MEASUREMENT OF PRESSURE CONVERTER WITH CONDUCTIVE INK

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Abstract
The paper presents characteristics and measurement process of conductive ink of type DZT-3K, acting as a converter of pressure into electrical signal. It mentions basic properties of the ink, including the explanation of the principle of function. Further it describes the measurement process with tactile sensors with circular electrodes of type PD. It studies the dependency of electrical resistance of the ink on the applied pressure. Various setups with different ink layer thicknesses are compared and their suitability to act as pressure converter is finally discussed.

Key words: conductive ink, tactile sensors, electrodes, pressure converter.

INTRODUCTION

For a planar converter of pressure into electric signal in a tactile sensor, there are generally two suitable materials: conductive rubber and conductive ink. The principle of converting pressure into electric signal is similar as in a microphone: as the pressure is applied, microscopic conductive particles in the transducer get closer, which causes the decrease of the measured resistivity of the material and increased current flow due the Ohm's law.

While before we used to employ conductive rubber, whose specification is closer described by SOUZA ET AL. (2005), VOLF ET AL. (1997, 2006, 2007, 2009, 2012). Now we decided to try and measure electrical properties of conductive inks. Among the reasons to try a new material is a relatively large hysteresis of conductive rubber, which prevents the measuring of the absolute pressure acting on the electrodes' field.

Conductive inks consist of ink filled with small pieces of conductive particles; we tested inks containing graphite and silver particles. For testing, we obtained four types of conductive inks: KH WS SWCNT (KH Chemicals, Korea) Luxor (Luxor, Taiwan), NGAP FI Ag-4101 (NANOGAP, Spain) and DZT-3K (DZP Technologies, United Kingdom). After preliminary evaluations, the ink DZT-3K has been chosen and used in the measurements since owing to its composition; it could form a relatively high-quality conductive layer. The other inks did not meet the requirements, either they were too thin and they did not form a continuous layer, or they did not adhere to the substrate (first two, both water-based inks) or they were excessively conductive – as the third ink with silver particles as a filler – the resistance of the ink was only in units of Ω. The selected ink uses carbon particles as filler. A possible disadvantage of the conductive ink might be the difficulty by creating a compact and stable layer, compared to the conductive rubber, according to TRINKL (2011) and VOLF (2016).

The aim of the study is to evaluate electrical and mechanical properties of selected conductive ink, which is used as transducer between pressure and electrical quantities in a planar sensor.

MATERIALS AND METHODS

The ink cannot be applied to the electrodes in the same way as the rubber layer, because it is unable to create a coherent conductive layer while applied to the electrodes directly, i.e. to sustain its integrity. Any negligible mechanical load caused the separation of the ink from the electrodes' surface. The measuring method – pushing with a force sensor tip on the ink layer – would not be applicable in this case. Additionally, a certain deformation of the ink layer between the inner and outer electrode was observed. As this setup proved not to be utilizable, we proceeded to an alternative layout: the selected ink was deposited on the surface of a PET foil and it was applied to the electrodes similarly as rubber.

The layout of a small section of the electrodes field is depicted in Fig. 1. The arrow at the picture indicates the direction of the current between two circular electrodes of the sensor. It means that the current flows from the inner electrode through the conductive ink to the outer electrode. The common electrode, supplied by a voltage of 1.8 V, is used to mutual separation of individual sensors, which prevents – by hardware – the mutual interaction of the sensors.

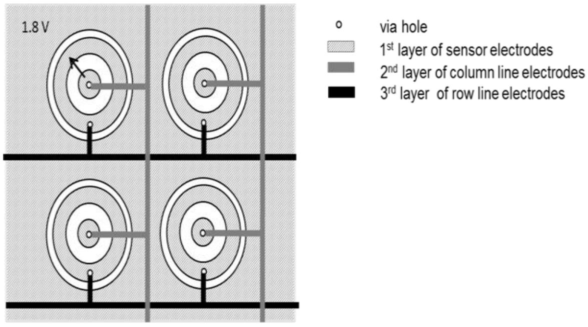

Fig.1. – Layout of the electrodes

The thickness of the selected PET foil was 0,3 mm. The ink was deposited on the foil by a TG-130 spray gun which can spray very low amounts of ink and enables fine control of spraying. A unique 12V Škoda 8P0012615A compressor originally used for inflating tyres was used as a compressor. Three thicknesses were selected of the deposited ink layer: 7 µm, 15 µm and 23 µm. The thicknesses were obtained by 6-fold, 12-fold and 18-fold repeated application. The spray applications were performed through a template made of the same foil with 3 mm holes in view of the 2,5 mm outer diameter of the circular electrodes. The thickness of the deposited ink layer was measured with a Mitutoyo SR44x1 digital micrometer with a measuring range of 0-25 mm and accuracy of 0,001 mm.

The measurements were performed on a scanning matrix comprising circular electrodes with a 2,5 mm diameter. The electrodes were placed on a Cuflex printed circuit board. Conductors were soldered to the outlets of lines and columns which enabled easy choice of a particular electrode. The dimensions of the PD marked electrode are described as follows, see Fig. 2:

Ø E = 2,5 mm, *Ø d* = 0,1 mm, *M* = 0,25 mm.

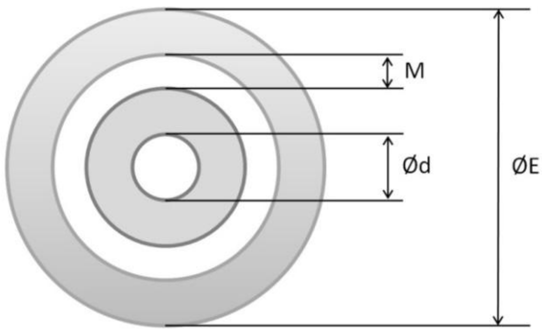

Fig. 2. – Dimensions of the measured PD electrodes

Measurements of the properties of conductive ink were performed at a robotized workplace equipped with a Turbo Scara SR60 robot. Pressure was imposed by means of the vertical motion of the robot´s arm. A Hottinger DF2S-3 tensometer force sensor with a measuring tip was fixed to the end of the robot´s arm. The foil with the deposited inks was placed on the electrode field. The measuring tip with its circular Ø 3 mm surface, which is larger than the diameter of the electrodes, touched down on the surface of one tactile point and pressed on the conductive ink deposited on the foil against the circular electrodes via which the electric resistance of the conductive ink was measured. The basic step of vertical motion of the robot's arm is 0,025 mm with a 0,01 mm resolution. The pressure was imposed by means of the vertical motion of the robot's arm by the measuring tip with mm in diameter. The load force was selected in the range from 1 N to 16 N. The pressure imposed on the electrodes was calculated from the known area of the surface of the measuring tip and the exerted force. This resulted in the measured range of pressure values ca. from 100 kPa up to 2 200 kPa for the particular measuring tip. The output voltage of the type DF2S-3 tensometer force sensor was measured by an Almemo 2890-9 Data Logger. Frequency response of the system is according to PAVLOVKIN ET AL. (2012) measured by system rc2000 eventually. The measuring workspace is depicted in Fig. 3, where (1) marks the foil with deposited conductive ink, (2) is for the measuring tip, (3) is the force sensor DF2S-3 and (4) indicates the robot's head.

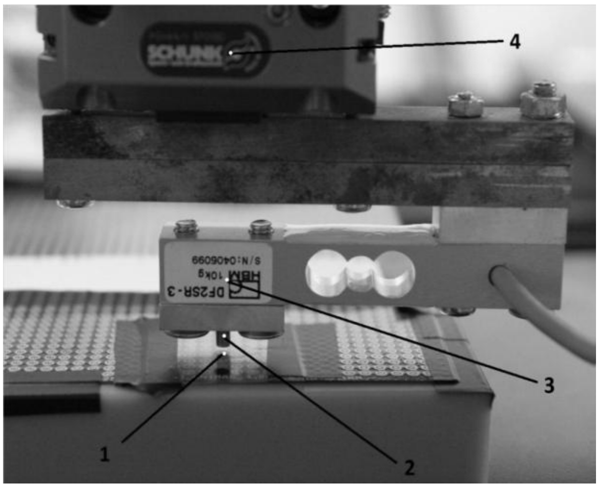

Fig. 3. – Robotized measuring workspace

RESULTS AND DISCUSSION

The measurements were carried out ten times for each ink layer, i.e. the 7 µm, 15 µm and 23 µm ink layer with the PD electrode type. The graphs bellow this paragraph show the dependency of the measured electrical resistance on the applied pressure. Based on the principle explained at the beginning of the paper, the electrical resistance should decrease with increasing pressure. Now it is to study the course of the dependency for selected ink layer and to evaluate its eligibility to act as a pressure converter. Fig. 4 bellow this paragraph give first an overall comparison of all measured ink layers and the following Fig. 5 describes a selected setup in more detail.

Fig. 4 compares the dependency of electrical resistance on the applied pressure for all three ink layers; each curve represents the respective ink layer thickness. As we can see from the figure, the resistivity of the 23 µm ink layer changes only insignificantly from the pressure above ca. 200 kPa. This is evoked by the high conductivity of ink layer. It causes such a low resolution (distinct change in pressure brings only negligible change in resistance), that we consider this useless for measuring in this pressure range. However, thicker layers may give acceptable resolution in lower pressure range, but this was not the subject of our measurements.

The 15 µm ink layer gave acceptable resolution for the pressure range 100 – 800 kPa, but above this value the resolution decreases as well. Other issue is the apparent nonlinearity of the dependency in the 200 – 400 kPa range, which has a very negative effect on the accuracy of the measurement in this range. The cause of the mentioned nonlinearity in this range is not exactly known, it might be a specific combination of ink layer thickness and used PD electrode, as this does not appear by other electrode types.

Last curve denote the dependency of the electrical resistivity for the 7 µm ink layer. It exhibits a quasi-linear shape of the dependency in the range from 200 kPa to 1 200 kPa, with sufficient resolution. This setup gave the best result, which is, however, not optimal; the dependency is still not perfectly linear, with significant changes in 300 kPa and 900 kPa pressure value, and we consider the maximum pressure limitation 1 200 kPa rather low for use in a planar transducer.

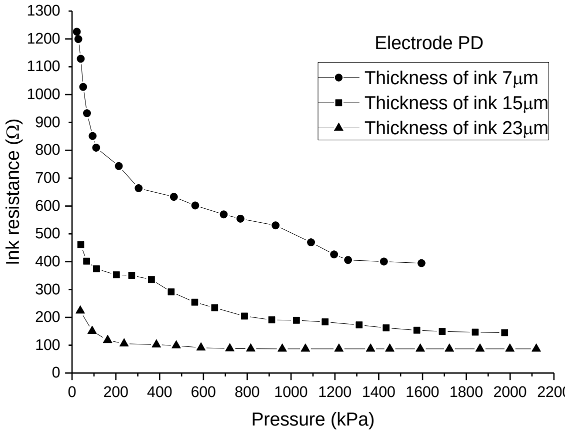

Fig. 4. – Overall comparison of three ink layer thicknesses

In the following Fig. 5 the circle marked curve represents the loading cycle and the triangle marked curve the unloading cycle. It also captures the uncertainty interval for individual measured values of the PD-type electrode in the loading cycle. The short dash style curve represents the approximation of the dependence of the electrical resistance on the pressure in the loading cycle.

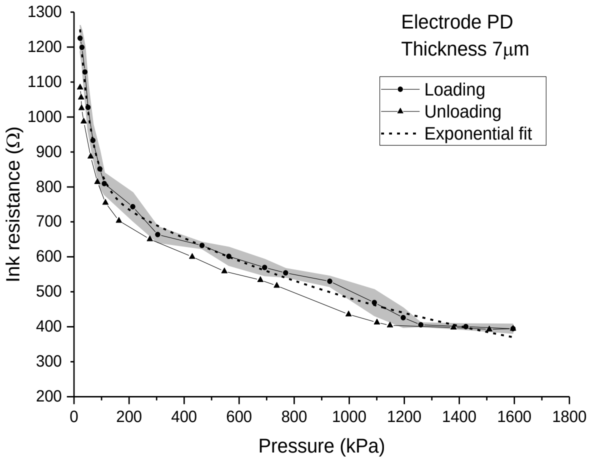

Fig. 5. – Loading and unloading cycle of 7 µm ink layer

We proved that conductive ink may act as a converter between pressure and electrical quantities in a planar pressure transducer. We measured the dependency of the electrical resistance of the ink on the applied pressure. We obtained satisfactory results for the 7 µm ink layer, with some limitations, e.g. limited pressure range, certain nonlinearity of the dependency and some hysteresis of the measured material. We also concluded that higher ink layer thicknesses of the

selected ink DZT-3K decrease the resolution of the transducer significantly, which is caused by high conductivity of ink. Due to lower hysteresis and better resolution, conductive ink may be a good alternative for previously used conductive rubber; the problem poses its limited adherence to the electrodes. This may be solved by using polymer-based inks instead water-based, which we are expected to do in the future.

CONCLUSIONS

We proved that conductive ink may act as a converter between pressure and electrical quantities in a planar pressure transducer. We measured the dependency of the electrical resistance of the ink on the applied pressure. We obtained satisfactory results for the 7 µm ink layer, with some limitations, e.g. limited pressure range, certain nonlinearity of the dependency and some hysteresis of the measured material. We also concluded that higher ink layer thicknesses of the selected ink DZT-3K decrease the resolution of the transducer significantly, which is caused by high conductivity of ink. Due to lower hysteresis and better resolution, conductive ink may be a good alternative for previously used conductive rubber; the problem poses its limited adherence to the electrodes. This may be solved by using polymer-based inks instead water-based, which we are expected to do in the future.

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