TRIBOELECTRIC SENSOR
APPLICATION AND
CHARACTERIZATION

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Abstract — This work describes advantages and possibilities of use triboelectric sensors. Sensor is possible to use for estimation applied force and movement (displacement). It opens door to wide spectrum of use, finally the sensor could be used for fitness applications especially for estimations of any applied force.

Keywords — BUT, FEEC, EEICT, PVDF, Sensor, Impact, Energy harvesting, TENG, Electrospinning.

1. INTRODUCTION

Triboelectric systems are very popular for energy harvesting purposes. It opens door for investigation of sensing possibilities in wide industrial branch and also for all sensing of natural process where any movement as acceleration are possible to measure. Triboelectric phenomenon could be used also for sensing of position. There are many applications: self-powered human motion sensors [1], self-powered automobile sensors [2]. Example of position sensing is possible to see from a work by authors Chen et al [3]. Energy harvesting describe flexible Nano generators [4], internet of things [5], environmental monitoring systems [6]. There are also many other applications in biomedicine as non-invasive biomedical monitoring systems [7].

Triboelectricity

Triboelectric nanogenerator (TENG) was first published in 2012 as an effective means to harvest wasted kinetic energy [8]. Since then, a lot of researchers have been trying applied this new approach in many applications. The working principle of TENG is based on triboelectric effect where separation of static charges between two contacting surfaces occurs [9–11]. TENG converts mechanical motion into electricity [12–15]. The triboelectric effect is caused by the transfer of electrons [11,16], ions [10] or charged materials [9], or a combination of these factors [17]. Very important parameter is a triboelectric surface charge density σ of TENG. Has been demonstrated that the magnitude of the σ is quadratically related to the output power density of the TENG [18,19]. Improving σ can be done by means of material choice, structural optimization, artificial ion injection and so on [20–25]. Nevertheless, a TENG operating on air is limited by the air avalanche breakdown, as can be deduced from Panchen’s law [26].

Active material

Polyvinylidene fluoride (PVDF) are the highly used negative material by many researchers for high-performance TENG [27–32] and self-powered sensors [29,33].

Electrospinning is considered as a simple, versatile, cost-effective and promising approach to fabricate continuous flexible nanofibers with many unique properties and features such as huge surface area, high surface roughness and flexibility [34,35]. This fact led us to fabricate a simple triboelectric sensor based on a PVDF fibrous structure.

Polyvinylidene fluoride material was made by electrospinning method. This procedure is very common for manufacturing of very fine non-woven fabric [36–39]. Product of used machine is PVDF non-woven fabric placed on aluminium foil. Our experiment was focused on fabrication of a simple triboelectric sensor based on this fibrous material. We have fabricated three concepts of triboelectric sensors where we have evaluated sensitivity of these sensors. Our goal was analysing which concept will be more suitable for continuous monitoring of movement and which system is more suitable for energy
2. MATERIALS AND METHODS

Manufacturing of PVDF

We used PVDF with molar weigh 275,000 g/mol (Sigma Aldrich, St. Louis, MO, USA). As solvents we used dimethyl sulfoxide p.a. (DMSO, Sigma Aldrich, St. Louis, MO, USA) and acetone (Ac, Sigma Aldrich, St. Louis, MO, USA). Solutions were electrostatically spined by machine 4spin (Contipro a.s., Dolni Dobrouc, Czech Republic).

Fibres are possible to rectifier to one direction, or it is possible to place them random as non-woven fabric. We are able to change thickness of final product simply by change of manufacturing time. Spined material is used without removing it from substrate for all sensing elements. We prepared material with thickness from 20 to 100 µm (pressed state). Fibres have diameter from 600 to 1200 nm, and thickness could be partially controlled by electric field between needle and substrate and also partially also by chemical compounds of input solution.

The morphology of the electrospun fibers was investigated by scanning electron microscopy (SEM, Verios 460 L, FEI Czech Republic s.r.o., Brno, The Czech Republic).

Concept of the sensor

Sensing part of this sensor was based on flexible electrodes. This concept was chosen to achieve better sensing properties as linearity and repeatability. Finally, permanent contact of electrode with active material was made in contact pressure mode. There were made stack which could cover also low frequency slow motion displacements due to higher surface of active material and electrodes. Construction details are possible to see from Figure 2 and Figure 3. Figure 1 show bended electrodes where active material is placed from both sides.

![Figure 1: Encapsulated stack – triboelectric stack system.](image1)

![Figure 2: Encapsulated stack – internal system.](image2)
Testing configuration

Sensor was mechanically connected to configurable holder made for testing triboelectric samples, see Figure 4. The charge output of the sensor was evaluated by electrometer 6517b (Keithley, USA) and experimental charge amplifier. The exciting part consisting of the impact rod was controlled by vibration test system TV 50018 (Tira, Germany). The displacement of exciting impact rod was measured via interferometer ILD 1402-10 (Micro Epsilon, Germany). Applied force was measured by force sensor PCB Piezotronics type ICP model 208C01. Output voltages generated by electrometer 6517b and experimental charge amplifier were measured by oscilloscope DSOX2024A (Keysight, USA). The same oscilloscope was used for evaluation of displacement of the exciter measured by interferometer. Oscilloscope was used due to fast setting of each channel and possibility to read all signals during continual tests. Higher resolution wasn’t necessary also due to low resolution of output signal from sensor of displacement and sufficient signal to noise ratio as is possible to see in chapter Results and discussion (Figure 6).
RESULTS AND DISCUSSION

We made and used non-woven example, see Figure 5 for SEM image as a basic active material.

![Non-woven fabric, SEM image, captured by CEITEC NANO](image)

**Figure 5**: Non-woven fabric, SEM image, captured by CEITEC NANO

**Typical use**

The sensor is possible to use for very small displacement measurement, applied force measurement and for other physical movement (change of air and liquid pressure, acoustical signals). Typical response of output signal is possible to see in Figure 6. Output signal is affected by stiffness of membrane, it brings phase shift due to input force and lower fidelity of carried information.

![Typical output of the sensor for excitation](image)

**Figure 6**: Output signal, applied force and measured displacement

**Frequency response**

Sensor is possible to use for signals with very low frequency up to frequency 10 Hz for force measurement and up to frequency 100 Hz for displacement measurement. Results are possible to see in Figure 7. Force measurement was measured with experimental charge amplifier with higher charge sensitivity, than results for displacement sensitivity, there was necessary to use maximal displacement 0.1 mm peak-peak.
Figure 7: Frequency response for applied force and measured displacement

Stability of sensitivity in time
The sensor was built in January 2021 and output signal didn’t show any changes due to time aging to these days. Aging effect can be seen at piezo electric accelerometers.

Example of fitness/industrial use
The sensor could sense changes of displacement and also changes of applied force. Sensor could be possible to use for estimation applied force, which is needed for lifting mass, there are examples in Figure 8.

Figure 8: Output of the sensor for lift of mass measurement

3. CONCLUSION
This investigation has to provide more information and exact data for development new types of triboelectric sensors. Sensor is suitable for force measurement in frequency range up to 10 Hz, and for
displacement measurement up to 100 Hz. Partial goal for possibility of measurement displacement wasn’t achieved due to this missing parameter is not possible to estimate applied work which is made. However, this work provides many inputs how achieve this information from next generation of sensors.

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