Project Title: Electrostatic and Piezoelectric Machines: State of the Art

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Project Necessity:

In recent years, electrostatic and piezoelectric electrical machines have been more considered in research centers and industrial companies. For feasibility study of the use of these electrical machines, it is necessary to know state of the art of these technologies. Therefore, this project, as titled above, is defined and execute.

Project Goals:

- Review of scientific resources (books, authoritative scientific articles and academic dissertations) about electrostatic and piezoelectric machines
- Investigation of structures, basic performance relationships, applications and status evaluation of electrostatic and piezoelectric machines
- Investigation of raw materials (piezoelectrics) used in piezoelectric machines and their supply sources (manufacturers)
- Review of methods and tools for designing electrostatic and piezoelectric machines
- Identify industrial or academic teams working in the field of designing and manufacturing electrostatic and piezoelectric machines

Abstract:

1- Electrostatic machines

Electrostatic machines work by interacting between electric charges and an electric field. Like electromagnetic motors, these machines have different structures (synchronous, induction, etc.) and are used in both motor and generator mode. Initially, the main use of these machines was limited to motor operation and in applications of low

power and micro-electromechanical systems, but gradually, electrostatic motors were built at higher powers (several watts to several tens of watts).

Electrostatic machines are divided into the following three categories:

1- corona machines

2- Electrostatic induction machines

3- Electrostatic variable capacitor (synchronous) machines

Corona machines work by moving ions produced by the corona and sitting on the opposite pole. There are two categories of electrostatic machines in this group of machines:

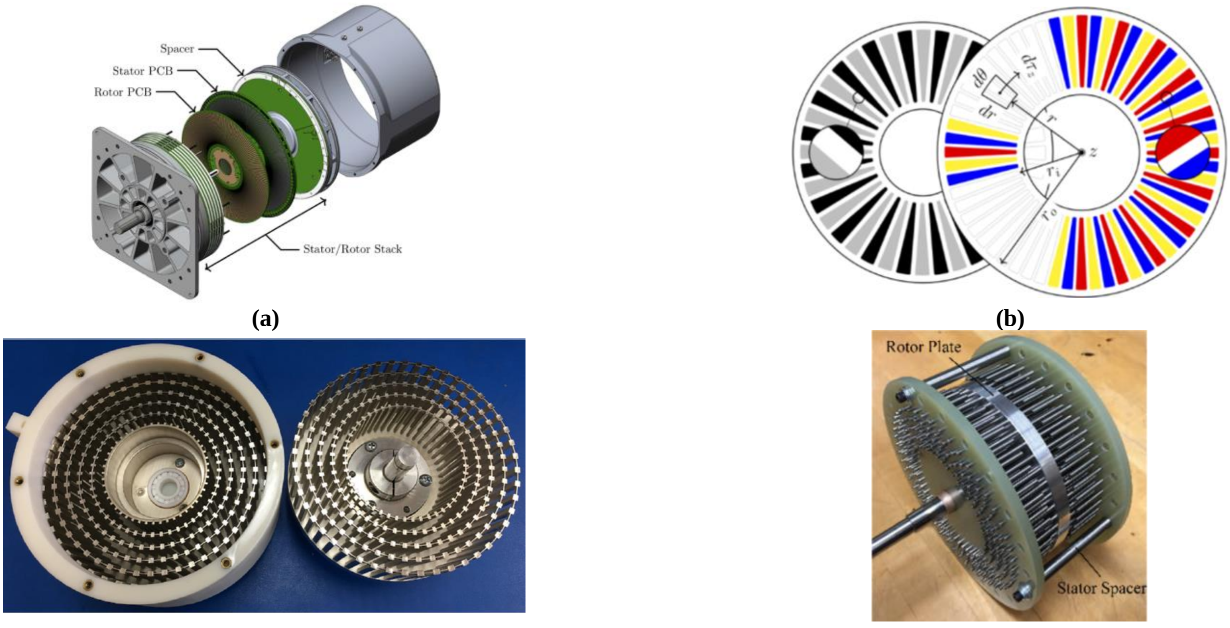
1- Corona motors

2- EWICON type wind generators

The power output of corona motors is very small. So far, only two models of the EWICON electrostatic generator have been installed; At Delft University (2013) and another on the roof of a tower in Notre Dame, England.

The performance of electrostatic induction motors is similar to that of electromagnetic induction motors; if a semiconductor material is placed in a moving electrostatic field (rotating or linearly moving), due to the interaction of the field and the electric charge that is induced on the surface of the material, a force is applied to it. In practice, a thin layer of conductive metal is applied to the surface of the semiconductor material to increase the amount of torque (force) and to reduce the nonlinear effects of resistance in the semiconductor material. In designing and analyzing these motors, it is necessary to note that the effects of power supply harmonics on motor performance are far greater than electromagnetic induction motors. Because, the amplitude of the supply voltage and consequently, the amplitude of the harmonics is considerable. Various structures of electrostatic induction motors have been proposed, almost all of which are disc or linear. Induction electrostatic motors have been proposed for applications such as computer hard disk drives and CD drives, as well as linear actuators in robots used in production lines. Most of the work in this area have been done at the University of Tokyo. It is necessary to note that electrostatic induction motors are designed for applications with a power of (maximum) several watts and for control applications.

Synchronous or variable capacitor electrostatic machines operate base on the tendency to achieve minimum elastance (or maximum capacitance). These machines have been studied mostly in motoring mode. The rotor and stator surfaces in synchronous electrostatic motors form a capacitor. Maximum power and torque in electrostatic synchronous motors occur when they are supplied by a square-wave voltage, and the minimum and maximum capacitors correspond to the minimum and maximum of applied voltages. Synchronous electrostatic motors are proposed and prototyped linearly and in disk form. One of the main disadvantages in electrostatic synchronous motors is the high torque ripple.



(a) (b) (c) (d)

Figure 1: Proposed structures for electrostatic motors a), b) axial motor and its components, c) , d) peg style and its component

2- Piezoelectric machines

When piezoelectric materials are subjected to mechanical stress, an electric charge accumulates on their surface. This property is called the direct piezoelectric. The inverse piezoelectric property is deformation of the piezoelectric material, when exposed to an electric field. Piezoelectric materials are in the category of insulating materials or dielectric materials. Similar to ferromagnetic materials, they have domains in which the electric dipoles are aligned.

There are different types of piezoelectric motors, including traveling wave, linear, stepper. The technology tree of piezoelectric motors is shown in the figure 2. Meanwhile, traveling wave motors have been invented earlier. Piezoelectric motors performance is based on creating waveform oscillation in the stator and transferring it to the rotor with the help of friction force. Efficiency of piezoelectric motors is very low Due to these fact that oscillation in the stator occur at the resonant frequencies of the material and, the mechanism of transmission of force to the rotor is based on friction. In contrast, piezoelectric motors has high power to volume ratio. So, it is suitable for applications where lower motor volume is important.

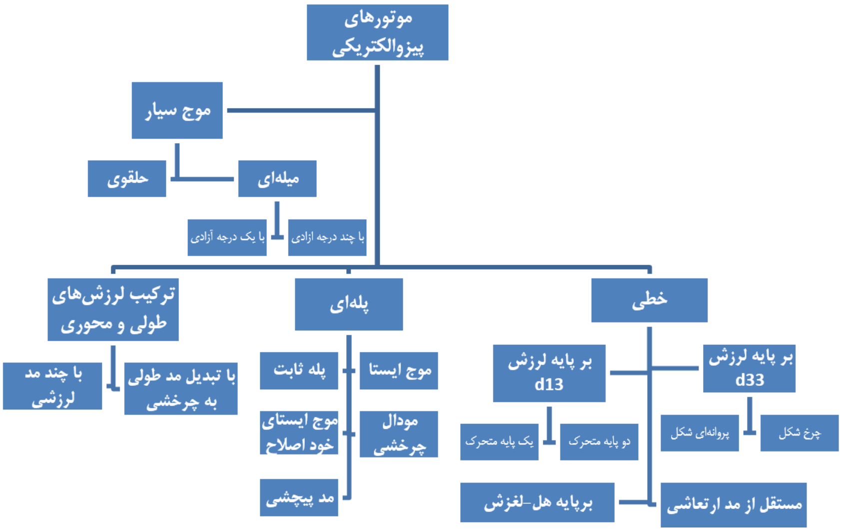


Figure 2: Technology tree of piezoelectric motors

There are many manufacturers (small and medium size) in the world that produce piezoelectric motors. These products include linear and rotary piezoelectric motors with nanometer and micro radian position accuracy. Therefore, these electric motors are suitable for position control applications, where high position resolution is required; relatively small size and large torque or force that produced by the motor (without the need for a gear) is most important advantages of piezoelectric motors in position control applications. Due to these advantages, piezoelectric motors can be used in troubleshooting robots of large equipment such as generators or large electric motors, as well as other large power plant equipment.

Piezoelectric transformers are classified into three categories:

1- Longitudinal vibration mode

2- Thickness vibration mode

3- Radial vibration mode

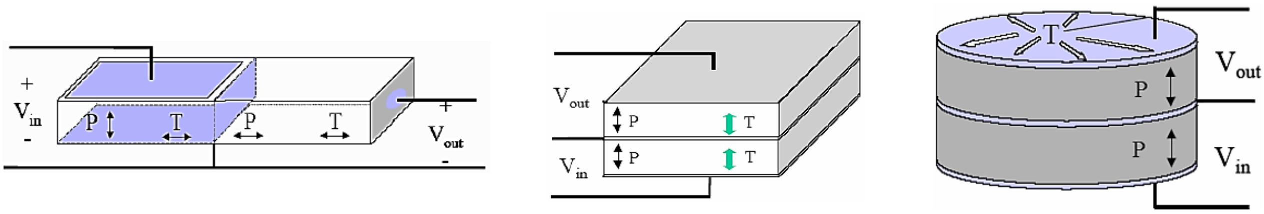
Longitudinal vibration mode transformers are step up transformers and have been used in CCFL lamps (for lighting of LCDs) since the 1990s. The input part of this transformer is polarized in the direction of thickness and the output part is polarized in the longitudinal direction. Longitudinal vibration mode piezoelectric transformers have a low power to volume ratio relative to the other piezoelectric transformers. The Tranoser brand is commercially known longitudinal mode transformer. In studied documents, maximum output power that has been acclaimed for the prototyped longitudinal vibration mode transformers is about 20 watts. The maximum reported value for the efficiency of this transformer have been up to about 95%.

Radial vibration mode piezoelectric transformers were invented in 1998. These transformers can be used for both step up and step down converters. For the following reasons, radial mode piezoelectric transformers are the best option for use in power electronic converters:

1- Radial mode PT has a simple structure and its operating frequency is relatively small and close to the first radial vibration mode of disk-shaped components.
2- Radial mode PT has relatively large electromechanical coupling factor
3- The geometry and layout of this transformer allows for the electrodes to have a large radius, which in turn allows for large force factors to be achieved
4- construction of radial vibration mode PTs are simple
5- Disc shaped PTs in radial motion have a nodal point at the center of the disc. Thus, a simple adhesive pad can be placed in the center of one of the PTs major surfaces to securely mount the device without noticeably affecting its electromechanical behavior

Highly depending the performance on the load is the major disadvantages of radial mode PTs. Also, at non pure resistive loads, the efficiency of these PTs are greatly reduced. Radial mode PTs have been demonstrated at power levels exceeding 100 W. Use in the fluorescent lamps ballast is mostly reported commercial application of radial mode PTs.

Thickness vibration mode PTs have relatively small dimension in thickness direction (relative to diameter or length and width). The inputs and outputs parts of these PTs are polarized in the thickness direction and operates at a frequency equivalent to vibrational modes in the thickness direction. It is worth mention that if the size of the piezoelectric part in the thickness direction becomes larger than other directions, the thickness mode PT converts to a longitudinal mode PT. Mobile phone chargers is the most important feasible application asserted for thickness mode PTs.



(a) (b) (c)

Figure 3: Piezoelectric transformers, a) longitudinal mode PT, b) thickness mode PT, and c) radial mode PT

In addition to the three mentioned categories of PTs, there is another category called thickness-shear vibration mode PT. despite of much research have been done in the field of these PTs, they have less practical application. The presence of undesirable vibrations in the other directions, causes losses and disrupts the output voltage waveform of the PT. The maximum reported output power in thickness-shear mode PTs prototypes is about 170 watts (a prototype with three outputs).

The main use of piezoelectric generators is in energy harvesting systems. Energy harvesting is a process that energy is absorbed from the environment and stored for use in equipment (often in electronic sensors). Therefore, it can be concluded that the amount of absorbed energy is not significant. Usual energy harvesting system is based on the installation of piezoelectric on a cantilever with one free end and one end mounted on a base. A mass could be installed on the free end of the cantilever to increase the amplitude of the oscillations and, consequently, to increase the energy harvesting. Mechanisms of absorption of environmental energy using piezoelectric materials are divided into the following two categories:

1- Small scale windmill
2- Aeroelastic instability; The mechanisms of this category can be divided as follows:
   - Energy harvesting base on oscillations caused by vortices
   - Energy harvesting base on galloping
   - Energy absorption based on fluttering

The amount of energy produced by piezoelectric energy harvesting systems is highly dependent on the load and has very low efficiency.

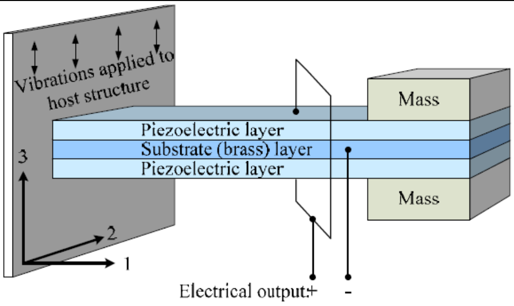


Figure 4: Usual energy harvesting system

Steps and Methodologies:

The research was conducted using a review on scientific documents, including books, well-known universities dissertations and articles in high rank journals. Also, the information provided on the website of the manufacturing companies has been used to determine the technical specifications of the products. This project has been done in three steps:

1- State of the art of electrostatic machines
2- State of the art of piezoelectric machines
3- conclusion and future works suggestion in these fields

Main Results (technical outputs, patents, papers, books, reports, etc.):

- Project steps (1 to 3) reports.