DOI 10.5162/sensor2015/P5.2

Measurement system to determine the contraction time of the forearm skeletal muscle

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Abstract

A measurement system is described which can measure the contraction time of the forearm muscles. During muscle contraction, the circumference of the forearm increases as a function of the force applied. As sensor for measuring that minor expansion, a cuff as compressible volume, is placed around the arm. Compression of the cuff volume increases the pressure; that pressure measures the muscle contraction. In this way, for example, the latency time or the contraction time of the electrically stimulated muscle can be measured by a non-electrical signal. The results can be used for medical diagnostics or fundamental physiological examination. First tests showed that latency and contraction time can be determined with sufficient accuracy for fundamental studies.

Key words: muscle contraction, electrical stimulation, contraction time, pneumatic force sensor.

Introduction

The current through the body in an electric accident can cause contraction of the skelatal muscles. In case of alternating current which exceeds the let-go threshold the duration of the contraction is equal to the time for which the current flows. Therefore, when the let-go threshold is exceeded, the victim loses control of his/her muscles and cannot stop the contact. This type of behavior cannot be observed in case of direct current. The question is how the muscle contraction proceeds when the current is turned on. Four different phases are identified in [1]: Latency, shortening phase, tetanic state and attenuation phase. Details of these phases have not been reported. The present studies into the effects of direct currents (DC) on the human body [2] show that the contraction duration and therefore the maximum contact duration cannot be specified so far. The purpose of the measuring system described below is to provide a very simple method by which the temporal processes of an electrically induced muscle contraction can be studied. In [4] and [5] are shown comparable but more complicated sensors with a local resolution for such measurements of muscle contraction.

Electric current is also used in medicine. Often, the purpose of treatments by which nerves and muscles are stimulated by electric current are to build muscles [3]. In these cases, the current is increased until the therapist can see the contraction. A system for measuring the muscle contraction can objectify that subjective approach. Besides, it is also possible to develop controlled therapy devices.

A measuring system is presented which offers a simple solution both for fundamental studies and therapeutic application.

Solution – Measurement System

The large-surface electrodes and the pressure sensor with a self-developed cuff as sensor are applied to the forearm as shown in Fig. 1 and Fig. 2. The stimulation is provided by a voltage step function with a resulting continuous current. The current flows only through the forearm and causes the required muscle contraction.

The measuring principle is based on the minimum enlargement of the arm circumference due to contraction of the muscles of the forearm. Grasping with the hand requires the contraction of several muscles of the forearm at the same time. A cuff is put tightly around the arm (see Fig. 2). Located on the inside of the cuff is a soft silicone tube to which a pressure sensor is connected. When the circumference of the arm changes, a force acts on the cuff. The force causes a reduction of the volume in the silicone tube between the arm and the cuff, which in turn causes the pressure to rise. The compliance (C) is caused both by the tube and the compression of the air in the tube.

$$C = \frac{\mathrm{d}V}{\mathrm{d}p} \qquad (1).$$

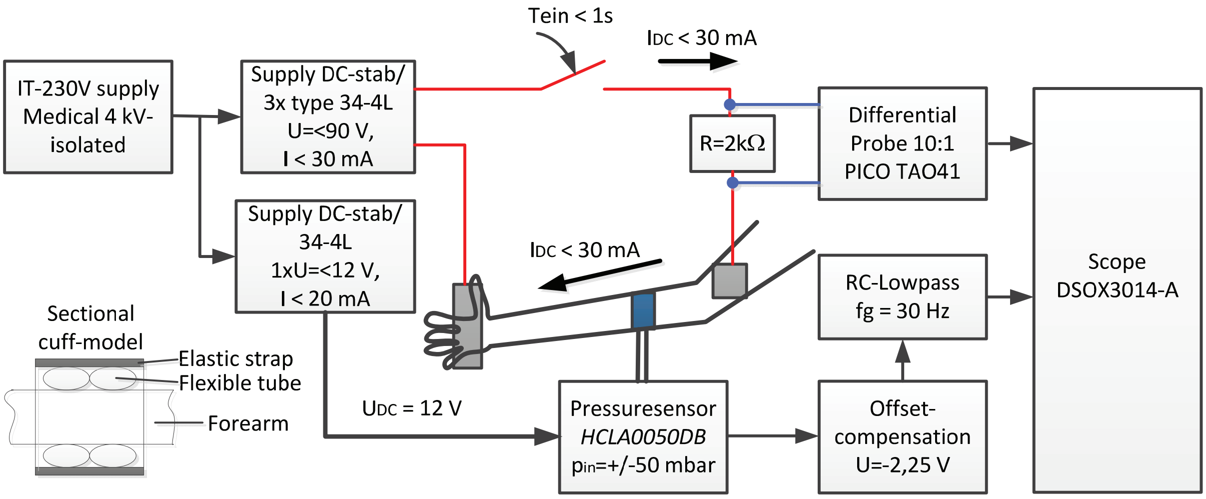

Fig. 1: Measurement setup

The volume change ΔV also causes a pressure change Δp, which is used for measuring the contraction. The pressure change Δp is a measure for the strength of the contraction. Ideally, the compliance C is constant.

To improve the sensitivity of the sensor, the silicone tube was placed around the arm in two loops. The cuff presses the tube against the arm with a resulting pressure offset p_A. The tube can, for example, be of type *SILI35* with the dimensions d_i = 3 mm and d_a = 5 mm. The silicone has a Shore hardness of 60°±5°. The tube length is 61 cm which means that the volume enclosed in the tube is 4.3 cm³.

The cuff and the pressure sensor are connected by a small blood pressure catheter tube. The inside/outside diameters of the catheter tube are 0.8 mm / 2.4 mm. At a length of 15 cm, the dead space volume of the connection amounts to 0.075 cm³. That can be neglected in relation with the volume of the silicone tube.

A three-directional valve is provided for zero adjustment after the cuff is put on. While the cuff is put on, the pressure sensor is also protected from damage due to pressure peaks in the open system. The pressure sensor (*HCLA0050DB*) measures pressure differences between the positive and negative input. When the negative input is open the measurement is made against the prevailing ambient pressure. The relation between output voltage and pressure is given by (2).

$$p\left(U_{\mathrm{a}}\right)=\frac{1\ \mathrm{bar}}{40\ \mathrm{V}}\cdot\left(U_{\mathrm{a}}-U_{\mathrm{ao}}\right) \qquad (2)$$

The measuring range of the pressure sensor pin is ±50 mbar. The analog and amplified output voltage is ”ratiometric“, i.e., it depends on the level of the supply voltage. The supply voltage was a 5 V reference voltage. Because of the negative measuring range the output voltage U_a has an offset U_{a0} of 2.25 V, which was compensated by an external circuit to make optimum use of the resolution of the connected measuring equipment. The signal quality was improved by a passive RC low-pass filter with cutoff-frequency of 30 Hz.

The compliance was determined without pressure offset and with pressure offset, i.e., applied to the arm. A volume was injected in the silicone tube by means of a syringe at 20 °C room temperature. This caused a pressure change. The compliance was calculated by (1) (Table 1).

Table 1 Results of the determination of compliance

Cuff not placed around the arm		
ΔV / ml	*Δp* / mbar	*C* / ml/bar
0.1	16.0	6.3
0.2	35.0	5.7
Cuff placed around the arm		
0.1	16.4	6.1
0.2	38.7	5.2

Placing the cuff around the arm caused a pressure offset and therefore a voltage change ΔU_{aA} = 350 mV ±50 mV. According to (2), this corresponds to a pressure rise by p_A = 8.7 mbar ±1.3 mbar. This pressure rise consists of two components. The first component is the result of the higher temperature at the arm. After about 2 minutes, this results in a pressure increase of p_T = 2.8 mbar. The second component is caused by the pressure which the cuff exerts on the arm and amounts to about 6 mbar. As the value of p_A varies in different subjects, it was eliminated by the three-directional valve at the end of the warm-up time of 2 minutes before contraction was measured. This shifted the operating point to p_A = 0 mbar.

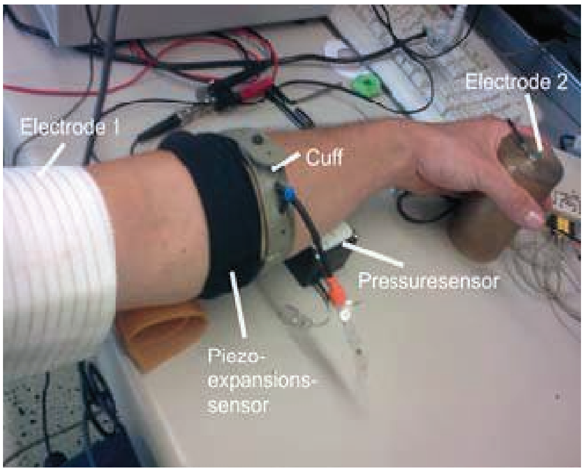

Fig. 2. Measurement setup at the forearm. Piezo sensor was applied for a test.

Force-pressure characteristic

The pressure change produced by contraction when a fist is clenched was measured as a function of force. The *Powerlab 4/25T* measuring amplifier with the related *grip force transducer MLT003/D* were used.

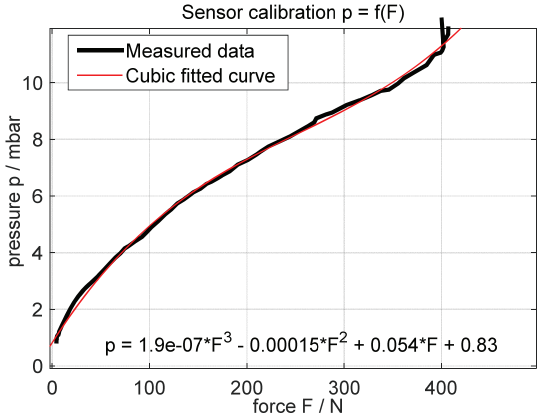

Fig. 3. Pressure measurement as a function of the force in the fist.

For determining the characteristic, the force was increased uniformly and the output voltage of the pressure sensor, U_{ak}, measured. Using (2), the voltage was converted to pressure and plotted as a function of force in Fig. 3.

This nonlinear characteristic should be analyzed statistically before it can be used. The curve in Fig. 3 is based on a single measurement and therefore merely shows that the contraction force can also be measured by the sensor.

Results

The contraction times of the forearm muscles were determined by the measuring system. Fig. 4 shows the time characteristics of the electric current and the cuff pressure. The general course of the contraction can be seen. The maximum contraction occurs after about 0.1 s. The contraction has abated after approximately 0.5 s. When alternating current is applied (Fig. 5) the maximum contractive force occurs after about 0.2 s (Fig. 6). Contraction continues for about 0.1 s after the electric current is turned off (Fig. 7).

The change of the output voltage that can be obtained by voluntary muscle contraction (grip of about 400 N) is of the order of 450 mV. According to (2), this is equal to a pressure change of 11.2 mbar. Under conditions of electrically induced muscle contraction, maximum pressure changes of less than 2 mbar were measured. For improving the sensitivity and the SNR a pressure sensor with a measuring range from ±5 mbar to ±20 mbar should be used.

Summary

The measurements performed so far on individual subjects have shown that fault effects are low. The change of compliance when the cuff is put on can be neglected. The temperature effect should be eliminated by an offset adjustment after thermal stability is reached.

The muscle contraction of the arm, maybe also of the leg, can be measured by the system described. Latencies and the duration of contraction, in particular, can be measured in a simple way with this system. The system is neither dependent on the time characteristic of the stimulating current nor is it affected by it. The results include the contraction of several muscles. This sensor should be used on many subjects for the purpose of obtaining general data on the duration of contraction in the event of direct current accidents. A check-back of the pressure signal to the force is not necessary for these examinations.

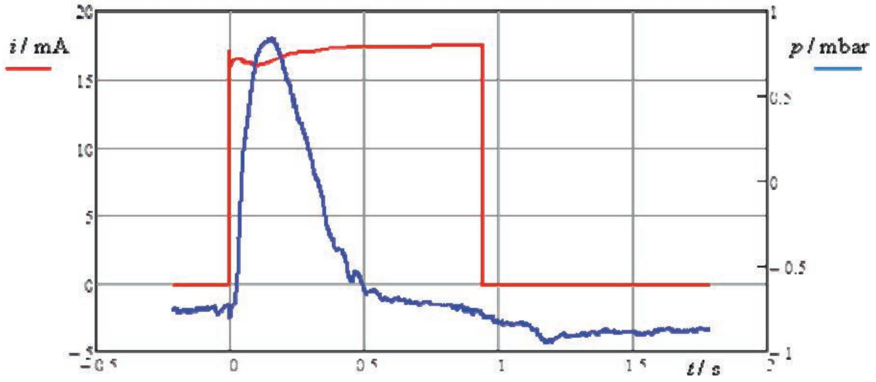

Fig. 4: Example for a current of 16 mA (red) and the pressure (blue).

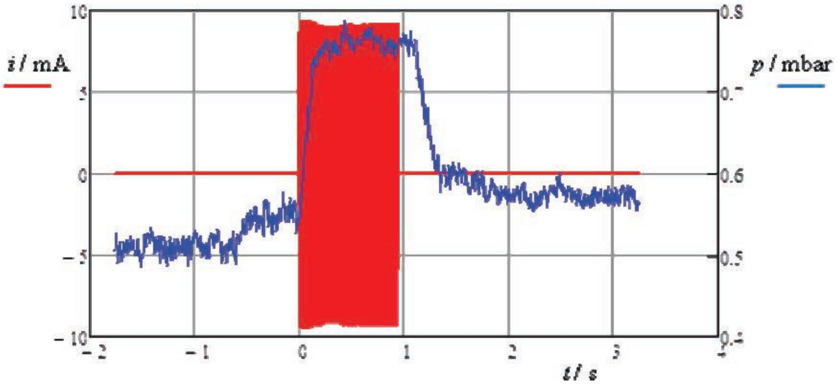

Fig. 5 Example for an alternating current (50 Hz) and the measured pressure (blue).

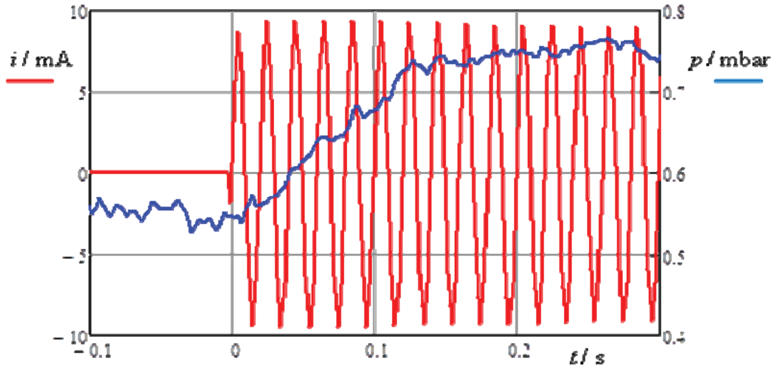

Fig. 6 Current and pressure at the beginning of the alternating current flow.

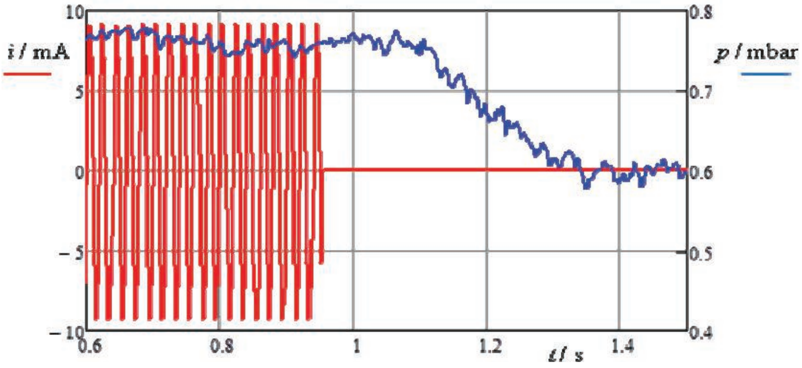

Fig. 7 Current and pressure after turning off the current.

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