摩擦発電原理を用いたジャーナル軸受けの駆動状況モニタリング

Condition monitoring of journal bearing based on triboelectric principle

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1. Introduction

With the wide application of IoT in mechanical systems, smart fault detection and condition monitoring technologies are urgently required in a mechanical system. Pad-type journal bearing (PJB) including tilting pad journal bearing is more stable than conventional bearing but more complex to assemble and maintain. Here, we develop a triboelectric PJB (T-PJB) with multi-monitoring functions, which can detect the working conditions with simple and direct approaches. High-performance tribological materials are applied as dielectric pairs to approach real bearings without changing their structure. This work proposes an easy and direct approach to contribute to the stability and longevity of smart PJB and shows a promising application prospect in a real mechanical system.

2. Fabrication of triboelectric pad journal bearing

The T-PJB comprises four parts that were fabricated based on the freestanding-mode TENG. The main structure includes a bearing housing, Cu electrode, PTFE film, and Al pipe shaft deposited with Si-incorporated diamond-like carbon (Si-DLC) film, which was selected as a positive triboelectric layer owing to its characteristics, such as low surface roughness, high tribological performance, high-temperature stability and exceptional adhesion with the substrates [1-5]. The fabricated TENG-based pad journal bearing is shown in **Fig. 1**a, and the COMSOL simulation result is displayed in **Fig. 1**b.

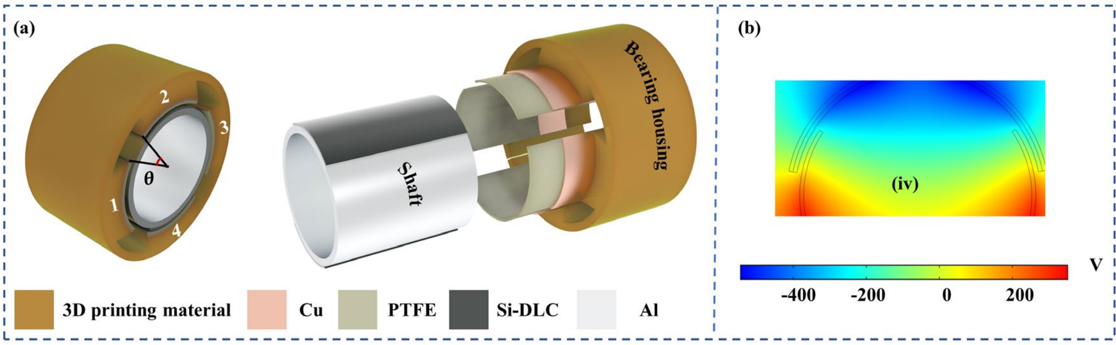

Fig. 1. (a) Detailed structure of the T-PJB, including triboelectric layers, induction electrode, and an auxiliary structure. (b) COMSOL simulation of T-PJB.

3. Results and discussion

Traditional misalignment detection of bearings is mainly based on vibration signals, which are invariably mixed with other signal components. This increases the complexity of subsequent signal processing, particularly in nonlinear systems [6]. The technical challenges in the condition monitoring of PJB, such as preload force and misalignment, can be ascribed to unbalanced forces from different directions. Fortunately, the sliding-mode TENG can sensitively characterize the force response [7], so it would be an ideal candidate to realize PJB condition monitoring.

To verify whether T-PJB can conduct condition monitoring or not, a misaligned PJB was experimentally fabricated. The displacement of the T-PJB along the horizontal direction could be precisely measured using a micrometer. Meanwhile, wires were led out from each pad (numbered as pads 1, 2, 3, and 4, **Fig. 1**a) so that the waveform of a single pad could be measured. First, the outputs of the T-PJB were measured at different rotational speeds with and without misalignment (the displacement was fixed at 0.2 mm). For the aligned case, speed had no significant effect on the output voltage of the PJB, while for the misaligned case, the output voltage increased with increasing rotation speed (**Fig. 2**a). In the case of misalignment, the higher the speed, the greater the peak voltage variance, and the easier it is to identify the operational failure of the PJB (**Fig. 2**b).

The effects of displacement on the PJB output were also investigated at a rotating speed of 1 Hz, as shown in **Fig. 2**c,d. The output voltage and peak voltage variance of the PJB increase significantly with increasing displacement, which is mainly caused by the increased contact force during the misaligned rotation. Although it could be determined whether there is a misalignment in the PJB, accurate fault diagnosis of a specific component is essential for machinery operation. **Fig. 2**e shows a comparison of the electrical output from each pad, and no obvious difference in the output voltage between different pads for the aligned case could be observed. However, the pad in a certain position was subjected to a greater force during rotation in an unaligned case,

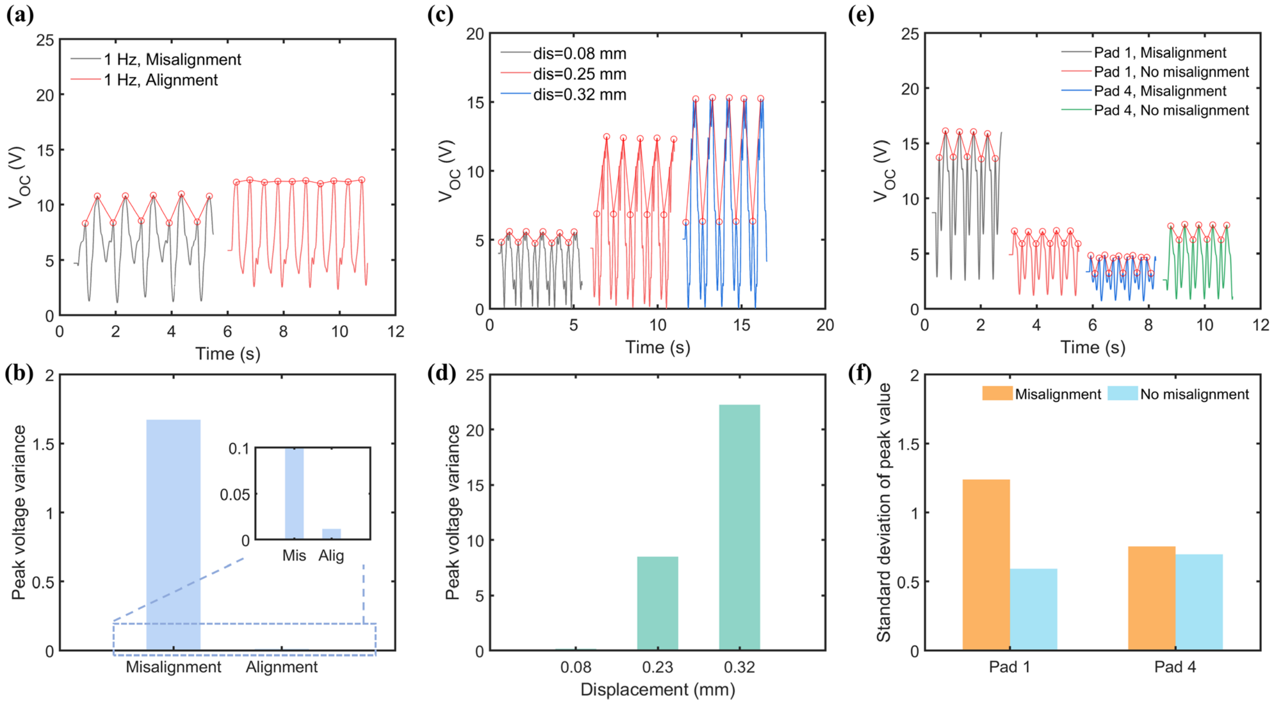

Fig. 2. (a,b) The output voltage and peak voltage variance of PJB with and without misalignment. (c,d) The output voltage and peak voltage variance of PJB at different displacements with a fixed rotation speed of 1 Hz. (e,f) The output voltage and peak voltage variance of different single pads.

resulting in a greater output voltage. For pads 1 and 4, the peak voltage variance in the misaligned case was larger than that in the alignment case (**Fig. 2**f).

Based on the experimental results, it can be observed that there is a high probability of misalignment if the peak voltage variance is extremely large, which enables the detection of an abnormal state caused by an unbalanced force.

4. Conclusion

In summary, a smart T-PJB was developed to realize condition monitoring using the triboelectric principle. Materials with high tribological performance, such as Si-DLC and PTFE films, were applied as dielectric layers. T-PJB was used to detect the change in the signal waveform caused by unbalanced forces, which were analyzed and verified experimentally. This inspection method could dramatically reduce the difficulty of condition monitoring for PJB, and the operation state could be determined based on the characteristics of the triboelectric waveform without prior knowledge. This study provides promising applications in fault detection for the journal bearings, which can be widely applied in rotating machinery and contribute to the establishment of smart plants.

References

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