ENERGY HARVESTING IN FLOORS
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Abstract: This paper reports the design, fabrication and testing of piezoelectric energy harvesting modules for floors. The harvesting modules consist of multiple mono-axial stretched thin layers of PVDF (Polyvinylidene fluoride). The multilayer modules are built like a roller-type capacitor. The fabrication of the harvesting modules is easy and very suitable for mass production. The modules are characterized by a great flexibility and the possibility to create them in almost any geometrical sizes. A base area was assembled to determine the most suitable size, alignment and geometry of the modules for harvesting energy in parquet flooring. The measurements proofed the functionality of the modules and have also shown some first promising results.

Keywords: energy harvesting, piezoelectric, PVDF, parquet floor

INTRODUCTION

In recent years great efforts have been made to power small electronic devices, like e.g. sensors without the need of batteries. Therefore the energy for those devices should be scavenged from the environment. Energy sources that can be used are for example radiation, heat flux or any mechanical forces (vibration, flowing media, etc.). In our investigations the dynamic compression of parquet floors, if people walk across, should be used as energy source.

Every floor is compressed elastically if a human or a vehicle moves upon it. This dynamic compression of floors can be converted into electric energy by the use of piezoelectric materials. [1]

The piezoelectric foil material for this approach is a mono-axial stretched fluoropolymer PVDF (Polyvinylidene fluoride). This type of PVDF has an amorphous phase with partly crystalline areas which could be piezoelectric. The piezoelectricity of PVDF was first observed and described by H. Kawai in 1969. [2] Stretching and a polarization procedure under a high electric field make the piezoelectric properties of PVDF.

Multilayer modules have been assembled using this foil in a simple manner with thin electrodes in between. Thus, a conversion of dynamic compression into electric energy can be achieved if the modules were loaded mechanically. Energy conversion efficiency of this technique was characterized by the surface size, the thickness and the geometry of the modules.

ASSEMBLY

Harvester modules

The thickness of the PVDF-foil was in all cases 55µm. In order to get energy harvester modules out of this PVDF foil, a plate capacitor was developed, in which the PVDF foil acts as the dielectric layer. Therefore, an electrically conductive layer was applied on the PVDF foil, which serves as electrode. To achieve a capacitor with several layers, the PVDF foil, provided with electrodes was stacked on top of one another, whereby the conductive layers acts as alternating interconnect layers.

The harvester modules were designed similarly as foil capacitors, to meet the desired requirements and to allow an effective production. Electrode material was an aluminum foil with a thickness of 10µm. Two sections PVDF foil and two sections aluminum foil were alternating laid on top of each other and coiled together afterwards. Figure 1 shows an assembled module in the cross section.

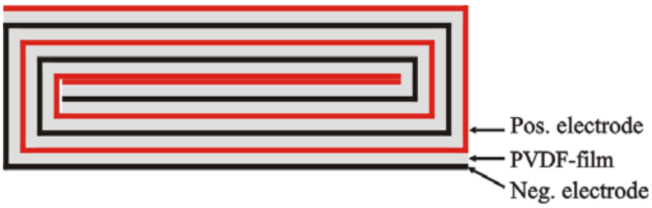

Fig. 1: cross section view of the multilayer roll

In order to make electrical connections possible, cables were fixed at the aluminum foil. Afterwards the coiled foils have been weld in laminate bags to provide adjustment and an overall protection of the modules. The geometrical dimensions of the modules could be changed easily with this assembling method. The length of a module is determined by the width of the foil sections. The coil diameter defines the width of the modules in each case. The thickness of the modules can be changed with the number of windings as desired.

In order to equip the PVDF films with controllable piezoelectric characteristics, their electrical polarization is necessary. This takes place in a strong continuous electrical field. A high voltage was applied in this case to the electrode layers of the modules. This was taken out at a temperature of about 100°C to accelerate the polarization process. The modules were warmed up in a furnace and subjected to the electrical field while reaching the temperature. For polarization field strengths up to 100kV/mm are necessary. During the polarization process however several modules showed an electrical breakdown due to defects of the material and the lack during the manual module production. The polarization field strength was limited to 60kV/mm, since after an electrical breakdown a further polarization is impossible.

Base area

For investigations of the modules they have been placed in the floor of a public building. A base area was used at the entrance of an institute building, which has a size of 1.1m x 1.7m. This base area was sectioned into six equal spaces in size (40cm x 40cm). These spaces can be equipped with harvester modules of different sizes (segments). The scheme of the base area is outlined in figure 2.

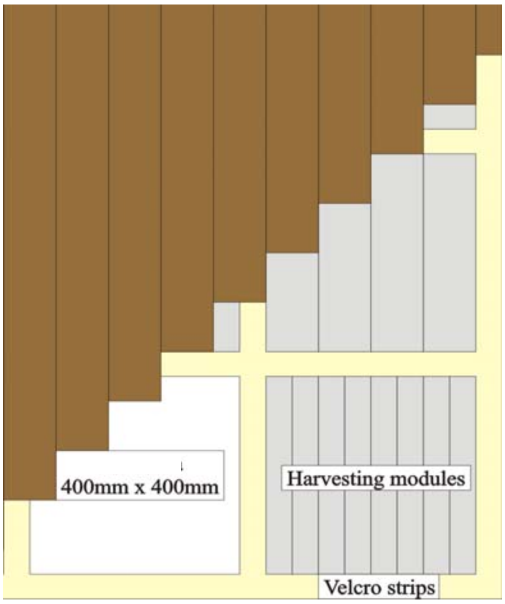

Fig. 2: schematic of the parquet base area

Modules were placed on a base plate in the ground, connected electrically and covered with parquet. A laminated velour layer beneath the parquet in combination with Velcro strips on top of the base plate act as fastener for the parquet (figure 3). During contact of Velcro strips with velour the parquet is fastened with the base plate.

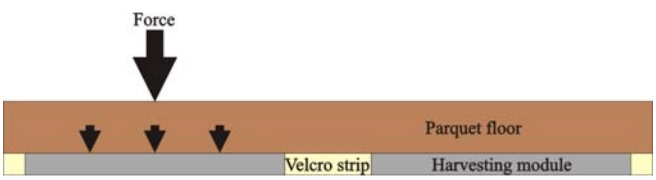

Fig. 3: cross section view of the parquet floor

This structure limits the maximum height of the harvester modules to d=1.5mm. Larger module thicknesses could prevent a safe fixing of the parquet. The maximum number of PVDF layers was therefore set to 19, in order to exclude this uncertainty.

Modules were manufactured in four different dimensions. Area size in cm² (width x length in cm x cm):

200 (5 x 40),
400 (10 x 40),
800 (20 x 40)
400 (20 x 20).

These different module sizes lead to a different number of modules necessary for one space in the base area (40cm x 40cm). So, eight pieces per space were needed with the smallest module size. In contrast, only two pieces of the largest module were needed. Modules of 20cm x 20cm and 40cm x 10cm should allow a comparison of the general influence of geometry on the energy generation.

Identical electrical circuits were used for each space to compare the modules of different dimensions. All generated AC signals were rectified by means of a diode bridge. For this propose, each module was connected separately with a commercial available standard electric rectifier. Finally, all rectifiers of one space were connected to a load capacitor (see figure 4).

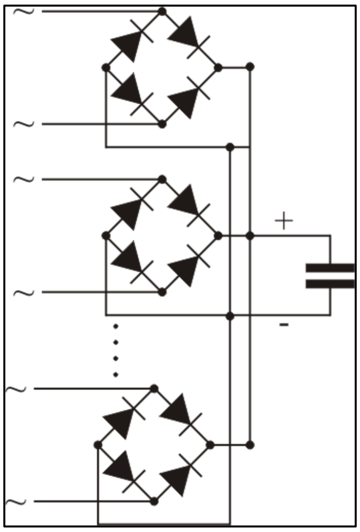

Fig. 4: schematic of the electric circuit

Due to this arrangement, the load capacitor was charged, if any module of the space was stressed mechanically. The capacitor was discharged immediately after charging over an appropriate laboratory resistor to determine the energy yield of one footstep continuously. During discharging the potential gradient at the resistor was collected by a data logger and transferred to a PC. Energy yield could be determined by means of a software routine taking into account the resistor value and the time-dependent voltage characteristic. Additionally, the average energy produced per one footstep was calculated by means of an integrated footsteps-counter.

EXPERIMENTAL

Preliminary investigations

First, selected modules were examined with regard to the strength of the applied force on the energy yield. The modules were not covered during these investigations with parquet.

A module of the size of 40cm x 5cm was loaded with different weights at full coverage. During mechanical stress and relieve, the potential gradient was recorded at an oscilloscope using a laboratory resistor of 10MΩ. Figure 5 shows the result of these investigations for different loading weights.

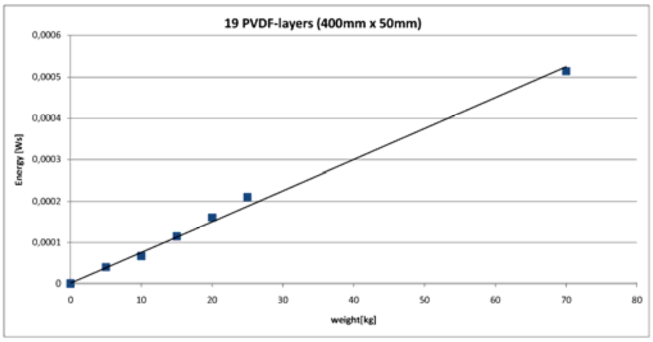

Fig. 5: Energy yield for different forces applied by weights

It shows an almost linear increase of the energy yield with rising weight. It is to be investigated whether this linear interrelationship is valid for even larger loads (e.g. cars).

Furthermore, the dependency of the energy yield with rising number of PVDF layers was examined. Modules were manufactured with different numbers of layers in a size of 40cm x 5cm. The investigation was taken out likewise to the first one. Figure 6 shows the results for a weight of 25kg.

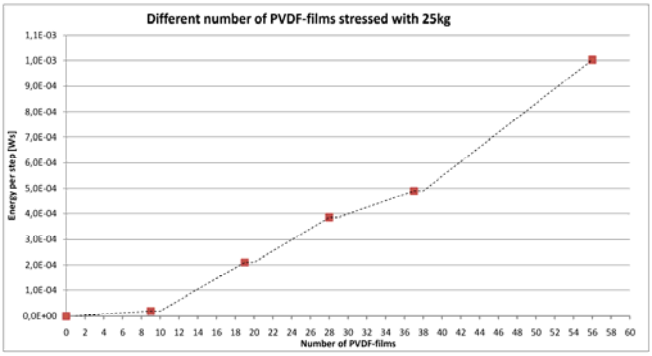

Fig. 6: Energy yield for different number of PVDF-layers

Similarly, as in the investigations with rising loading weight, the energy yield increases with rising number of PVDF-layers. However the dependency between number of the layers and energy yield is not really linear. For example, the energy yield that can be achieved with 28 layers is clearly larger than the energy yield that results in the sum of the modules of 19 and 9 layers. Thus modules with more layers, like they were used in the base area a preferable.

Investigations on the base area

The following measurements were accomplished at the base area, which was in the entrance area of the institute building. All modules were covered by the parquet generally.

Individual measured values for the energy yield per one footstep varied widely for all module sizes. This can be explained first by the difference in weight of all (unknown) persons walking across the parquet. Secondly, the coverage of the foot and the underneath lying module affects the energy yield strongly. The higher the coverage the higher the energy yield. Since both effects are determined only statistically it is obvious that the energy yield can vary strongly from person to person and from footstep to footstep.

The values in figure 7 represent average values from about six measurements each. One measurement cycle was accomplished during one working day. The six measurements of each module size correspond to the six possible positions on the base area. Thus, a possible influence of the position on the base area should be excluded.

Figure 7 shows the average values for energy yield per step for modules of a length of 40cm. Additional, the arrangement of the modules can be distinguished between length- and crosswise to middle direction of walking.

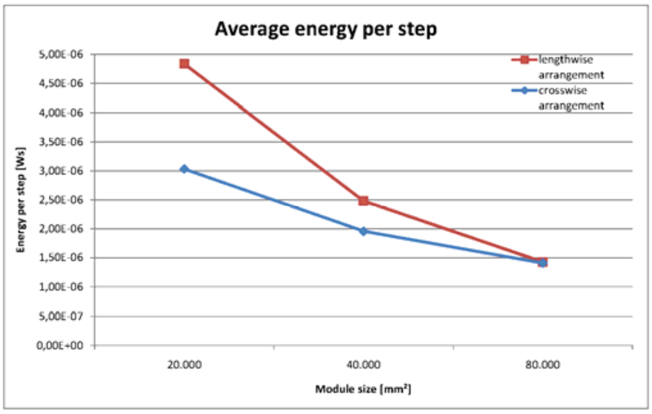

Fig. 7: Average energy yield per step in the base area for different module sizes

A slightly decreased average energy yield per step was observed compared to values achieved in preliminary investigations. This decrease could have several reasons. One reason is the already mentioned uncontrolled distribution of footsteps on the base area. Furthermore, the energy yield can be decreased by power consumption of the electric circuitry and the damping effect of parquet floor that covers the modules.

Nevertheless, these measurements show some interesting results. A clear increase of the energy yield with decreasing size of the modules is observed. Furthermore a difference in the energy yield occurs also, caused by the arrangement of the modules. A lengthwise adjustment of the modules to the main direction of walking leads to a higher energy yield. The difference is clearest at the module size of 40cm x 5cm. These modules have a ratio of length to width of 8:1. Modules with a size of 40cm x 20cm show virtually no difference in energy yield for different adjustments. Reason could be the ratio of length to width of only 2:1. Additionally modules with dimensions of 20cm x 20cm were manufactured and assembled in the base area. They make it possible to determine the influence of the geometry of the modules on the energy yield. Their surface area (400cm²) is equal to that of the 40cm x 10cm modules. Figure 8 shows the middle energy yield per step of both 400cm² modules with the different geometry. 20cm x 20cm modules supply a noticeable smaller energy yield per step than 40cm x 10cm modules.

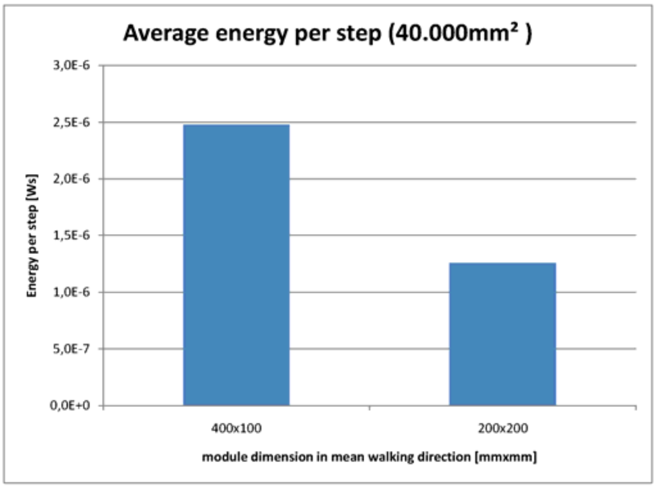

Fig. 8: Average energy yield per step for modules of the quantity 400cm² in different dimensions

DISCUSSION

The results show that the suggested technology is comparatively easy for the conversion of dynamic compression of floors by walking or driving across it, into electric energy. Although similar solutions for this approach had already been published, the solution with coiled PVDF-foils offers some great advantages. [3, 4] Crucial disadvantage of other solutions is the use of PZT (lead zirconate titanate) as piezoelectric transducer material. PZT-ceramics are extremely brittle, possess lead as basic element, can only be manufactured in small-sizes and are extraordinarily cost-intensive. In contrast to this, PVDF offers substantial advantages. The base material - monoaxially stretched PVDF foil - is extremely economically compared to piezoceramic (more than 1000-times more favorably).

By the use of PVDF foil a high flexibility is always ensured. This leads on the one hand to a great pliancy and elasticity of the modules and furthermore to robust and resistant products in regard to mechanical destruction. Secondly, regarding to the manufacturing of modules, it is possible to design them in many different sizes and shapes. Width and length can be changed in a simple manner by appropriate foil cuts and freely definable winding width. The number of PVDF layers can be increased or reduced likewise.

In addition, the manufacturing method of the modules is very suitable to the application of mass production technologies. They could be assembled in a reel-to-reel process.

CONCLUSION

A new harvesting device was shown, which is able to convert mechanical forces into electrical energy. The device operates by means of the piezoelectric effect. Mechanical power due to weight forces produced by walking or driving across the floor will be converted into electrical energy directly. Instead of piezoelectric ceramic the harvester consist of an organic polymer. It is designed in a modular shape. The consistent use of foils allow for a assembling of a wide variety of geometrical shapes. Energy harvesting modules for floors are characterized by simple assembly a great flexibility and no brittleness. They contain no lead and are not flammable. They can be produced by very simple production technologies and are suited for mass production.

First investigations have shown very promising results. In preliminary investigations of selected modules a dependency of the load weight and the number of PVDF-layers was observed on the energy yield. Further investigations under parquet floor in a public base area showed that the size of the modules can influence energy yield strongly. Last but not least the geometry and the adjustment of the modules can influence the energy yield. Energy yields above known harvesting devices show the potential of this harvesting propose.

Further investigations are required to optimize the systems and to maximize the power output. A noticeable increase in energy conversion is expected by enhancement in polarization, optimization in geometrical design, floor constellation and by increasing the number of piezoelectric layers.

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