AN EXPERIMENTAL DEVICE TO PROVIDE SUBSTITUTE TACTILE SENSATION FROM THE ANAESTHETIC HAND*

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Abstract—Anaesthesia of the hand can result from injury or disease. It severely impairs the normal use of the hand and brings with it the danger of accidental self-inflicted injury due to the absence of pain. A prosthetic device intended to overcome this non-correctable handicap will have to measure the pressure at the finger of the hand and produce a suitable stimulus that is a function of this pressure. The experimental device described uses flexible pressure sensors, based on the principle of the mercury strain gauge. An RC beat-frequency oscillator emits an audible sound whose frequency is a function of this pressure. The considerations for the design of the device are discussed and first results of the practical use are reported.

INTRODUCTION

The motor control of the human hand involves a complex array of feedback mechanisms that use the receptors of the skin, sensitive to pressure, temperature and pain. Normally one is not aware how much all activities involving the use of the hand rely on this feedback signal. Only when this mechanism fails due to a neurological disorder does one become aware of its importance. Not only does the lack of pressure sensation lead to the danger of either dropping or crushing small objects, the lack of pain frequently results in accidental self-inflicted injuries due to excess pressure, sharp edges or hot surfaces.

Anaesthesia of the hand can occur as the result of traumatic injury involving sensory nerves. One of the authors, in his work as a surgeon, had encountered many such cases. This experience led him to initiate the development of the device described in this paper. In most cases, sensation is restorable by surgical reconstruction of the damaged nerves. In a few cases this is not possible due to severe and extensive damage, especially near the shoulder and cervical spine.

More often, irreversible anaesthesia occurs in the course of some medical diseases such as diabetes mellitus. Anaesthesia of the extremities is a common symptom of Hansen's Disease (leprosy). While leprosy is uncommon in the United States with fewer than a thousand reported cases (DOULL, 1962), the world incidence is estimated at between ten and fifteen million. The biggest concentration of this disease occurs in Africa where the known cases amount to 0.6 per cent of the total population (MANSON-BAHR, 1966).

The danger of accidental injury in patients with anaesthesia of the extremities can partially be overcome by wearing protective gloves and specially padded shoes (MANSON-BAHR, 1966). The wearing of some kind of prosthetic device to augment the impaired sensory function seems

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to be an alternate solution. Sensory aids are not new and one sensory prosthesis using electronic methods—the hearing aid—has found wide acceptance. The U.S. Department of Health, Education and Welfare, interested in the rehabilitation of victims of leprosy, had funded the development of a device which warns the patient when a dangerous pressure at the fingers is exceeded (Tims et al., 1967) thus preventing injury.

The authors of this paper had set themselves a somewhat higher goal: the development of a device that not only protects its bearer from injury due to excessive pressure but that also acts as a substitute tactile sense over a wide pressure range. It is hoped that after sufficient training, the patient can partially reintegrate the substitute tactile sensation into the motor control pattern of the hand and thus overcome his handicap.

THE INSTRUMENTATION PROBLEM

The development of a prosthetic device to provide a substitute tactile sensation from the anaesthetic extremity can be divided into two instrumentation problems:

(a) The construction of a suitable pressure sensor that can be attached to the extremity and that provides an electrical signal proportional to the pressure exerted by the extremity.

(b) The development of a stimulus generator which delivers a physiological stimulus that is a function of an electrical signal.

For the pressure sensor it is desirable that it be constructed from a flexible material so it attaches easily to the curvature of the mounting location, does not interfere with the natural action of the limb, and reduces the chance of accidental injury due to excessive pressures. These requirements are quite different from that for a transducer to be used in artificial limbs (Becker et al., 1967).

The stimulus generator has to use one of the unimpaired senses of the subject as an information input but it should not interfere with other activities. It should be able to indicate a wide range of pressures but should avoid the possibility of the stimulus becoming accidentally noxious or painful.

The subject should be able to wear both pressure sensor and stimulus generator in an inconspicuous way. Most of the potential users of such a device live in parts of the world with a very low socio-economic level and the device, therefore, should be very inexpensive.

Design considerations: pressure sensor

Because of the natural limitations of the response at low frequencies inherent in active pressure transducers, this type seemed not suitable to meet the set requirements. Among the passive transducers, some preliminary experiments with a flexible capacitive sensor were conducted but dropped in favour of the resistive transducer principle which seemed to be more promising. The pressure sensor that was finally developed is based on the principle of the mercury strain gauge. This principle was apparently first described in a patent by Kocmich (1948), its use for biomedical measurements was reported first by Whitney (1953). Such strain gauges consist of a piece of very thin tubing manufactured from an elastomer, usually silicone rubber, which is filled with mercury or another conducting liquid. Electrical contact to the conductive column is provided by two metal electrodes at the end of the tubing. When the length of the conductive column is changed by stretching the tubing or its cross section is decreased by squeezing it, the electrical resistance increases, thus making the simple arrangement a transducer for mechanical forces.

For our application a length of silicone rubber tubing (Dow Corning Silastic® medical grade tubing 0.020 in. i.d.) was rolled up in the form of a double spiral with the help of an epoxy mould. The tubing was fixed in this pattern by a thin coat of silicone rubber (Dow Corning bathtub caulk) which, together with the tubing, could be stripped from the mould after curing. This tube skeleton was cemented to a reinforcing layer of nylon gauze which had been preformed to the shape of the finger. This gauze was used in later models of the sensor to reduce