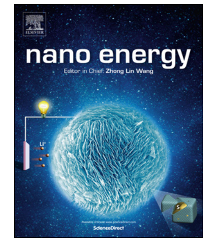
Nano Energy (2015) 13, 92–102

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/nanoenergy



RAPID COMMUNICATION

Triboelectric smart machine elements and self-powered encoder

Majid Taghavi[a,b,*], Ali Sadeghi[a], Alessio Mondini[a], Barbara Mazzolai[a], Lucia Beccai[a], Virgilio Mattoli[a,]**

[a]*Center for MicroBioRobotics@SSSA, Istituto Italiano di Tecnologia, Viale Rinaldo Piaggio 34, Pontedera 56025, Italy*
[b]*BioRobotics Institute, Scuola Supperiore Sant'Anna, Pisa, Italy*

Received 5 December 2014; received in revised form 5 February 2015; accepted 6 February 2015
Available online 21 February 2015

KEYWORDS
Bearing;
Gears;
Belt-pulley;
Triboelectric sensor;
Self-powered encoder;
Smart machine element

Abstract
A new concept for recovering a part of wasted energy caused by friction in typical mechanical components is introduced. Triboelectric charge generation on movable surfaces is the principle used for conducting electrons through external loads. The concept is evaluated by development and study of three versatile elements, including a bearing, gears and belt-pulley systems. Moreover, the first self-sufficient encoder, which is entirely powered by the energy captured by triboelectricity, is presented. Indeed, the capability of using introduced ad hoc modifications on the structure of machine elements is illustrated for measuring and displaying the rotational speed of a belt-pulley system.

Introduction

Efficiency in any kind of mechanical system is less than 100% due to the lack of perfectly rigid and frictionless structures. In other words, due to the existence of friction, some of the input energy is lost. As the friction is generated by resisting the relative motion of materials, most of the wasted energies are converted in heat. Waste heat can be recovered by conversion into other useful types of energy [1-3]. On the other hand, friction occurring between two different materials can cause the building up of triboelectric charges.

The triboelectric phenomenon has mostly been studied during the last decades as a potential hazard, where the generated spark is able to ignite flammable vapors [4,5] or to destroy electronic devices [6,7]. However, in recent times, it drew attention for investigating the potentiality of the effect for energy scavenging, sensing and self-powered sensors [8-10].

Abbreviations: TESME, TriboElectric Smart Machine Elements

*Corresponding author at: Center for MicroBioRobotics@SSSA, Istituto Italiano di Tecnologia, Viale Rinaldo Piaggio 34, Pontedera 56025, Italy.
**Corresponding author.
E-mail addresses: majid.taghavi@iit.it (M. Taghavi), Lucia.Beccai@iit.it (L. Beccai), virgilio.mattoli@iit.it (V. Mattoli).

http://dx.doi.org/10.1016/j.nanoen.2015.02.011
2211-2855/

Various strategies were followed to build triboelectric generators stimulated by different mechanical forces such as bending [11], compressing [12], stretching [13], vibrating [14], sliding [15], rotating [16], and body motions [17]. In this way, waste energies harvesting was pursued for powering low power devices.

In this paper, we present an innovative concept for developing TriboElectric Smart Machine Elements (TESME) by introducing ad hoc modifications in the structure of three well known components. Our aim is to harvest part of the energy that is wasted during the relative motion of the components of such systems. A huge number of movable components are currently being used as building blocks of man-made technologies. Since, in such moving parts, the friction itself is the source of triboelectric charges, the main idea consists of gathering the generated electrostatic energy by means of parallel electrodes on those active surfaces. In this work, three versatile components that are usually employed in all sorts of mechanical assemblies were selected and modified with the purpose of developing TESME, these being: a bearing, gears and a belt-pulley system. We present the design of the smart mechanical structures, which are simulated and fabricated in order to evaluate the output power generated when they are subjected to rotation. Furthermore, the ability of developing a self-powered encoder is investigated and performed on a belt-pulley system based upon the introduced technology. It is worth noting that after that this work prepared, an investigation similar to our belt-pulley system has been published [18]. However, our TESME concept is investigated by presenting different machine elements, and, importantly, the first self-sufficient encoder is developed.

Material and methods

The schematic drawings of the smart components, including a bearing, gears, and a belt pulley system, are shown in Fig. 1a-c, respectively.

Bearing

Fig. 1a describes, in exploded and assembled view (Fig. 1a-i and a-ii, respectively), a cylindrical roller bearing made of Teflon® rollers trapped between two Plexiglas® rings (not shown in figure). Nine Teflon® cylinders were cut using a laser cutting process (VersaLaser VLS3.50, Universal Laser Systems, Scottsdale, AZ) having both diameter and length of 8 mm,. They were placed between a ring and a shaft made by Plexiglas®. The ring, as the outer part of the bearing, was fixed on the base where the motor was installed. The shaft transfers the motor power to the rollers and causes their rotating motion, assisted by the teeth. The parallel electrodes, made of aluminum tape, were attached on the inner side of the outer ring in order to detect the triboelectric charges. The diameter of the ring was 46 mm, and 18 electrodes with the same width and distance between, i.e. about 4 mm, were created. Every other electrode was connected to each other, forming two needed terminals for harvesting the generated signals.

Gearing

A set of 1:1 spur gears, as shown in Fig. 1b-i and b-ii, were made of Teflon® and Plexiglas® thick sheets. The pattern of spur gears with 10 teeth was drawn where the pressure angle and the pitch diameter were 20°and 40 mm, respectively. They were printed on two different sheets, made of Teflon® and Plexiglas® with the thickness of 8 mm, by means of the laser cutting process. The former was used as one gear without further improvement, but the half part of each tooth of the latter was covered by aluminum tape to develop parallel electrodes. The ends of the electrodes were attached to the top side of the gear. Two terminals made of brass were placed on the electrodes and attached to the fixed base that keeps the motor body. Flexible PET sheets were placed at the other end of the brass tip to push them and keep connected to the electrodes besides permitting them to move freely along the tips, avoiding scratching the hand-made electrodes.

Belt-pulley

The belt pulley system, indicated in Fig. 1c-i and b-ii, was developed as follows. Two pulleys were made by cutting a circle in an 8 mm Plexiglas® by means of the laser cutting apparatus. One of them was covered thoroughly by aluminum, and another one was covered by aluminum parallel electrodes, where the width of each and the distance between them were about 2.5 and 0.5 mm, respectively. The ends of the electrodes were attached to the top side of the shaft. The two stationary terminals which were developed for the gears were also used here for making the periodic connection to the electrodes. The belt was made of Teflon® tape, reinforced by attaching to a polypropylene tape, followed by cutting with the width of 8 mm. It was looped over the pulleys, the Teflon® side of which made contact with the shafts.

Control unit

The TESME were put in action by using an electrical motor (MAXON, 266748, Maxon Motors, Switzerland) (see inset in Fig. 1a-ii-c-ii).With the purpose of studying the output signal behavior versus rotational speed, simple sets of infrared laser source and a photodiode detector were used. They were fixed to the base of the system, where the motor was installed, on the top and down side of the shafts of each system. A S1336-18BQ photodiode (Hamamatsu, Japan) was placed under those shafts which are covered by parallel electrodes in all the mentioned structures. An 808 nm Infrared laser source LDM808/3LJ (Roithner Lasertechnik Gmb, Austria) was also fixed to the base at the top side of the shafts, in a way that by rotation, the electrodes break the laser path periodically. This circuit was able to detect the passage of, both, the Teflon® rollers and aluminum electrodes, in both gear and pulley systems, as each of them frequently interrupted the light path.