

# Effect of Circle Electrodes with Conductive Ink on Properties of Tactile Sensors

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**Abstract** – The present paper deals with tactile sensors with circular electrodes in which conductive ink was used as a converter converting pressure into an electric signal. The dependence was studied on the thickness of the deposited ink layer and the properties were compared. Also the properties of identical tactile sensors in which a conductive elastomer Yokohama rubber CS57-7RSC was used were compared with those with conductive ink.

**Keywords**—conductive elastomer, conductive ink, tactile sensors and transducers

## I. INTRODUCTION

Up till now the conductive elastomer Yokohama rubber CS57-7RSC was used in the production of tactile sensors [1] - [6], [8]. Properties of different polymers are described in [9] - [11]. Due to some of its negative properties, and due to changes in the design of the Plantograf measuring system, we searched for another type of material for the conversion of the imposed pressure into an electric signal. The decision was to use conductive ink. Four types of conductive inks were obtained for the tests: KH WS SWCNT from the Korean firm KH Chemicals, Luxor from the Taiwanese firm Luxor, NGAP FI Ag-4101 from the Spanish firm NANOGAP and DZT-3K. The last type of ink was the only used in the measurements since owing to its composition it could form a relatively high-quality conductive layer. Carbon particles were used here as a filler. The other inks did not meet the requirements, either they were too thin and did not form a continuous layer or did not adhere to the substrate (first two, both water-based, inks) or were excessively conductive – the resistance was only in units of  $\Omega$ . The filler in this case was silver (third ink).

## II. SUBJECT AND METHODS

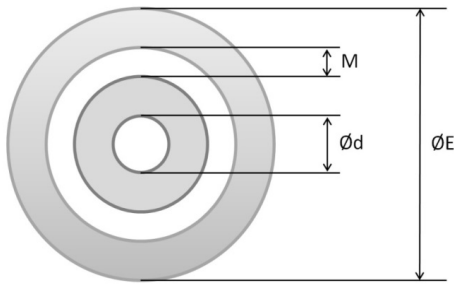
### A. Production of DZT-3K ink specimens

The selected DZT-3K ink was deposited on the surface of a PET foil and applied to the electrodes similarly as the conductive elastomer. The thickness of the selected PET foil was 0.3 mm. The ink was deposited on the foil by a TG 130 spray gun that 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  $\mu\text{m}$ , 15  $\mu\text{m}$  and 23  $\mu\text{m}$ . 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 3mm holes in view of the 2.5mm 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.

### B. Shape of the measured electrodes

The dimensions of the measured electrodes are in Fig.1. The measurements were performed on a scanning matrix comprising circular electrodes with a 2.5mm diameter. The same sizes of the electrodes as in paper [8] were used to enable comparison of the properties of tactile sensors with a conductive elastomer with those with a conductive ink. Also the designation of the electrodes was the same. 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 electrodes are denoted accordingly to their marking “PD”: E = 2.5 mm, d = 0.1 mm, M = 0.1 mm.

Figure 1. Dimensions of the measured electrodes



### C. Measurement method

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 with a 3mm circular surface 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  $\square$  3mm 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 pressure imposed on the electrodes was calculated from the known area of the surface of the measuring tip and the exerted force. The output voltage of the type DF2S-3 tensometer force sensor was measured by an Almemo 2890-9 Data Logger [7]. Frequency response of system is possible to measure by System rc2000 [12].

### III. ASSESSMENT OF MEASURED RESULTS

The measured results for PD-type electrodes for all 3 thicknesses of the ink layers – 7  $\mu\text{m}$ , 15  $\mu\text{m}$  and 23  $\mu\text{m}$  – are represented graphically in Fig. 2. – 5. All measurements were repeated 10x and the total (combined) measurement uncertainty was calculated and graphically represented by respective intervals for each measured value. In all diagrams both the loading cycle (triangle points) and the unloading cycle (round points) were repeated.

Fig. 2 presents this graphical result for the conductive ink of thickness 7  $\mu\text{m}$ . Hysteresis is apparent in all electrodes, similarly as in the case when a conductive elastic material was used, however, it is much lower [8]. Initial insensitivity is apparent in all electrodes which are obviously caused by the force necessary for the touch-down of the foil with the deposited ink on the electrodes.

Fig. 3 shows the dependence of the resistance of 7  $\mu\text{m}$  thick ink layer on the applied pressure with an approximation curve while loading. This curve is used to calculate the load of the sensor.

Figure 2. Dependence of resistance of 7  $\mu\text{m}$  thick ink layer on the pressure for an PD-type electrode

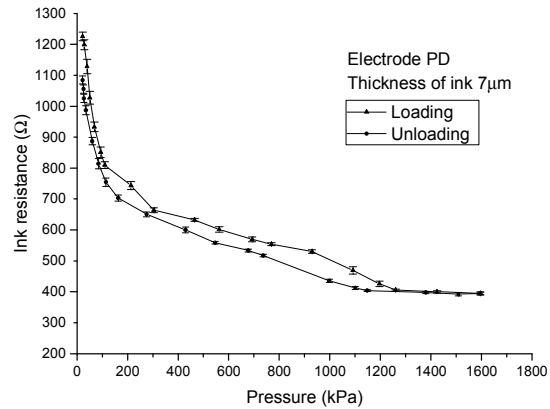
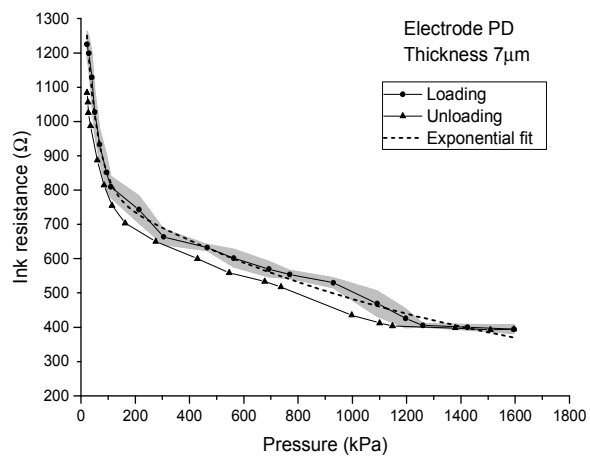


Figure 3. Dependence of resistance of 7  $\mu\text{m}$  thick ink layer on the pressure for an PD-type electrode with approximation



The presented graphs capture 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.

Figure 4. Dependence of resistance of a 15  $\mu\text{m}$  thick ink layer on the pressure for an PD-type electrode

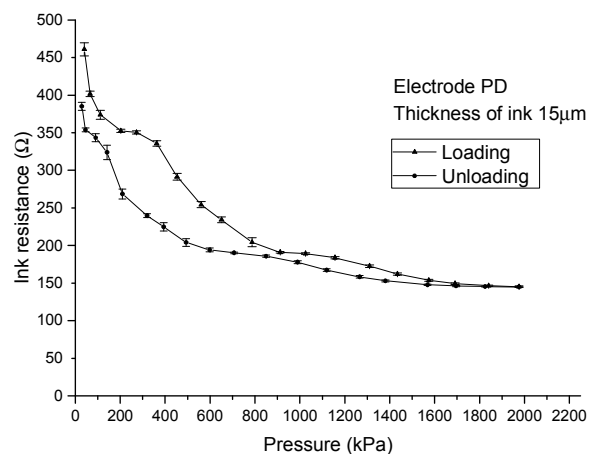


Figure 5. Dependence of resistance of a 23  $\mu\text{m}$  thick ink layer on the pressure for an PD-type electrode

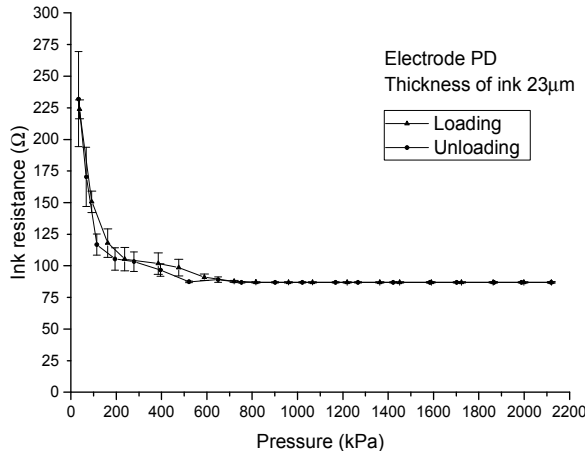


Fig. 6 gives the comparison of the dependence of the variation of resistance on the pressure during loading of PD-type electrodes for various thicknesses of the deposited ink layer. From the diagram it is apparent that maximum sensitivity is achieved for a 7  $\mu\text{m}$  thickness of the deposited ink.

Figure 6. Comparison of PD-type electrodes

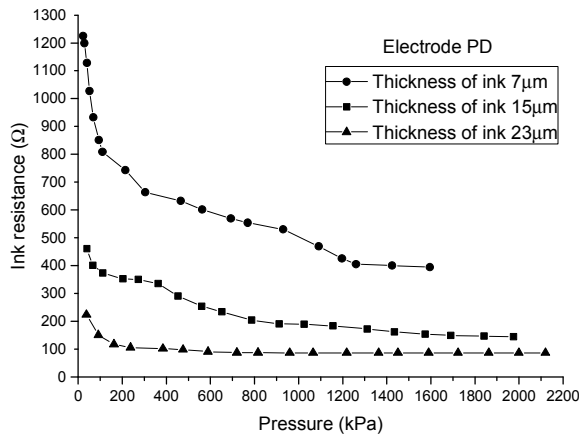


Fig. 7 presents the overall layout of the measuring post. The measurements were performed by means of the robot TURBO SCARA SR60. The force was applied by the vertical motion of the robot's arm; the motion of the robot was controlled by a dedicated remote controller.

Fig. 8 shows the detailed view on the measuring head: the (1) is for the conductive ink deposited on a foil, (2) indicates the measuring tip, (3) is the force sensor DF2S-3 and (4) indicates the robot's head.

Figure 7. Layout of the measuring post

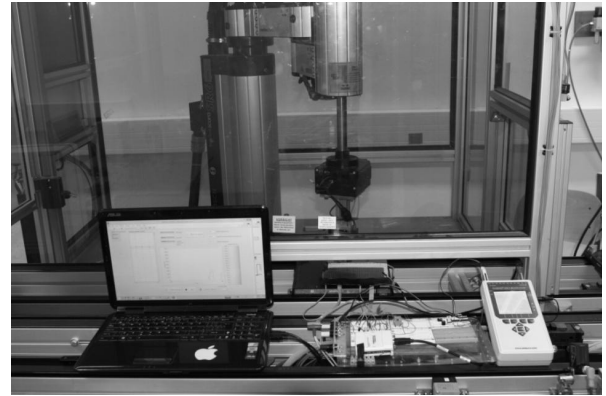
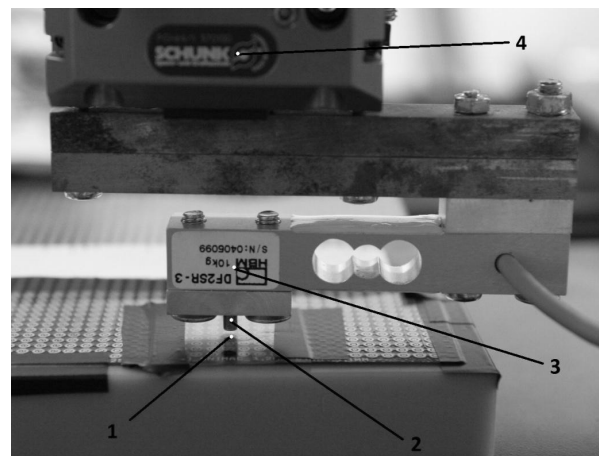


Figure 8. Detail of the robot's head



#### IV. DISCUSSION

The aim was to measure the effect of conductive ink on the properties of a tactile transducer. Conductive ink was used as a converter of force to electric resistance. Electrodes are used in the Plantograf V12 apparatus. Here, however, up till now a conductive elastomer was used. We measured PD-type electrodes with conductive ink. Three differently thick ink layers were used for the measurements and their effect determined on the variation of the electric resistance of ink in dependence on the exerted force. Four different types of conductive inks with various properties were tested. Carbon ink DZT-3K appeared to be most appropriate. When we applied to the surface of the electrodes it had a very low resistance to mechanical stress and hence an alternative method was selected, i.e. deposition of the ink on a foil substrate which was then pressed against the surface of the electrode.

The dependence of the variation of electric resistance of ink on the magnitude of the load was performed with a Turbo Scara SR60 robot. The measuring electrodes showed best results for a 7  $\mu\text{m}$  thick ink layer. Such a combination of electrodes and ink thicknesses gave the best sensitivity, resolution and a partially linear character. Higher thicknesses

increased the conductivity of the sensor and consequently decreased its resolution. All measurements showed hysteresis caused predominantly by the inaccuracy of positioning of the robot and relaxation of the ink and foil.

Measurements proved that conductive ink could act as a force transducer converting force to electric resistance. Its application, however, is affected by a number of factors and selection of the most appropriate ink is not easy. A great problem with ink is its adherence and resistance to mechanical stress on the surface of the electrodes. The measurements are expected to continue with other types of conductive inks.

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