NEW PHONOCARDIOGRAPHIC TRANSDUCERS UTILIZING THE HOT-WIRE ANEMOMETER PRINCIPLE*

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Abstract—Hot thermistors and hot wires have been adapted to detect vascular and precordial pulses and heart sounds, respectively. The activity from the skin is amplified hydraulically by sealing a plastic cup over the area of interest and mounting the sensing elements in the centre of a small exit port plugged into a hole in the cup. Two thermistors can be mounted physically and electrically in such a way as to produce biphasic unbalancing of a Wheatstone bridge for sub-audio pulses. Fine heated wires sense higher frequency sound waves.

Records of external carotid, jugular venous and apex pulses and heart sounds are presented and comparisons are made with two standard transducers as evidence of the usefulness of the devices. A compact, low impedance transducer, rugged enough to withstand dropping from ceiling to floor, with a superior signal-to-noise ratio and insensitive to ambient sounds is evident.

INTRODUCTION

Great emphasis has been placed on the development of non-invasive techniques for cardiac diagnosis and study of cardiac function. When heart sounds and pulses are detected and recorded accurately their analysis can produce generous amounts of information (Benchimol and Diamond, 1963, 1966; Diamond, 1964; Edmonds, 1966; Luisada and Magri, 1952; Tafur et al., 1964a, b). Present methods and equipment while providing adequate information are often cumbersome, time consuming and may require nearly soundproof rooms for good results. A microphone system was devised utilizing a pair of heated thermistors and shows promise of overcoming some of these deficiencies. After development of the low frequency transducer the method was extended to the hot-wire system for higher frequencies.

The hot-wire anemometer was first discussed in detail by King (1914). Hubbard (1957) used constant temperature hot-wire bridges for air velocity fluctuations up to 10 kHz. Our wires are operating in a mode that is neither constant temperature, constant voltage nor constant current. Our bridges are energized with a constant voltage, but with respect to the actual wire conditions all three of these parameters vary. The results to date have been encouraging, although a higher frequency response can be achieved with other bridge drive systems.

The problem of determining the frequency response of the microphones was considered. Oestreicher (1951) suggests that over the audio range most of the vibratory energy is propagated in body tissue in the form of transverse shear waves and not in the form of longitudinal compressional waves. Sound energy from an earphone comes via longitudinal waves, thus, if Oestreicher’s theory is correct an earphone would not form an adequate basis for calibrating a microphone. Berson and Pipberger (1966) measured chest wall movements in three separate planes and in some cases found larger transverse components than normal components. According to von Gierke (1959) the mechanical impedance of the skin is important to the sound transmission, and we felt we could not accurately

* Received 1 July 1971.
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simulate this with an earphone, nor simulate the acoustic coupling between the skin and transducer. In spite of these difficulties it was deemed important to attempt frequency response comparisons between several microphones. For the subaudio transducers a pulse technique was used and for the sound transducers a calibrated earphone was driven from an audio oscillator. LITTAUER (1965) gives simple equations relating the step input response of a system to its frequency response.

ABBOTT (1969) presented a detailed study of the fidelity of externally recorded pulses and it is not our intent to duplicate his work. We will present evidence that heated elements can be superior transducers for whatever information in the form of skin displacement comes to the surface of the body. Our method for verifying the quality of the instrument described in this report is to compare clinical data with data obtained using other equipment available in our hospital.

THEORY

There are two aspects of the theory which must be described. One is the electrical method of driving the sensing element and obtaining information from it. The second is the hydraulic amplification that takes place in this application which produces the high signal-to-noise ratio. The latter feature is particularly fortunate because it allows sensitivity to the sounds from the body while producing insensitivity to ambient sounds.

A pair of fine heated wires is used to detect heart sounds and a pair of heated thermistors to detect pulses. Both heart sounds and pulses are transmitted through the skin at various points on the body. Pulses are considered to be slow waves from 0.2 Hz to perhaps 15 Hz while sounds range from 50 to 1000 Hz. The thermistors have enough thermal inertia not to respond to sounds, but enough thermal activity to respond to cardiac pulses. In order to detect pulses with high fidelity both inward and outward movements of the skin must be detected. Two thermistors placed physically in a longitudinal position in a stream of air and electrically in two arms of a Wheatstone bridge will produce a biphasic unbalancing of the bridge as the direction of air flow reverses. The thermistor proximal to the flow will cool more than the distal one so that an unbalance of a certain polarity will be produced; as the flow reverses the proximal, or coolest, thermistor takes the opposite position in the bridge hence an unbalance of opposite polarity appears, accomplishing the detection of inward and outward movements of the skin. Two wires, both of which cool in moving air are sufficient for sounds since they are superimposed on the side of the large pulse wave, and thus modulate a mean velocity of air. The wires form two arms of a Wheatstone bridge and unbalance is produced as heat is driven away from them decreasing their resistance.

The characteristic of a fine wire and a thermistor which allows them to sense acoustic energy is their change in resistance as a function of temperature. Metal wire has a small positive temperature coefficient of resistance in the range of \(+0.45\) per cent per °C. Thermistors, on the other hand have a large negative temperature coefficient of resistance in the range of \(-4\) per cent per °C. For this instrument these elements are self-heated by an electric current flowing through them. This same current is used to detect changes in resistance of the wire or thermistors. The cold resistance, \(R_0\), of each wire was approximately 30 Ω depending on its length. Using the equation

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R = R_0 (1 + a\Delta T)
\]

where: \(R = 52 \, \Omega\) = resistance of wire at operating temperature

\[
R_0 = 30 \, \Omega
\]

\[
a = 0.0045 \, ^\circ C^{-1}
\]

the temperature of the wire above ambient (\(\Delta T\)) was calculated to be close to 163°C. Measurements on the thermistors at room temperature and at operating temperature showed a change