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A Fundamental Study of Piezoelectric Plate Type Power Generator for Tire Pressure Monitoring Systems

圧電板を用いた自動車タイヤの空気圧モニタリングシステム用発電素子の基礎検討

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1.Introduction

The tire pressure monitoring system (TPMS) is used for improving the safety of automobiles. The batteries are used on the pressure sensors in TPMS at present. However, as for using the batteries, there are a lot of problems, such as inconvenience, expensive costs of taking an extra wheel balance and of replacing battery and a limitation of communication frequency which originates in longevity of battery. Recently, the several techniques have been proposed for the battery-less pressure sensors in TPMS, such as the mechanical vibration energy systems [1-4]. In this study, the piezoelectric plate type power generator is investigated to substitute the battery in TPMS. First, the strain of inside of the automobile tire is measured by deformation of the tire. Next, the characteristics on piezoelectric plate type power generator are calculated using the finite element method with the measured strain values. Then, the calculated results are experimentally examined using the piezoelectric ceramic plates attached to the rubber samples.

2. Experimental results of strain by deformation of automobile tires

Figure 1 shows the experimental set up for strain measurement by deforming the automobile tire. The strain was measured with Wheatstone bridge circuit by detecting the signals of strain gages attached inside of the tire. As the static force was impressed to the upper part of tire, the relation between the deformation of tire and the strain was measured. Figure 2 shows the experimental results of relation between amount of compression and strain of tire with normal tire pressure of 200kPa. In this figure, X-axis and Y-axis show the direction where the automobile runs and the perpendicular direction. The value of strain in the X-axis direction increased when the amount of compression was enlarged. The strain characteristics showed a saturated tendency when the amount of compression was 20mm or more. On the other hand, the value of strain in the Y-axis direction almost indicated the constant values. Therefore, it was clarified that the inside of tire was strained by 0.15%.

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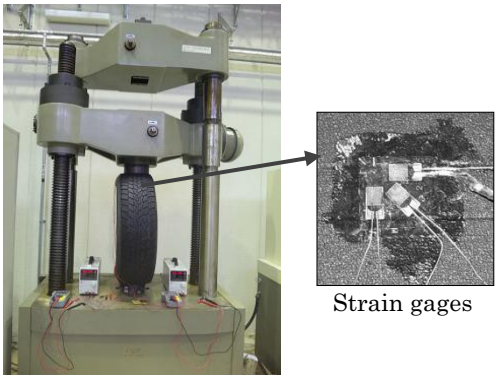

Fig.1. Experimental set up.

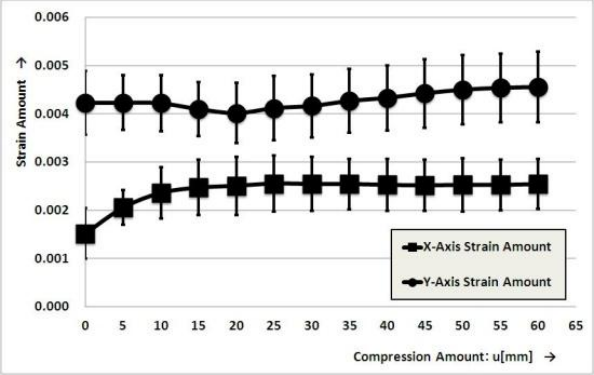

Fig.2. Experimental results between the compression and strain.

3. Examination of power generator using finite element method

To consider the characteristics on power generator, the generated charge and voltage on piezoelectric plate were calculated using the finite element method. The analysis was performed using the finite element analysis program of ANSYS (Cybernet Co.). Figure 3 shows the construction of piezoelectric plate type power generator. The piezoelectric ceramic plate was attached to the inside of the tire, which dimensions was $60\times30\times25(mm^3)$. In order to obtain the characteristics on power generator, the finite element analysis was performed according to the following procedures. First, as the compressive force was impressed from the outside of finite element model without piezoelectric ceramic plate, the inside on the model was strained by 0.15%. Next, as the compressive force of the same value was impressed to the model with piezoelectric

ceramic plate, the generated charge and voltage were calculated. Then, the difference of the characteristics of power generator was examined with changing the material constants and dimensions on piezoelectric ceramic plates.

Figure 4 shows the calculated characteristics of power generator, where the thickness is 1mm. The generated voltage and electrostatic energy increased accordingly to the area of piezoelectric ceramic plate. The maximum voltage of 1.8V was generated using the ceramic plate made by N-4 material.

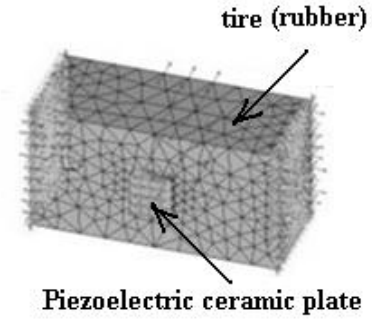

Fig.3. Finite element model for calculation.

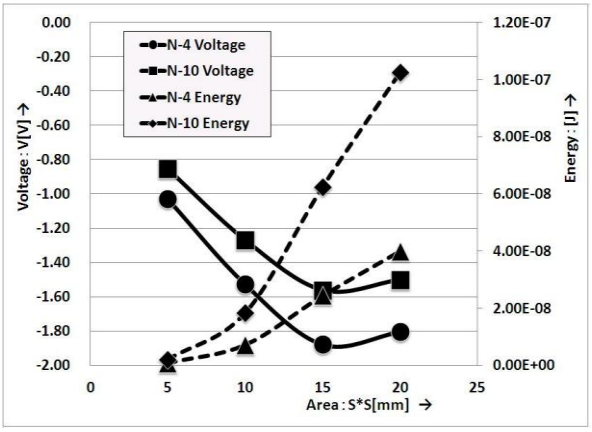

Fig.4. Calculated relationship between voltage and the dimensions.

4. Experimental results of power generator using piezoelectric ceramic plate

To evaluate the calculated results of power generator, the rubber plates ($100\times100\times5mm^3$) which were attached to piezoelectric ceramic plate (N-10,$10\times5\times1mm^3$) were fabricated for test pieces. The triangular shaped load force was impressed to the test pieces using EZ-test (SHIMADZU Co.). The generated voltage was detected using measurement system developed with LabVIEW software.

Figure 5 shows the response characteristics of generated voltage as a parameter of compressive force speed. The generation time of voltage became longer and the maximum value of voltage became small as the compressive force speed was lower. On the other hand, Fig.6 shows the characteristics between the compression speed and the generated voltage. The value of generated voltage was proportional to the compression speed. It is quantitatively clarified that the generated voltage of 1.0V was obtained on the compression speed of 50mm/min.

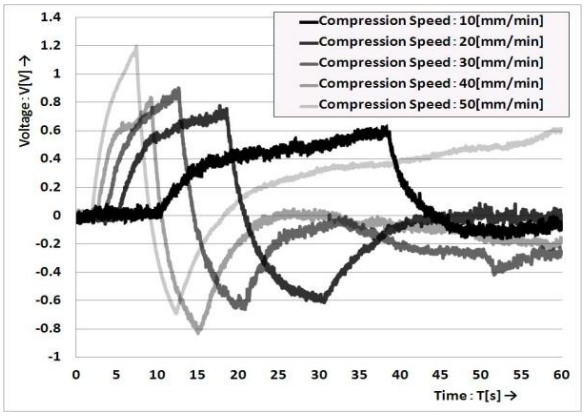

Fig.5. Response characteristics on generated voltage.

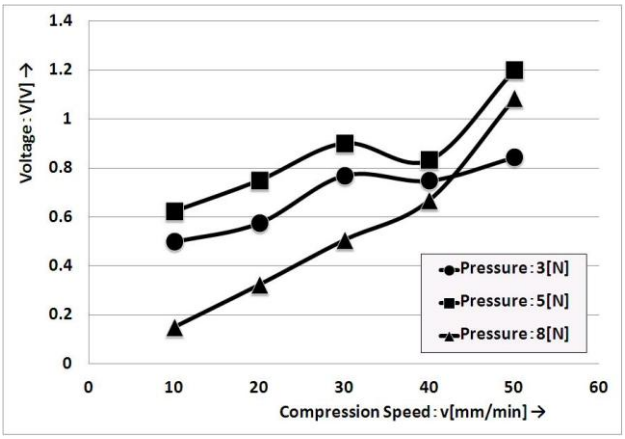

Fig.6. Experimental relationship between the compression speed and the generated voltage.

5. Summary

The piezoelectric plate type power generator was studied in this paper. The characteristics on piezoelectric plate type power generator were calculated using the finite element method and experimentally examined. The detailed examination for substituting the battery in TPMS is scheduled in the next paper.

References

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