A PRELIMINARY INVESTIGATION OF CONVERSE PIEZOELECTRIC EFFECT IN BIRD FEATHERS

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ABSTRACT

Piezoelectricity is a relatively common phenomenon exhibited by a large number of crystalline structures. Piezoelectric effects have been investigated in a number of hard and soft tissues and so far appear to be a fundamental property of living tissues whose importance has been overlooked for a long time. Piezoelectricity accounts in principle for a number of biological phenomena that play an important role in some physiological mechanisms. The present work describes the investigation of the converse piezoelectric effect in bird feathers for a number of feather configurations in the frequency range 1 to 20 Kc/sec using a phonograph pick-up. The converse piezoelectric effect in bird feathers is attributed to the protein keratin constituents of the feather structure. The influence of several parameters such as detection position, temperature, humidity, etc have been investigated experimentally.

Investigations conducted in the last two decades have recognized piezoelectricity as a new and fundamental property of living tissue that can account for a number of biological phenomena that appear to be electro-mechanically induced. This direct effect is attributed to the presence of oriented long chain fibrous molecules. Piezoelectric effects have been reported so far in skin, bone, tendon, and hair by several authors (1, 2, 3, 4, 5, 6). Here, we report the converse piezoelectric properties of the calamus of chicken feathers in the 1 to 20 Kc/sec region for two different geometrical configurations. We attribute the converse piezoelectric effect detected in bird feathers to their highly keratinized structure, where the keratin plays the same role as collagen in bones.

The net electric polarization exhibited by the molecule is due to its asymmetry of charge distribution. This asymmetry causes a periodic strain, when an alternating electric field is applied to certain faces of the crystal, that propagates through the structure. The mechanical disturbance can be detected by several methods. In the present work the induced mechanical vibrations in the structure are detected by a phonograph pick-up of the ceramic piezoelectric type. A length of the calamus of the feather is painted with silver paint and the excitation voltage (sinusoidal) is applied to a fine pair of electrodes located on the painted area. The excitation voltage is provided by an audio amplifier and transformer driven by an oscillator. The output from the phonograph pick-up is amplified, filtered, rectified and finally applied to a plotter for spectrum display and to a CRO for pulse amplitude control. Two different feather configurations have been studied i.e. cylindrical and semicylindrical. The feathers used were plucked from the wing of an adult Leghorn and the calamus (about 5 cm length) was removed and mounted in a short length of polyethylene tube by means of a coupling material such as plasticine, glytal, epoxy resin, etc (according to experiment). The so called cylindrical geometry corresponds to the normal configuration whereas the semicylindrical geometry corresponds to the normal feather slit lengthwise along its axis.

The excitation voltage ranged from 10v to about 200 v peak-to-peak. The effect is not strictly linear and the response falls off as the voltage increases indicating a saturation effect. The spectral response of the specimen varies with the detection position along and about the feather axis and as a function of the angle between the crystal detector and the feather axis. The results indicated the existence of compound modes (7) of vibration, their relationship being dependent on position. Experiments to determine the effect of the silver painted area indicated that there is no influence on the spectral shape, only on the output amplitude. This is not difficult to understand since the painted area determines the number of molecules excited by the applied electric field.

The effect of temperature and degree of humidity on these converse piezoelectric properties have also been investigated. For the temperature dependence experiment an IR lamp of medium output power was used as the heat source. The temperature of the specimen was measured using a copper-constantan thermocouple. In order to avoid mechanical interference, the thermocouple was inserted inside a twin feather placed alongside and a few mm apart from the feather under study. The results from a typical experiment are shown in Figure 1. The experiments were conducted at temperatures between 25°C and 65°C. To study the effect of humidity the temperature of the environment was kept constant and the humidity was varied by means of two humidifiers from 25% to 60% relative humidity.

DISCUSSION

The spectral response of the two configurations is markedly different. A large resonance peak in the low frequency range (about 1.5 Kc/sec) is characteristic of the semicylindrical geometry while a large resonance peak at relatively high frequencies (about 8 Kc/sec) characterizes the cylindrical configuration. This is attributed to the difference in geometrical shape and physical dimensions of the specimens which affects the production of standing waves, the conditions of propagation, etc and for which reflections at the boundaries are different.

The effect of the temperature on the spectral response is similar in both configuratieons, being characterized by a decrease of the resonance amplitude with a broadening of the peak which shifts to lower frequencies as the temperature increases. This effect is attributed to an increase of the thermal vibrations of the crystal lattice which partially destroy its periodicity and the condition for resonance to occur over a narrow bandwidth. The possibility of structural changes in the keratin moleuule can not be ruled out since the chains of aminoacids (peptide chain) are held together in the keratin molecule by disulfide bridges -S-S- which can be loosened by heat and moisture. Such a loosening of the -S-S- cross-links permits chains of aminoacids in the keratin molecule to slide past each other more freely and take up new positions.

The effect of the degree of humidity on the spectral response of the specimens is simply to reduce the resonance peak amplitude with no change in the shape of the spectrum. This may be due in part to electrical leakage between the electrodes due to the water vapor deposited on the surface of the feather, which has the effect of lowering the potential difference between the inner and outer surfaces of the specimen and therefore decreasing the electric field strength inside the feather structure. This effect may also be due in part to structural changes in the keratin molecule since under moist conditions its alpha form can be extended and the peptide chains can stretch to form beta keratin. The contribution due to the latter is not known due to the fact that the main component of the feather is beta keratin.

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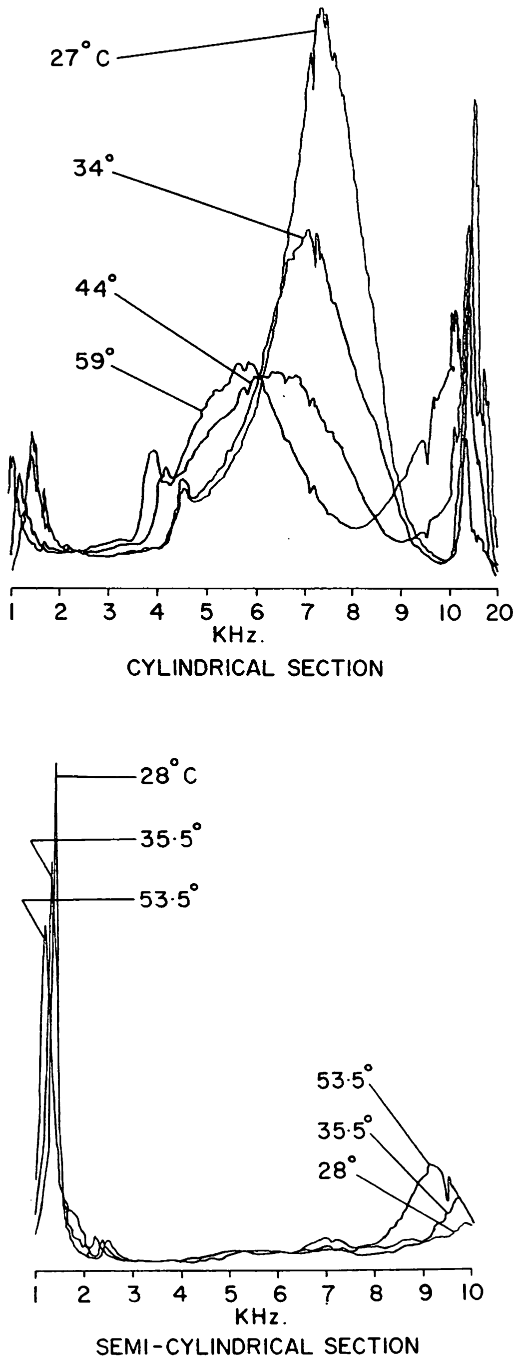

FIGURE 1. CALAMUS SPECTRAL RESPONSE