ability with triboelectric effect has been applied to various application areas, such as machines [3], wearable electrics [4], IoT devices [5], etc. The wear monitoring of sliding bearings is a critical and challenging issue with traditional methods. However, the TENG pave a new route to resolve this problem. In this study, we developed a triboelectric wear detection sensor (T-WDS) with self-powered sensing ability for the sliding bearing. The Si-incorporated diamond-liked-carbon (Si-DLC) films on the steel shaft were employed to achieve the signal output with a minor change to the original structure. Firstly, different wear situations were simulated to explore the influence on the wear area. Then, real bushing bearings with different wear surfaces were used to verify the simulation results. This research demonstrated a way for wear condition monitoring for bushing bearing and potential smart bearing by the triboelectric effect. The Si-DLC film was deposited on half of the steel shaft with two pads by PBII&D (Bipolar-type Plasma-based Ion Implantation & Deposition) [6]. Some key parameters of deposition are displayed in **Table 1** and the whole experiment structure is shown in **Figure 1**.

Table 1. The detailed deposition conditions for preparation of the coatings.

Positive Pulse	Duration (μs)	5
	Voltage (kV)	+1.5
Negative Pulse	Duration (μs)	5
	Delay (μs)	20
	Voltage (kV)	-5
Pulse frequency	4 kHz	
Precursor Gas	Toluene ($C_6H_5CH_3$, 2 sccm)	TMS ($Si(CH_3)_4$, 8 sccm)

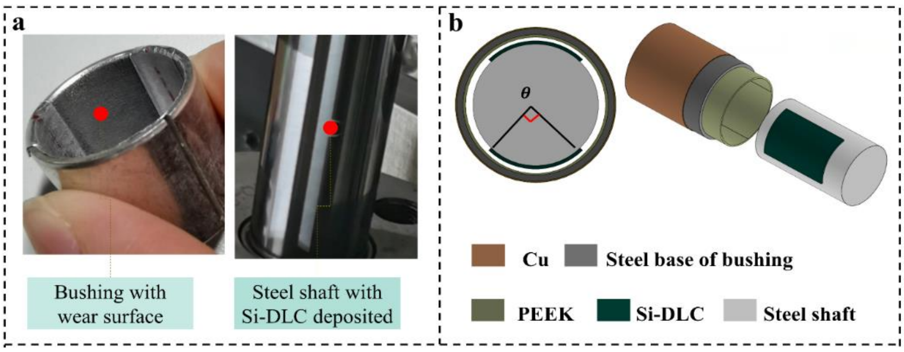

Figure 1. (a) Worn bearing and steel shaft coated with Si-DLC film and (b) detailed structure components.

The T-WDS generates an electrical signal based on triboelectrification and electrostatic induction. The triboelectrification will happen when Si-DLC coating contacts with PEEK, making these two surfaces differently charged. The irregular worn bearing surface leads to a separation between Si-DLC and PEEK during rotation. The charges on PEEK thus cannot be balanced, leading to the inducted charges appearing on the steel electrode due to the electrostatic induction, which raises the charges transfer between the steel base electrode and ground and thus gives electricity. However, when there is no wear in the bearing, Si-DLC film will always keep in contact with PEEK, which cannot generate electrical signals. Therefore, the wear condition of a bearing can be monitored by the electrical signals as shown in **Figure 2**.

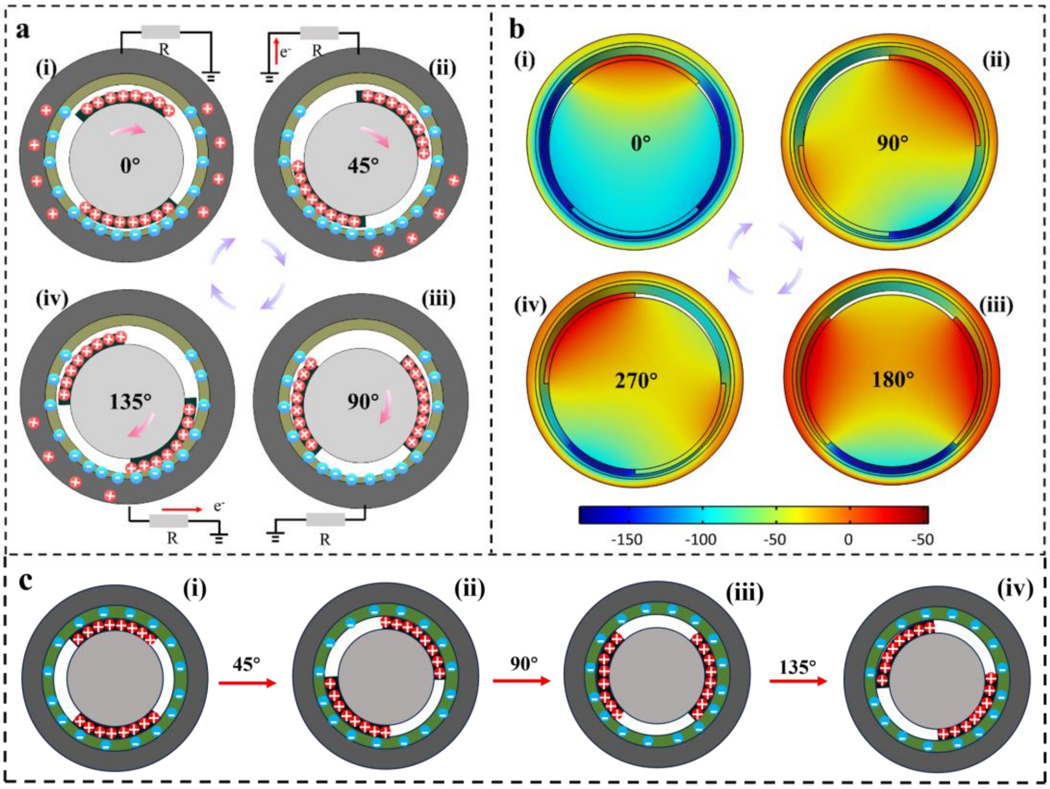

Figure 2. (a) Working principle of T-WDS, (b) COMSOL simulated potential distribution, and (c) Conditions for a no-wear bearing.

The proposed T-WDS can sensitively detect the signals caused by worn surfaces, which were then analyzed by computer simulation and verified experimentally under different wear areas, wear depth, and rotation speed. This inspection method could dramatically reduce the difficulty of condition monitoring for sliding bearings, and the wear state can be determined based on the amplitude of the waveform without prior knowledge.

References

1) Z. L. Wang, Adv. Mater. 24 (2012), 280-285.
2) Z. L. Wang, ACS Nano. 7 (2013), 9533-9557.
3) M. Zhu, M. Lou, J. Yu, Z. Li, B. Ding, Nano Energy. 78 (2020), 105208.
4) X. Rong, J. Zhao, H. Guo, G. Zhen, J. Yu, C. Zhang, G. Dong, Adv. Mater. Technol. (2020), 2000641.
5) W. Liu, X. Wang, Y. Song, R. Cao, L. Wang, Z. Yan, G. Shan, Nano Energy. 73 (2020), 104843.
6) S. H. Ramaswamy, J. Shimizu, W. Chen, R. Kondo, and J. Choi, Nano Energy. 60 (2019) 875-885.