論 文 の 要 旨

題目

Study on the Measurement of High-Speed Impulsive Force Using Piezoelectric Film
（圧電フィルムを用いた高速衝撃力の計測に関する研究）

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In a series of practical problems of various fields of engineering science and technology, even in our daily life, people will encounter a variety of impact loading problems. And it can be observed that mechanical response of objects under impact loads and static loads often have significantly difference. Understanding the mechanical response of an object under impact loading conditions will greatly contribute to the project application and engineering design of these materials.

The main purpose of the new designs and evaluations of a physical/mechanical sensor for the measurement of dynamic load is focused to be smaller, more versatile and more accurate. From now on, developments of tactile sensors have been considered with consideration of miniaturization and high sensitivity. The driving force toward smaller, cheaper component and more flexible sensor is one of the major trends in sensor development. At the same time, flexibility in its dimension generates new applications in the sensor market. Therefore many sensor designers and sensor companies have spent their energy to achieve those goals.

In the field of impulsive force measurement, load cell is the most widely used tool, however, load cell is limited to the test environment and affected by vibration deeply. Furthermore, strain gauge load cells require continuous electric energy for the production and display of signals. Subsequently on the high-speed occasion, the high-speed impulsive force waveform whose shock time from contact to separation is below 1 millisecond usually will produce residual vibration because of the overlap and resonance of subtle shock waves. Therefore, it is required to develop a portable light and high-precise impulsive force detection plate.

In case of the signal is dynamic, piezoelectric material has been used for the same purposes in similar way as conventional strain gauges. Piezoelectricity, Greek for “pressure” electricity, was discovered by the Curie brothers more than 100 years ago. They found that quartz changed its dimension when subjected to an electrical field, and conversely, generated electrical charge when mechanically deformed.

This study is conducted to develop a thin sensor which is capable of measuring a high-speed impact using a polymeric piezoelectric material (PVDF). Firstly, the three kinds of prototype sensor which are sheet-type impact force sensor, pad-type sensor and fluctuating load detection plate are developed, and these three types sensor have been experimentally revealed that exhibit excellent response characteristics for high-speed impact load. In addition, their applicability already is clarified through measuring the striking force of the baseball bat and the sand bag hit test of boxing. Subsequently, a falling impact force measuring device has been developed, on which impact force sensor are installed on both the load side and the receiving side. By using this device, the impulsive force waveforms of some kinds of soft materials are measured. It is shown that the most of soft material show the thorn-shape waveforms resulting from the strain rate dependence occurring in the initial stage of impact force. Furthermore, by performing an impact simulation using the dynamic model, it is revealed that the occurrence reason of the thorn-shape waveform is caused by the viscosity transient phenomenon.

Chapter 1 presents the background of this research, and the outline of other chapters.

In chapter 2, it shows the properties of polymer piezoelectric material and the principle of measuring impact force using a polymer piezoelectric material.

In chapter 3, three kinds of prototype sensors which are sheet-type impact force sensor, pad-type sensor and fluctuating load detection plate are developed. And the performance of these three types has been clarified in a variety of impact tests. Sheet-type sensor has a structure in which silicone rubber sheets are pasted on both surfaces of the piezoelectric film. By strain amplification effect of silicon rubber, even small impact force is still possible to accurately measure. The pad sensor consists of a piezoelectric film sandwiched between two pieces of metal sheet, and the whole body is laminated by the resin film. The pad sensor features light-weighting and high-rigidity in thickness direction, therefore, it is verified that the thin pad sensor can be used to measure the greater extent high-speed impact compared to the conventional load cell. The fluctuating load detection plate owns the structure that two metal plates grip a pad sensor and tightened with bolts. Since the fluctuating load detection plate possesses the metal plates, it can only be used in the plane, but it still can accept impact from hard object. The accuracy of these sensors are demonstrated based on the measurements of the waveform impulse and the momentum theory.

In chapter 4, as an example of application to high-speed impact force of the pad sensor, a sensor that can be used in wrapped on a cylindrical curved surface is developed. The sensor is placed on the baseball bat, aiming the impact force of hitting. Firstly, a friction removal mechanism in contact interface, a bendable sensor configuration and a method of sensor installation on the surface of the pipe are discussed. Then, prototype sensors that can be installed on a pipe with diameter of about 70mm are made. The performance of sensor is investigated by the pipe punch test and the ball drop test. Then, the impulsive force is measured by the test that a batter hits the ball which the pitcher threw. A metal bat and a hard ball are used for the experiment of hit and bunt.

In chapter 5, targeting an impact force sensor that can be used in a flexible surface, a flexible impulsive force sensor has been developed in which multiple miniature sheet-type impact force sensor are formed by matrix arrangement. Firstly, several mechanical phenomena, which are the cause of the error signal of the sensor, are discussed. These are the influences of out-of-plane bending deformation, shear force caused by rubbing, shear force caused by the Poisson's effect of contact material, and the lateral compressive force caused by the overhanging deformation of flexible material. Then, a prototype sensor that can eliminate the error factors of these is developed. The sensor is a distribution type impact sensor in which sixteen sensor elements are arranged in a 4 × 4 matrix. Punching experiments using a boxing glove are carried out by installing the sensor on the load cell, on the concrete wall and on the sandbag. From the experiment, it is found that the impact force can be measured with good accuracy by using the sensor.

In chapter 6, at first, we assembled a prototype falling type impact load device using a pad sensor and fluctuating load detection plate as detection units. Synchronized impact forces are measured using two sensors installed on both the drop hammer side and the floor side. Subsequently, using this device, the falling impact onto some soft materials which includes agar, rubber, gels, clay, sponge rubber and meat are measured. A flat frontal impact is the condition where a drop hammer with a flat bottom surface strikes a plate-like soft material in the normal direction. Then, under the condition of flat frontal impact, it is verified that a thorn-shape waveform occurs in the initial stage of impact with most of the soft materials

In chapter 7, in order to elucidate the physical reason of the thorn-shape waveform, using a dynamic model (standard linear solid model) that takes into account the viscosity transient phenomenon, simulation of the impact force waveform is performed. The viscosity transient can be stated that, the moment when the impact force is loaded, in the vicinity of the apex of the thorn, the viscosity resistance of soft material is rapidly decreased and the material becomes soften. Although physical reason for viscosity transient phenomenon occurrence have not been elucidated yet, by assuming a viscous resistance transition occurs, the overall impact waveform containing the thorn is shown to be able to simulate to a value close to the experimental value.

Chapter 8 describes the conclusions of the research and recommendations for future