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# Application of IEPE Accelerometer based on Lead-Free Piezoelectric Ceramic for Pump Testing

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## 1. Introduction

Piezoelectric accelerometers are key sensors for monitoring and diagnosing the status of major devices and structures in various industrial fields such as nuclear power plants, chemical plants, automobiles, aerospace, and construction. [1,2] IEPE type Piezoelectric accelerometers with relatively high performance and reliability are mostly used. [3] Traditionally, these sensors have been manufactured using PZT piezoelectric ceramics containing lead as sensing materials, but the use of hazardous substances such as lead raises environmental concerns. [4,5]

In this study, a voltage-type accelerometer sensor based on lead-free piezoelectric ceramics was manufactured by introducing the self-developed IEPE circuit and housing to the charge-type accelerometer prototype. In order to verify the performance of the manufactured IEPE accelerometer sensor, the voltage sensitivity and frequency characteristics were evaluated by using a vibration system. In addition, a field test was performed using a cooling pump of a research reactor owned by KAERI. The performance of the lead-free KNN-based sensor was compared to a PZT-based commercial sensor used in general industrial sites under the same conditions. Based on these results, we aim to demonstrate the industrial applicability of the developed lead-free accelerometer.

## 2. Methods

Polycrystalline KNN-based ceramic rings, which are essential for sensor fabrication, were prepared through solid-state synthesis. KNN-based ceramic ring had an outer diameter of 12.40 mm, an inner diameter of 7.46 mm, and a thickness of 2.56 mm.

An IEPE accelerometer sensor was fabricated using a KNN-based ceramic rings, components of a charge-type accelerometer prototype based on the compression mode operation principle, a housing that fits it, and a self-made IEPE circuit.

## 3. Results

The density and piezoelectric properties of the 0.96KNN-0.03BNKLZ-0.01BS and PZT-5A ring ceramics are shown in Fig. 1. In particular, the phase transition temperature ($T_C$) and piezoelectric constant ($d_{33}$) were confirmed to be 330 ºC and 373 pC/N, respectively. $T_C$ is related to the operating temperature, and $d_{33}$ is proportional to the charge sensitivity of the compressive accelerometer sensor. [6,7]

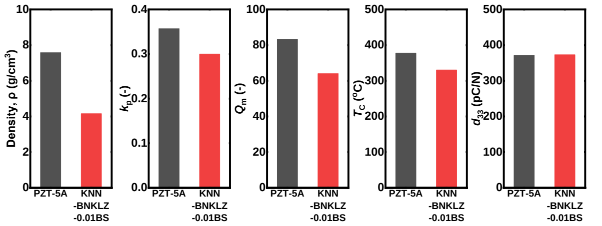


Fig. 1. Density, $k_p$, $Q_m$, $T_C$ and $d_{33}$ values of PZT-5A and 0.96KNN-0.03BNKLZ-0.01BS ceramic rings.

An actual photo of the IEPE circuit, housing, and accelerometer prototype components is shown in Fig. 2(a). The piezoceramic rings, which are responsible for the core function of the accelerometer sensor, were made of two 0.96KNN-0.03BNKLZ-0.01BS piezoceramic rings. The housing, screw, tail, and base plate were made of stainless steel, and the electrodes and wires, which transmit electrical signals, were made of Inconel and Cu wire, respectively. The left side of Fig. 2(b) is a sensor module manufactured by assembling the accelerometer sensor components excluding the housing, and the right side is a photo of the housing manufactured with a three-pin (3PIN) connector according to the manufactured IEPE circuit. An IEPE accelerometer with an outer diameter of 64.0 mm and a diameter of 24.4 mm was manufactured, as shown in Fig. 2(c).

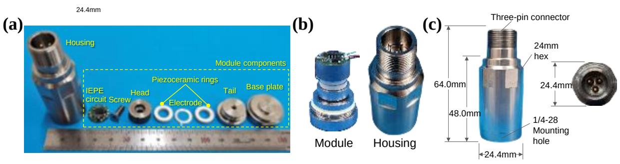

Fig. 2 (a) Accelerometer sensor components and 0.96KNN-0.03BNKLZ-0.01BS ceramic ring. (b) Accelerometer prototype with IEPE circuit attached (left) and 3PIN housing (right). (c) Fabricated IEPE type accelerometer sensor and external dimensions.

Fig. 3(a) and (b) show the frequency response profiles of the PZT-based commercial sensor and the KNN-based sensor. The resonant frequency of both sensors was observed at approximately 20 kHz, and the additionally provided inset figure confirmed the frequency flatness characteristics of both sensors from approximately 20 Hz to 10 kHz with a ±3 dB criterion. This indicates that both sensors provide stable performance even in the high-frequency band. Fig. 3(c) and (d) show the voltage-acceleration characteristics measured in the range of 1 g to 10 g at 159 Hz. The measured voltage sensitivity was 93.2 mV/g for the commercial PZT-based sensor, while it was 101.1 mV/g for the KNN-based sensor.

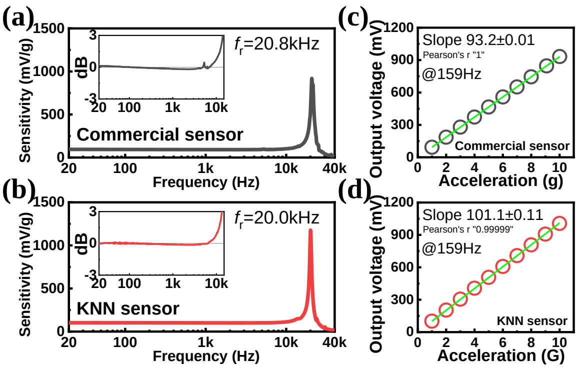


Fig. 3. Frequency response profiles of (a) commercial PZT-based sensor and (b) KNN-based sensor measured through vibration experiment. Voltage vs. acceleration characteristics (test frequency = 159 Hz) of (e) commercial PZT-based sensor and (f) KNN-based sensor

To confirm the applicability of the developed KNN accelerometer in an actual industrial environment, a field test was conducted on a rotating machine. Fig. 4(a) and (b) show the test target pump, the installed measurement system, and the attached sensors for pump vibration measurement.

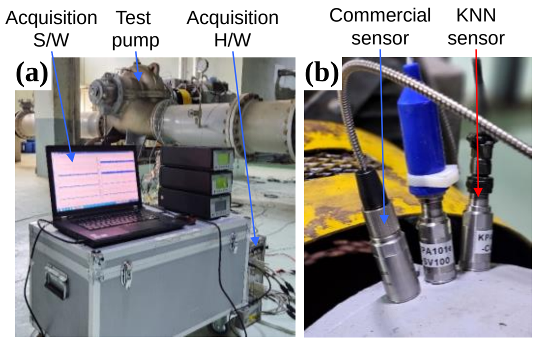


Fig. 4. (a) Photo of rotary pump field test. (b) Photograph of the commercial PZT-based sensor and KNN-based sensor attached to the bearing housing.

Fig. 5 shows the results of calculating the Auto Power Spectral Density (APSD) after performing FFT on the signals generated from the commercial PZT-based sensor and the KNN sensor. The locations of these peaks are indicated by symbols in the inset of Fig. 5, and the observed peaks were confirmed at the same locations by both sensors. These peaks are commonly used to diagnose representative pump defects, such as mass unbalance, misalignment, bent shaft, eccentric rotor, rotor rub, and mechanical looseness. [8]

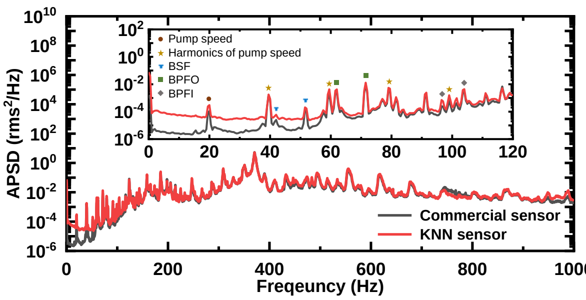


Fig. 5. Frequency spectrum for the measured signals from the commercial PZT-based sensor and KNN-based sensor.

These results confirm that the developed eco-friendly accelerometer has similar performance and reliability compared to commercial PZT-based sensors, and show that it can be used along with commercial PZT-based sensors for condition monitoring and fault diagnosis of pumps in actual industrial fields.

## 4. Conclusions

This study fabricated an IEPE accelerometer sensor based on lead-free ceramics and confirmed the performance of the fabricated sensor and its applicability in actual machine equipment operation environments. From the above results, it was confirmed that the lead-free IEPE accelerometer developed in this study has performance and reliability equivalent to or superior to commercial PZT-based sensors. Therefore, the developed sensor has proven the possibility of replacing commercial PZT-based sensors in condition monitoring and fault diagnosis of facilities and structures in various industrial sites.

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