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A SOLAR PANEL CLEANING SYSTEM BASED ON A LINEAR PIEZOELECTRIC ACTUATOR

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A linear piezoelectric actuator based solar panel cleaning system is proposed in order to make a solar panel operate at the best power generation state while the solar panel is used in dusty environment. A piezoelectric actuator linearly moving on a guide is employed to drive a wiper fixed on the actuator. At a proper pressure force between the wiper and solar panel, the actuator can drive the wiper to effectively wipe a dust layer away from the solar panel's surface. The cleaning system's energy gain, which is defined as the ratio of a solar panel's output electric energy increase caused by cleaning to the energy consumption by the piezoelectric actuator, is much higher than 1. The merits of using the piezoelectric actuator in a solar panel cleaning system is that the cleaning system has light weight and compact structure, which is a common feature of piezoelectric systems.

Keywords: Photovoltaic panel; Cleaning; Piezoelectric actuator; Energy gain

1. INTRODUCTION

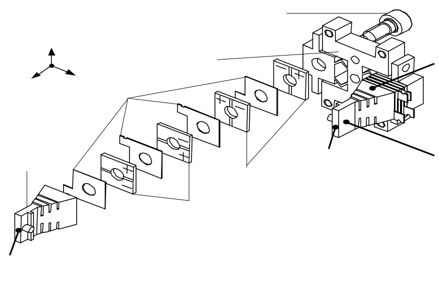
In recent years, photovoltaic technology has advanced fast for power generation from sunlight. Cleaning methods for solar panels are researched in order to keep solar panels efficient [1]. There are mainly three cleaning methods, i.e., mechanical cleaning [2], nano-film based self-cleaning [3] and electrostatic cleaning [4]. Compared with other methods, mechanical method has a large dust removal force, rapid operation, good environmental adaptability and control performance. However, the mechanical cleaning system usually has a bulky and heavy structure owing to its driving components.

Piezoelectric actuators have been successfully used in optical adjustment [5], biomedical manipulation [6], space exploration， ultra-precision measurement, and other areas, due to their merits such as silent operation, no electromagnetic interference, high torque to volume ratio (5~10 times higher than electromagnetic actuators), flexible structure design, high positioning position, etc. These merits make this type of actuator competitive in many special applications than conventional electromagnetic actuators.

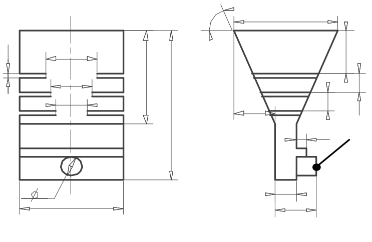
In this paper, we have proposed, fabricated and characterized a linear piezoelectric actuator based solar panel cleaning system. The piezoelectric actuator's two driving feet are assembled face to face onto a guide, and excited at the same operating frequency to form two symmetric elliptical trajectories at two driving tips. The guide is clamped between the two driving feet and the piezoelectric actuator's linear motion can be realized by a friction force between the driving feet and guide. The finite element method (FEM) is used to confirm the working principle of the actuator, and its characteristics are measured. After that, we use the actuator in a solar panel cleaning system. Major energy characteristics of the proposed cleaning system are measured and discussed.

2. PIEZOELECTRIC ACTUATOR

2.1. Structural design and working principle



(a)



(b)

Fig. 1 Construction of the vibrator (a) Components and assembling (b) Size of the driving bar

The linear piezoelectric actuator consists of two vibrators with identical structure and materials and a support. As shown in Fig. 1, the vibrator has two driving feet (A&B) with the same structure and materials. The two driving feet are assembled face to face to a linear guide. Each vibrator consists of driving bar 1, electrodes 2, piezoelectric plates 3 and 4, and fastening screw 5. Electrodes and piezoelectric plates are stacked between the driving bar and support, fastened by a screw. Piezoelectric plates 3 are used to excite the driving foot's bending vibration mode in the z direction, and piezoelectric plates 4 to excite another bending vibration mode in the y direction in the same driving foot. Thus two motions of the tip of the driving feet are orthogonal to each other. In order to adjust frequencies of the two modes to be the same, slots are cut out on the driving bars. Driving feet A and B are used to form two symmetric elliptical motions for the linear driving. The reason for using the actuator topology shown in Fig. 1 is to obtain sufficient driving force with a compact structure.

The apparent size of two vibrators of the actuator is 32.6mm × 30mm × 26.8mm, and more details about the driving bars' size parameters are shown in Fig. 1(b). Piezoelectric material used in the vibrators is PZT-8H. It has the density of 7450 kg/m^3, electromechanical coupling factor k_{33} of 0.60, piezoelectric constant d_{33} of 200×10^{-12} C/N, mechanical quality factor Q_m of 800 and dielectric dissipation factor *tanδ* of 0.5%. Bronze is chosen for making the electrodes, and steel for the vibrator's other metal parts.

Applied with a sinusoidal voltage which has frequency close to natural frequency of the 2nd bending mode (in the z-direction) of the vibrators, piezoelectric plates 3 can excite a z-direction vibration in feet A and B, in the same z-direction. Applied with a cosine voltage which has frequency close to natural frequency of the 2nd bending mode (in the y-direction), piezoelectric plates 4 can excite a y-direction vibration in feet A and B, in the same y-direction. When these two voltages are applied simultaneously, the resultant of the two linear orthogonal vibrations at the tip of each driving foot is an elliptical motion. Both the tips of feet A and B will move along the two elliptical trajectories. Due to the symmetry of vibration excitation structure, they drive the vibrators or the actuator to move linearly along the guide (the guide is fixed on a solar panel).

Based on the size parameters in Fig. 1(b) and above listed material properties, the prototype actuator's vibration pattern is computed by the FEM with ANSYS software. Calculated natural frequencies in the two vibration direction are around 20.2 kHz.

2.2. Assembling of the actuator

Based on the above design, a prototype of the linear piezoelectric actuator is fabricated and assembled onto a guide which will be fixed to a solar panel. As shown in Fig. 2, the prototype actuator is fixed onto a base, and its two driving feet are pressed face-to-face onto the two sides of the guide. The two sliders, bolted onto the base, are coupled with the guide and can linear move along the guide. The two sliders stabilize the vibrators' movement along the guide. In the experiments of this work, unless otherwise specified, the preload between the driving feet and guide is 15 N, and operating frequency and voltage of the prototype actuator is 18.8 kHz and 100 $V_{0\text{-}p}$, respectively. The stalling load is 3.2 N and no-load speed is around 115 mm/s.

3. Solar panel cleaning system

3.1. Structure of the cleaning system

Based on the prototype actuator, a solar panel cleaning system is built. It mainly consists of a solar panel with active area of 260 mm×300 mm, a villus wiper with an active length of 300 mm, and the linear actuator. The guide is fixed to the frame of the solar panel, and the wiper is assembled to one side of the actuator's base. Cleaning function is realized when the wiper is driven by the actuator to wipe the dusts on its surface away. The cleaning effort is related to the pressure force between the wiper and panel, which can be adjusted. Images of the solar panel before and after cleaning are shown in Fig. 3. It is seen that a dust layer of flour on the solar panel can be effectively cleared.

3.2. Experimental results and discussion

Energy gain of the solar panel cleaning system is defined as:

$$\eta_s = \frac{\Delta P \times 3600}{P_{in} \times N \times \Delta t}$$

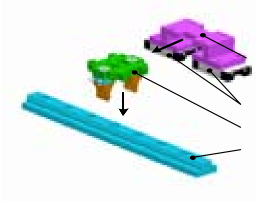


Fig. 2 Assembling of the actuator

Where ΔP is the increase of electric output power of the solar panel, P_{in} is the input electrical power of the prototype actuator, N is the cleaning times per unit time (/h), and Δt is the actuator's operating time for each cleaning.

In the following experiments, flour is evenly distributed on the solar panel's working surface to simulate the dust, and its surface-density is 256 g/m^2. Fluorescent lamps are used to produce 8420 lux light (measured by light meter TES-1339R) for the solar panel. In order to get the maximum output power from the solar panel, different resistance values of external resistor are used. The optimum load resistance is 200 Ω for the clean panel, and it is 550 Ω for the panel with flour. With the experimental conditions, measured electric output power of the solar panel before and after the cleaning is 0.23 W and 1.29 W, respectively. In addition, it was observed that the electric output power increases gradually during the cleaning process.

Fig. 4(a) shows the energy gain of the solar panel cleaning system versus cleaning times per unit time N at different pressure forces between the wiper and panel. In the experiments, the highest energy gain is 252 at a pressure force of 1 N and cleaning time per hour of 1, and the lowest gain value is 16 at a pressure force of 3 N and cleaning times per hour of 10, which indicates that this cleaning system has very good energy gain. It is observed that the energy gain at a pressure force of 1 N is the highest in the experiments for given cleaning times per unit time, which indicates that small pressure force is beneficial to increasing the energy gain. It is observed that the energy gain decreases with the increase of cleaning times per unit time, which means that as the environment becomes dirtier and more cleaning times per unit time are needed, the energy gain decreases. However, electric output power of the solar panel is still increased by the cleaning because the energy gain is larger than 1.

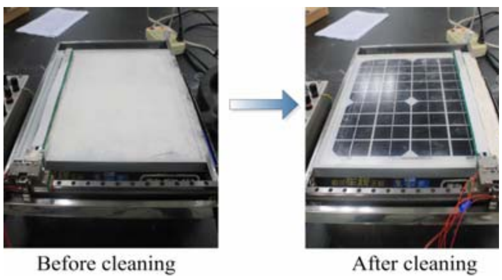
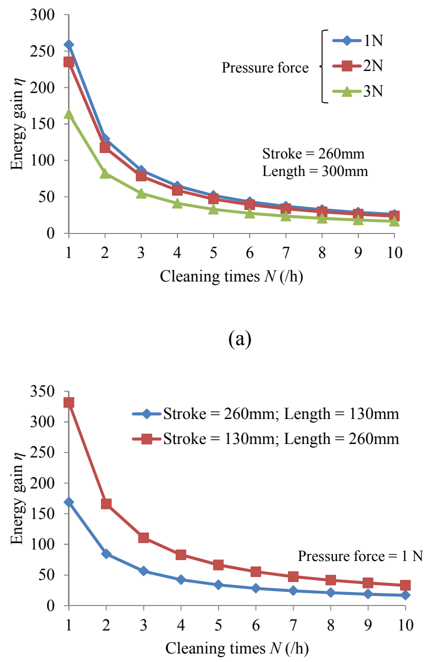


Fig. 3 A solar panel before and after cleaning

For investigating the effect of solar panel dimension L perpendicular to the wiping direction on the energy gain, a rectangular solar panel with active area of 260 mm×130 mm is employed. Measured results of the energy gain versus cleaning times per unit time for two different solar panel dimensions perpendicular to the wiping direction are plotted in Fig. 4(b). The energy gain at L = 260 mm is larger than that at L =130 mm. This means that for a solar panel with given active area, wiping the panel in the direction with a shorter wiping distance (or stroke) results in a better energy gain.



(b)

Fig. 4 (a) Energy gain versus cleaning times per unit time at different pressure force (b) Energy gain versus cleaning times per unit time at different wiper lengths

4. SUMMARY

A linear piezoelectric actuator based solar panel cleaning system is designed, fabricated and characterized. In the linear piezoelectric actuator, two elliptical motions of the driving feet are employed to drive the vibrator and the wiper. Exciting by the driving voltage of 100 $V_{0\text{-}p}$ at resonance, the prototype actuator works well at both the forward and backward operation. In the solar panel cleaning system, the prototype actuator can drive a wiper to clear a dust layer on the solar panel's active area. The experimental result indicates that a proper pressure force between the wiper and panel, and longer panel width perpendicular to the wiping direction, are beneficial to the energy gain improvement. Due to the use of the linear piezoelectric actuator, the cleaning system has the merits such as light weight and compact structure, just like other piezoelectric systems. These merits make this technology competitive in the cleaning of solar panels in astronautic and aeronautic applications.

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