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Effects of viscoelastic properties on the performance of the polyurethane sensor

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Abstract

The purpose of this study is to develop self-sensor type tactile sensing technology where the material itself serves as sensor, to actually apply the technology into the arm of robot, and to monitor the location and intensity of the external force exerted on random place in real time. In order to develop such system, preceding study conducted experiments on the output signal of sensor for different magnitudes of the external force, speeds, and locations. Among all, the results of the preceding study identified the decreasing tendency of output signal with increasing load input speed. Hence, this study conducted viscoelastic property test of the material and compared and analyzed the two results to identify the cause of decrease of output signal.

Introduction

As the researches on the tactile sensor emulating human skin get activated, flexible polymer materials are widely used as sensors (Yamada *et al*., 1994; Engel *et al*., 2002; Meng *et al*., 2006; Kim *et al*., 2010; Yamada *et al*., 1994). Among these polymers, polyurethane is used as base material of sensor due to relatively higher mechanical properties and adhesive properties. Also, polyurethane is used as sensor due to its piezoelectric properties (Hwang *et al*., 2011, 2013). However, polymers have nonlinear relationship between load and deformation along with hyper-elastic and viscoelastic properties which make it very important to understand the dynamic properties before applying on to mechanical structure.

Hence, this study identified the correlation between dynamic load input speed and output values of polyurethane sensor through experiments and conducted DMA (Dynamic Mechanical Analyzer) during the dynamic property analysis tests to identify the effect of dynamic properties of polyurethane on the output signal of sensors.

Experimental methods and results

Materials

The skin materials of the robot applied to this study should have elasticity and flexibility like human's skin with durability that can resist against the repetitive external impetus and impact. Moreover, as a piezoelectric material, it should have the outstanding piezoelectric properties generated by the external impact or load. As for materials making an outer cover of robots used in the study, polyurethane resin S - 1090 (Songwon Industry) which is a piezoelectric material. The property of basic materials of polyurethane was shown in Table 1.

Table 1: Mechanical properties of polyurethane

PROPERTIES	
Elastic modulus (Thermoplastic)	1.31GPa
Tensile strength	35MPa
Density	1.12(Mg/m^3)
Piezoelectric constant	d33 : 0.2(pC/N)

Test conditions and test results

Polyurethane tactile sensor proposed in this study is shown in Figure 1. The electrode plate 5mm of square-shaped electrodes arranged in the length and width of 30mm and 20mm respectively was manufactured. And the electrode plate was attached to a polyurethane sensor.

For measuring signals, a small load cell was attached to end of the driving part of the self-designed dynamic material testing machine as shown in the Figure 2 and external forces are applied to the test specimen in the form of a sine wave. Then, the electric signal (charge signal) generated by external forces was analyzed by collecting signals to the DAQ Board 9214, Module 9215, and Module 9263 National Instrument Co. USA through a Conditioning amplifier (type 2626, Bruel & Kjar Co. Denmark).

The experiment was conducted under the condition of Table 2 to measure the output signal of sensor for different input load speeds. Figure 3 indicates the electric signal form generated by the load applied to the material in a dynamic material testing machine. It is found that the reversal patterned electric signals were generated when the sine-wave load is applied to the material. The signals were analyzed by collecting the peak and bottom electric charges generated per 1 cycle of the external force.

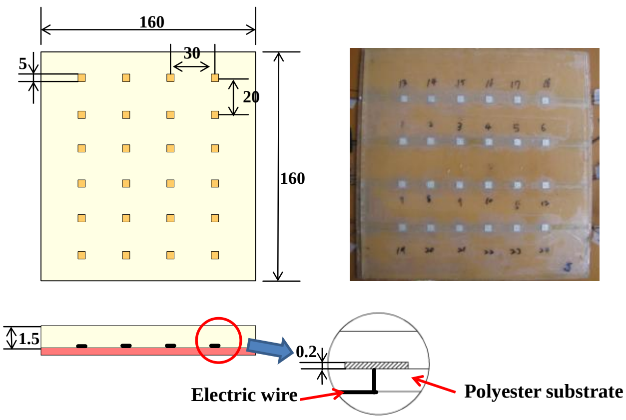

Figure 1: Configuration of specimens for tactile sensing of robot skin materials

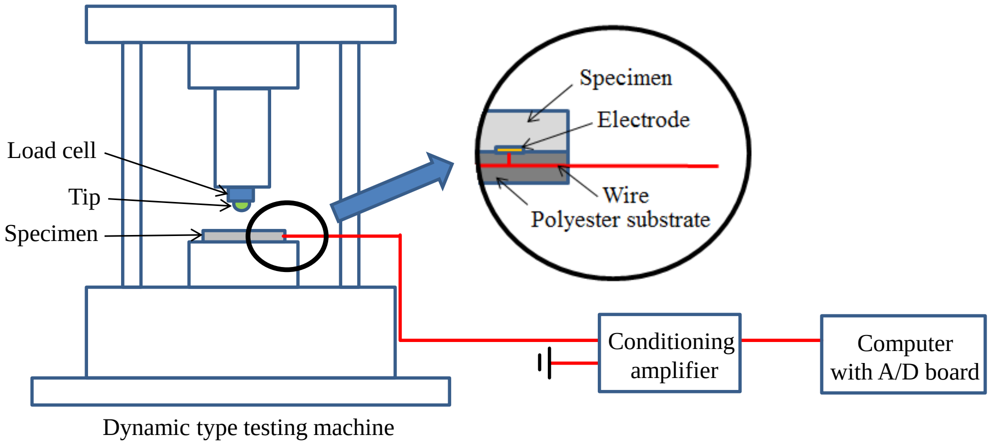

Figure 2: Specially equipped electro dynamic testing machine.

Table 2: Test conditions

TEST CONDITIONS	
Loading type	Dynamic sine wave
Loading size	15N
Loading speed	1~50Hz
The distance between electrodes and loading position	10mm

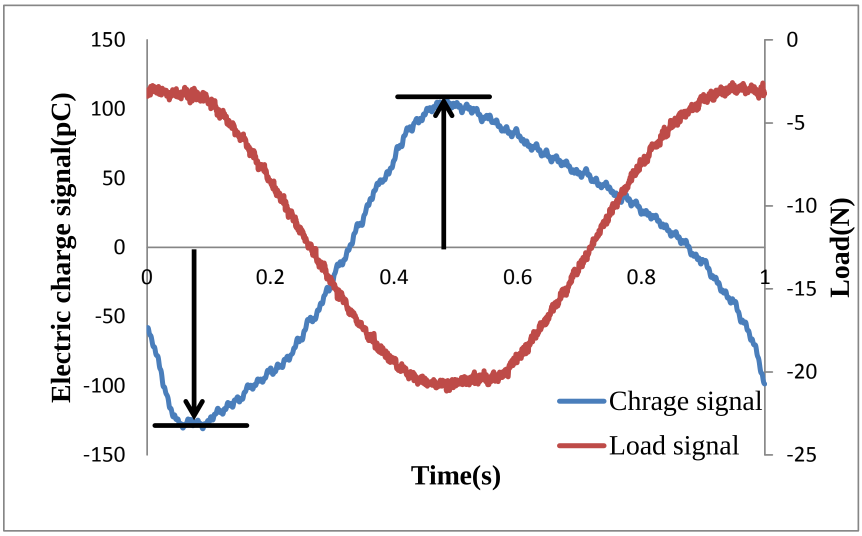

Figure 3: Typical electric charge signal and applied load.

The results of the experiment are shown in Figure 3. In the initial stage of the experiment, 0~25Hz, the measured output signals were similar but the results confirmed that output signal measurement decreased in the 25Hz~50Hz interval.

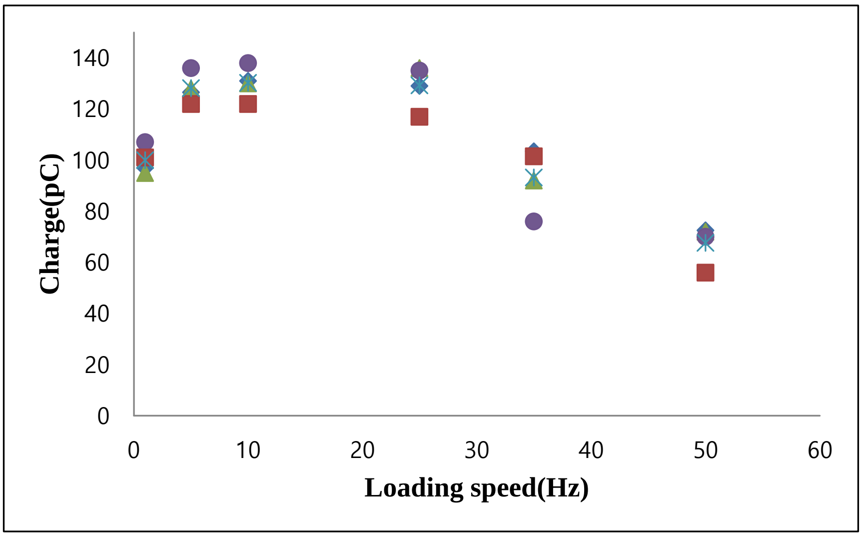

Figure 4: Magnitude of measured electric charge signals with respect to loading speed.

Dynamic mechanical analyzer test

In order to analyze the cause of degradation of sensor performance following input speed, elasticity dependence of the material on input frequency was tested through experiment using DMA (DMA Q800. TA Instruments. USA). The experiment was carried following the sectional shearing method which is appropriate for elastomer materials. (Menard, 1999; ASTM 4065) The specimen was produced with 10mm width, 40mm length, and 25mm thickness. Also the experiment was carried under room temperature and input frequency range of 1~100Hz.

As a result, the increase of storage modulus (G`) and loss modulus (G``) followed the increase of frequency as shown in Figure 4. Comparing with the results of the experiment, increase of input frequency results in increase of material rigidity, and such physical properties are led to degradation of sensor performance during high frequency input signal.

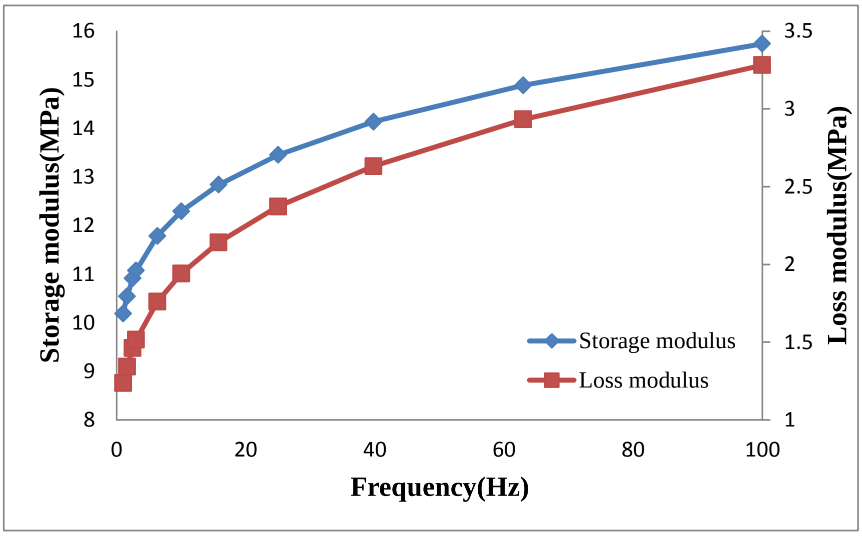

Figure 5: Measured storage modulus and loss modulus of frequency.

Conclusion

This study conducted test on the performance of sensor and dynamic mechanical test on the material in order to analyze the correlation between load input speed and output signal of piezoelectric polyurethane tactile sensor. The results of performance test for different input speed showed that increase of load speed was followed by rapid decrease of output signal of the sensor. DMA experiment was conducted to find the cause of such tendency which identified the rigidity of the material for different input frequencies and the effect of input frequency on rigidity of the material. That is, the changes of rigidity of the material for input frequency must be considered as important parameter as interdependency between transformation rate of material and signal of the sensor exists in the piezoelectric sensor.

Acknowledgements

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References

ASTM 4065: *Standard practice for determining and reporting dynamic mechanical properties of plastics.*

Engel, J., Chen, J., Liu, C., Flachsbart, B. R., Selby, J. C. & Shannon, M. A. 2002. Development of polyimide-based flexible tactile sensing skin. *Materials Research Society*. **736**:D4.5.2002

Hwang, H. Y. 2011. Piezoelectric particle-reinforced polyurethane for tactile sensing robot skin. *Mechanics of Composite Materials.* **47**(1):137-144.

Hwang, S. K. & Hwang, H. Y. 2013. Development of a tactile sensing system using piezoelectric robot skin materials. *Smart Materials and Structures.* **22**:1-8.

Kim, M. S., Park, Y. K. & Kwon, S. Y. 2010. Tactile devices that mimics human's sensory system. *Physics and High Technology*. **19**(9): 15-22.

Menard, K. P. 2008. *Dynamic mechanical analysis: a practical introduction* (2nd ed). CRC Press.

Meng, Q. & Lee, M. H. 2006. Design issues of assistive robotics for the elderly. *Advanced Engineering Informatics.* **20**(2):171-186.

Yamada, Y. & Cutkosky, M, R. 1994. Tactile sensor with three-axis force and vibration sensing functions and its application to detect rotational slip. *IEEE International conference on Robotics and Automation.* 8-13 May 1994. San Diego, California. **4**:3550-3557.